CB12 - Improvements in Baked Anode Quality through Reducing Process Variations and Debottlenecking Carbon Plant

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Abstract

EGA has long-focused on continuously increasing production through amperage increases and technological upgrades. Currently the capacity of the carbon plants has reached its maximum limit and therefore, it has become very important to focus more on improving quality through reducing process variations and debottlenecking critical equipment. Based on customer needs, critical baked anode quality KPIs were identified and prioritised with targets. This became the steppingstone for developing a network of opportunities across different process steps, e.g., linking the shopfloor practices with the final baked anode quality, improving efficiency of the critical equipment through upgrades, optimisation of the internal processes, and taking operation to the next level with the utilisation of Industry 4.0 tools. Also, to empower the employees, Carbon & Port management created an interactive platform through a quality campaign that emphasised personal ownership and teamwork towards quality. This paper narrates the challenges, which were faced starting from raw materials to anode performance in potlines and the response plans in mitigating them during the anode manufacturing process.

Keywords: Baked anode quality, Debottlenecking critical equipment, Industry 4.0, Process optimisation, Reducing process variation.

1. Introduction

EGA is the world's biggest ‘premium aluminium’ producer with business from mining and refinery to smelting and casting. EGA produced a record 2.653 million tonnes of hot metal in 2022 in its two production sites, Jebel Ali and Al Taweelah as per Figure 1. Carbon plant is an important enabler to EGA’s metal production, with more than 1.39 million tonnes of anodes produced for both Jebel Ali and Al Taweelah of different sizes to meet the production requirement. It has become crucial that the carbon plant produces anodes of the required quality especially as most of the technologies in EGA reached their optimum design limits.

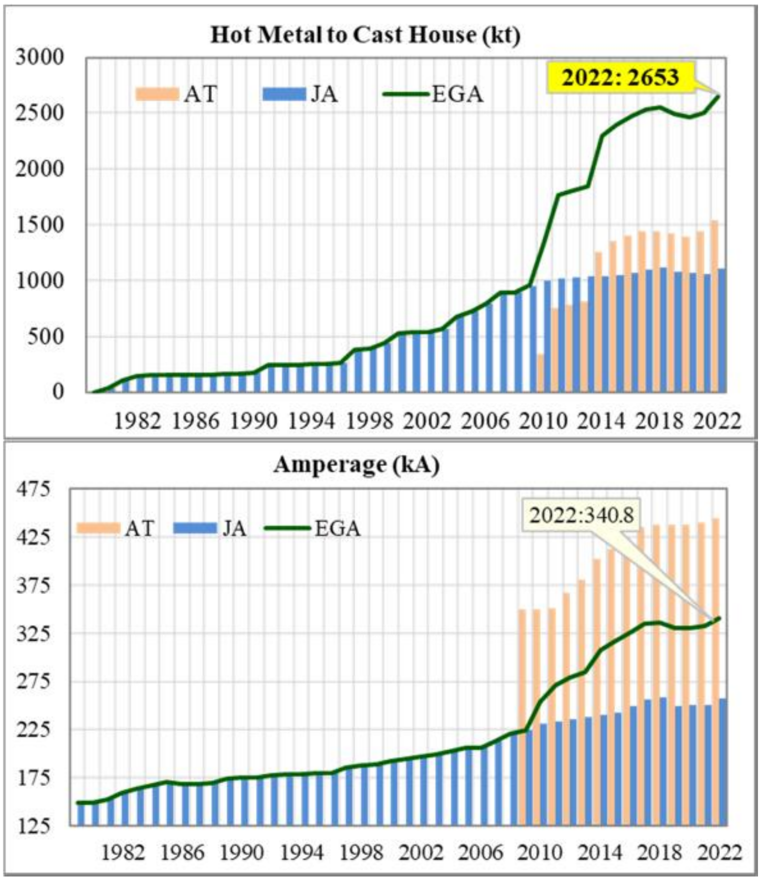


Figure 1. EGA's hot metal production and amperage.

As EGA continues its amperage increase strategy there are multiple challenges which were identified by both Potrooms and Carbon plant that had to be addressed in order to achieve the strategy. Figure 2.

The main key challenges are summarised below for both potlines and carbon plant.
Potroom key challenges during amperage increase:

- Increased anode current density,
- Reduced anode-cathode distance,
- Sustaining pot internal heat.

Carbon plant key challenges:

- Debottlenecking the carbon plant to meet the increased anode requirement,
- Reduce anode quality variation,
- Tighten the raw material specifications.

Based on the above challenges it became evident that the carbon operational strategy had to be aligned with the potroom plan of achieving higher productivity while improving pot stability with reduced anode problems. In order to achieve this, EGA Carbon & Port has transformed its anode production process compliance by aligning the anode quality strategy with customer expectations in the potline and EGA's business strategy for amperage increase. Carbon & Port has prioritised the commitment to quality in its process compliance efforts. As a first step, a Service Level Objectives (SLO) were established to define compliance targets for critical anode quality indicators, including electrical resistivity (ER), carboxy-reactivity dust (CRD), the average crystallite size (Lc), and baked apparent density (BAD). These indicators were selected considering priority of potline operations to ensure best utilisation of the anodes. This approach allowed EGA Carbon Plant to shift their methodology of assessing quality based on averages to percentage compliance since an average absorbs the extreme variabilities which are the trigger for anode problems. This has developed a platform which allows to represent customer happiness and guide the development team's prompt response. This paper elaborates EGA carbon journey and the major modification in the process towards addressing plant productivity and improving smelter performance.

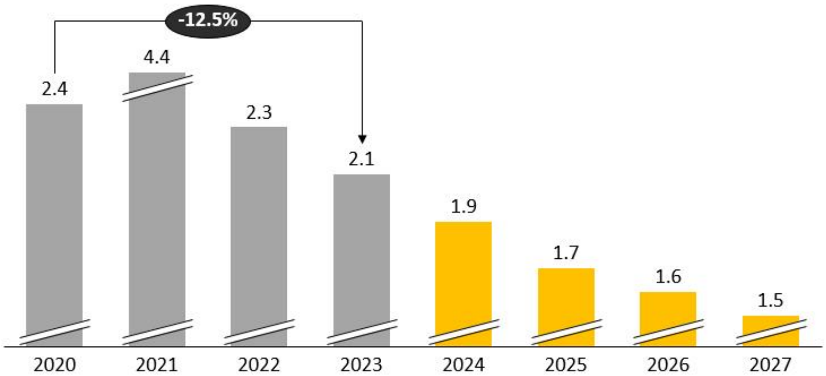


Figure 2. EGA amperage increase strategy and ahead of schedule history and forecast.

2. Raw Material Specification Changes

A major raw material that impacts the anode quality is calcined petroleum coke (CPC). EGA Carbon plant sources two types calcined cokes (high density coke and standard density coke) from multiple suppliers across the globe [1]. Based on the types of the crude (sweet, sour) and calcining technology (shaft, rotary and rotary hearth) the coke inherits special characteristics that creates the necessity to adapt the anode manufacturing process. Thereafter, the specification limits of the calcined coke were established for individual calciners based on their process capabilities and operational limitations as per Figure 3.

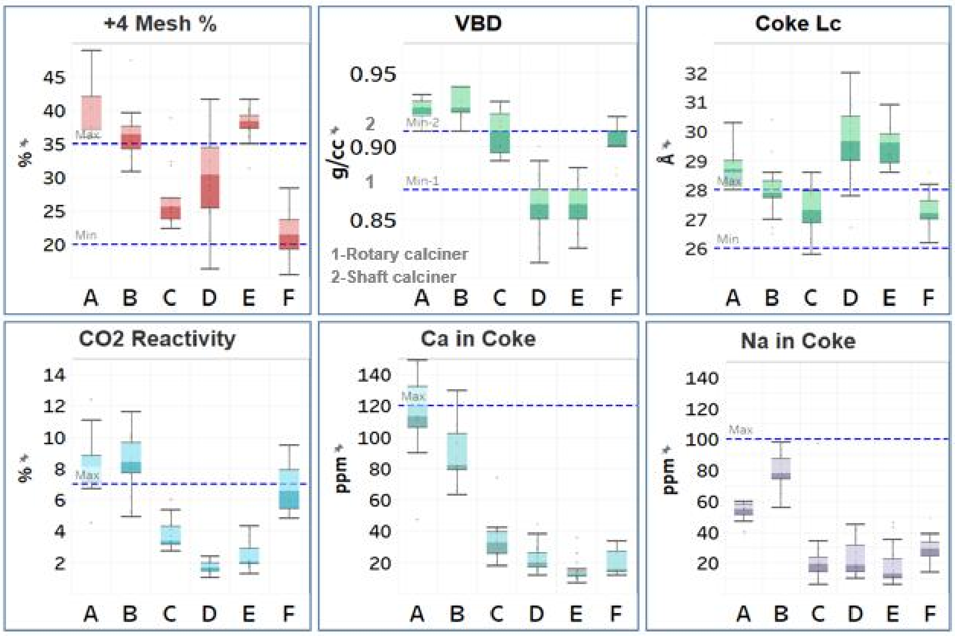


Figure 3. Supplier wise coke quality and specification limits were set based on individual supplier capability.

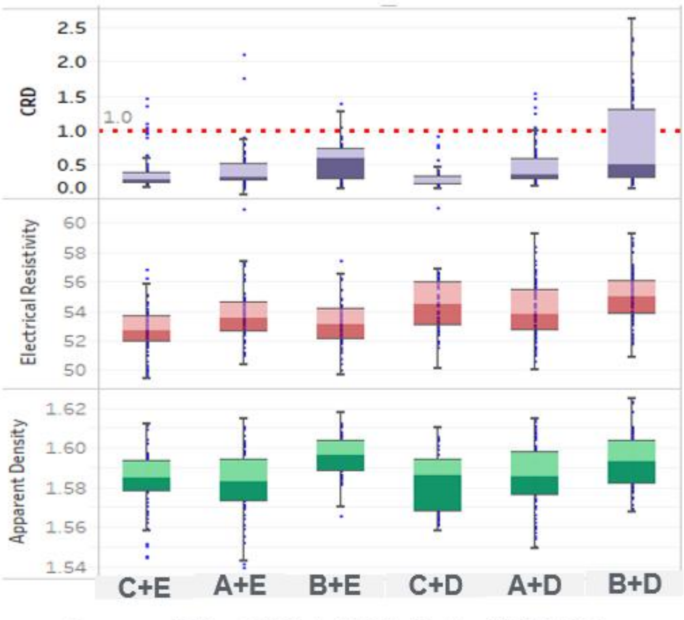
To improve the anode structure the key focus was on the consistency in the coke granulometry and coke vibrated bulk density (VBD). Therefore, the coke sizing parameters specifications were reviewed for +4 mesh, -20 mesh and maximum particle size. In addition, the coke VBD parameters were reviewed based on the calcining technology and green petroleum coke (GPC) quality which is impacted by the refinery operation conditions particularly in integrated calciners. The minimum VBD of rotary calciner cokes and shaft calciner cokes were changed to 0.87 g/cm^3 and 0.91 g/cm^3, respectively.

To address the anode reactivity challenges the calcination level and impurities were addressed. Coke Lc was changed from 27-30 Å to 26-28 Å this translates to real density (RD) target level from 2.05 to 2.08 g/cm^3. Coke impurities were also revised for Na and Ca to 100 ppm and 120 ppm, respectively. CO_2 reactivity (CO2-R) of coke was reduced from 12 % to 7 %. This will reduce anode spike formation and dusting in the cells.

From environmental perspective the maximum specification limit of sulphur in the coke was set to 2.80 %.

3. Blending Strategy

The use of different types of cokes provided an opportunity to study the behaviour and compatibility of cokes along with the granulometry change associated with the transition from one coke shipment to another as per Figure 4. This helped us to allocate the cokes based on the smelting technology present at individual sites. In addition, to minimise the number of coke transitions in the silo the parcel sizes were maximised to ensure longer production runs and sustainable anode quality. All these efforts have contributed towards developing the optimal blending strategy. This was possible through dedicated teams to coordinate the procurement, shipping and coke blending adjustments to mitigate risks during disturbances in coke supply.



Source: AT2 – 2020 to 2021, Butts % [25-30]

Figure 4. Blending strategy and impact on baked anode quality.

Performance of blended cokes are consistently monitored and any deviations arising out of coke quality are addressed with the suppliers through sharing their process deviations and actions to mitigate their risks.

4. Silo Design Upgrade

Despite the above approaches there is yet another challenge with respect to coke segregation that is associated with the nature of the silo design. Al Taweelah site has two 25 kt single discharge silos which promote funnel flow that results in coke segregation The variation in the coke granulometry with silo level and its impact on anode density was studied. The negative impact of coke segregation is commonly experienced during coke mixing, silo filling and discharge, smaller parcel sizes and any process instability in calciners impacting the product quality. This behaviour is more prominent in high density cokes at low silo levels.

To reduce the impact of coke segregation on the short term the following the actions were implemented:

- Regular monitoring of the size distribution of the material discharged from each silo,
- Defined silo management rules, e.g., no anode production below 30 % of silo level,
- Adjusted coke screening and crushing parameters to improve the consistency,
- Redefined blending strategy, e.g., blending based on coke sizing.

In the long-term strategy, EGA is investing on silo design modification where multiple discharge outlets will be replacing the current conical bottom silo. This design will help in the mass flow of the coke across the silo and henceforth minimise coke segregation and maximise silo capacity utilisation.

This issue is not significant in Jebel Ali due to the silo design having multiple discharge points and multiple different silo sizes.

5. Modification of Crushing and Screening Systems

Unlike the standard paste plant designs, Al Taweelah Phase 1 (potlines 1 and 2) had a unique feature of processing the complete stream of input coke through cone crusher and hence its product was varying in a big range which had difficulty in meeting the individual coke fractions requirements. In addition, the low screening efficiency, raw material variation and silo segregation issue made the operation quite challenging due to imbalance in the material availability in different fraction bins. Hence, the anode recipe was changed frequently, and in extreme cases finer material had to be drained out to restart the plant. Such operations led to variations in the anode quality such as density, electrical resistivity variation and coke sticking issues.

Material flow through the existing coke crushing and screening system was upgraded to improve the screening efficiency as per Figure 5. Following changes were introduced:

1- Replacement of two decks to a six decks screen,
2- Incoming coke was diverted to the new screen,
3- Particle size range of individual fractions was changed to meet the process requirement.

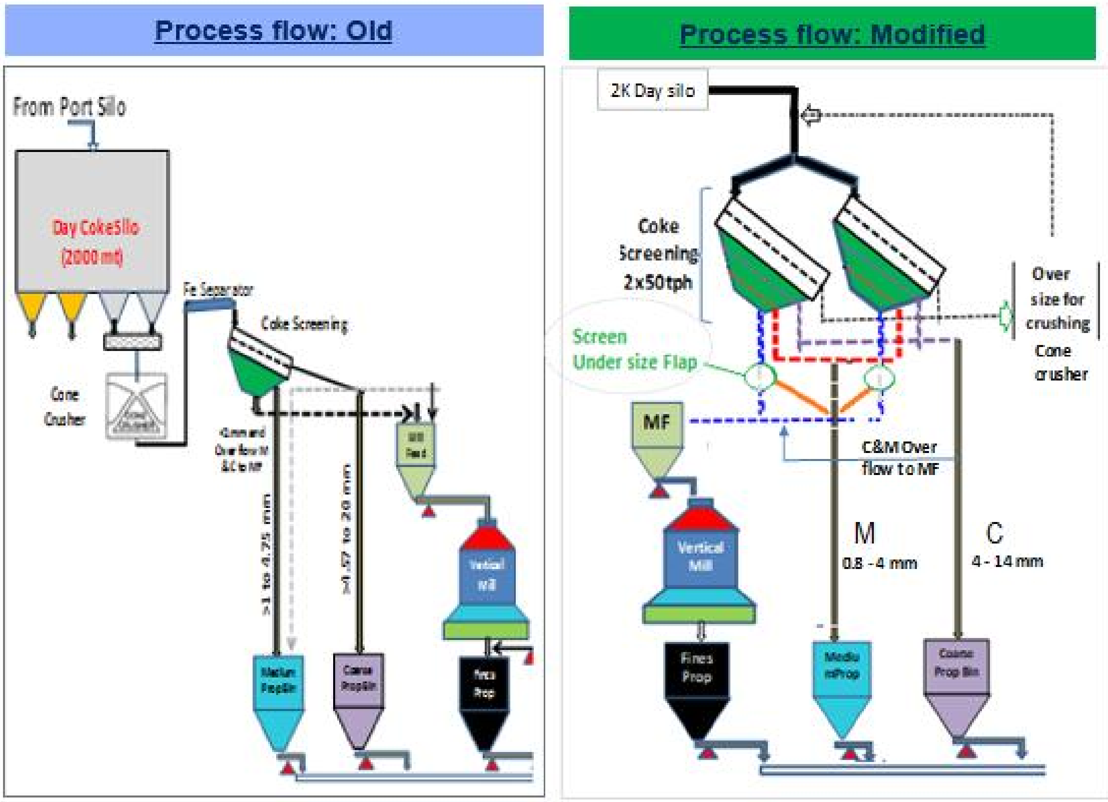


Figure 5. Crushing and screening system old and new.

The above modification resulted in;

1- Oversize coarse fraction was recycled,
2- Maximum particle size in the coarse fraction was reduced from 20 mm to 13 mm,
3- Fraction ranges were redefined as per Table 1.

Table 1. Fractions range changes before and after.

Fraction	Unit	Before	After
Coarse	mm	4.75-20	4.0-13
Medium	mm	1-4.75	1-4
Fine	Blaine No	5000	4500

This resulted in reducing the variation in the granulometry of each fraction and hence contributed to the improvement of baked anode density, electrical resistivity and flexural strength as per Figure 6.

Critical equipment of the paste plant was identified and its impacts on the overall anode quality were assessed. Significant importance was given to 100 % compliance to preventive maintenance and availability of spare parts of critical equipment. As an example, Al Taweelah Phase 2 (Potline 3) is presented as a case study.

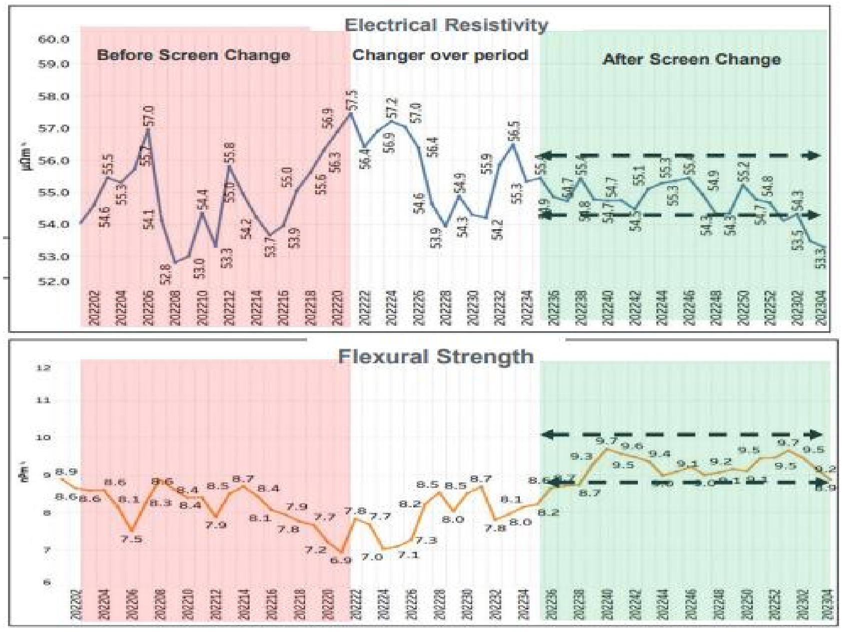


Figure 6. Electrical resistivity and flexural strength improvement following screen modification.

When the granulometry of the coke becomes finer the mixing energy drastically reduced in Al Taweelah Phase 2 as it does not have the gate control system for specific mixing energy target. This leads to reduction in throughput and in extreme cases severe impact of electrical resistivity and baked anode density. The mixing energy was impacted negatively by the wear and tear of both, flights and shaft. With the replacement of new ones the mixing energy improved, and throughput increased to the design capacity as per Figure 7. One of the lessons learnt from this case study was to establish a maintenance regime of critical equipment’s in consultation with the original equipment manufacturer (OEM0.

Figure 7. Impact of critical equipment on operational and quality parameters.

6. Anode Sticking and Cracking Issue

Jebel Ali site had continuous challenges with anode sticking which has added a lot of strain to the operations team to conduct manual cleaning. Therefore, a trial was conducted to address this concern where the vacuum system was disabled during the vibroforming and the fines content in the dry aggregate was increased from 26 % to 30 %. The results showed significant improvements in coke sticking as per Figures 8a and 8b along with electrical resistivity and flexural strength.

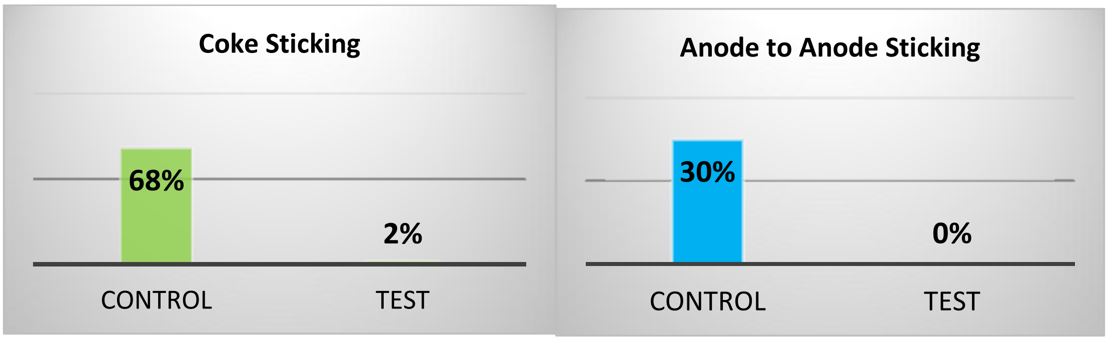


Figure 8a. Coke sticking and anode to canoed sticking improvement after vacuum system disabled.

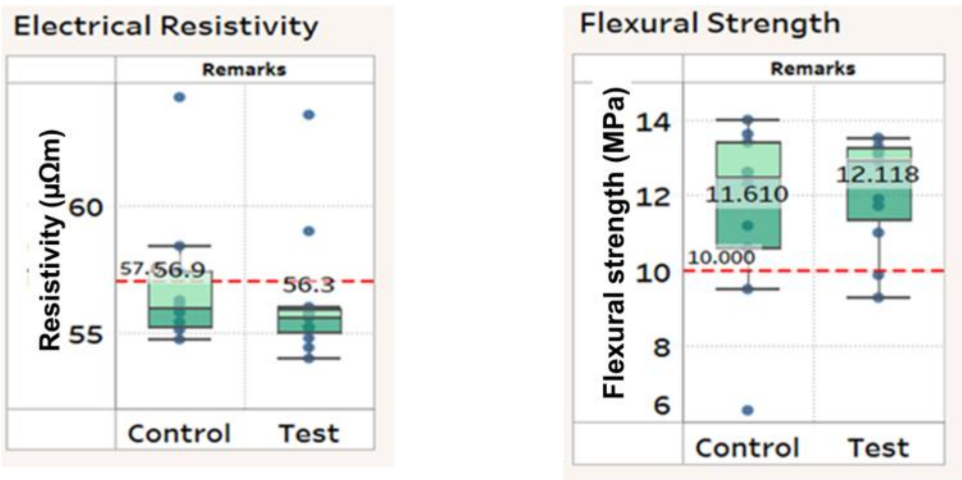
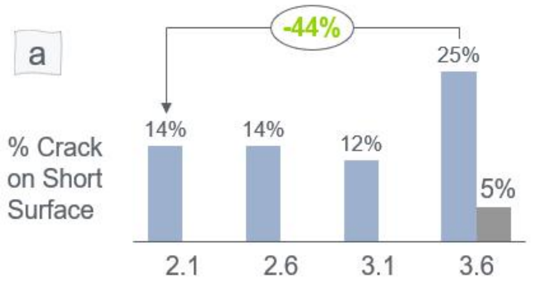


Figure 8b. Coke sticking and anode to canoed sticking improvement after vacuum system disabled.

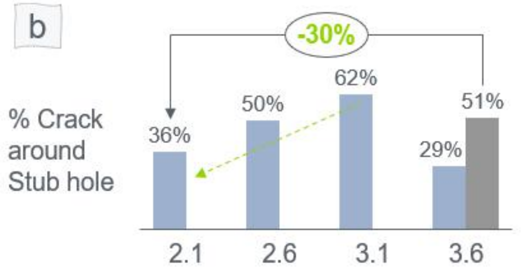
In addition to reduce the anode rejection due to coke sticking and cracking trials on the vibro-compactor in Al Taweelah Phase 1 was conducted to reduce the stress in the anodes during the baking process in Al Taweelah. By conducting trials at different air bellow pressure settings, the aim was to optimise the compaction process and minimise anode defects

During the trials on the vibro-compactor, challenges were encountered in achieving the desired compaction levels and addressing potential equipment limitations. To overcome these challenges, process parameters were carefully adjusted, and real-time monitoring of the compaction process was implemented.

The results of the trials on the vibro-compactor revealed several findings. Firstly, there was a significant decrease in anode's external cracking propensity when the bellow pressure setting was below 3.6. Additionally, as the bellow pressure set point was reduced, the radial cracks around stub holes also decreased. Notably, the bellow pressure set point of 2.6 bar exhibited potential optimum results as per Figure 9.



	Test			
	2.1	2.6	3.1	3.6
Good	86%[36]	86%[36]	88%[37]	75%[18]
Big Crack	7%[3]	2%[1]	5%[2]	4%[1]
Small Crack	7%[3]	12%[5]	7%[3]	21%[5]



	Test			
	2.1	2.6	3.1	3.6
Good	64%[27]	50%[21]	38%[16]	71%[17]
Crack	36%[15]	50%[21]	62%[26]	29%[7]

Figure 9. Anode cracking trial results.

These findings from the trials on the vibro-compactor provided valuable insights into the compaction process, indicating the potential for improving anode quality by adjusting the bellow pressure settings.

7. Baking Kilns Rebuild Program

Considering the flue wall conditions of all baking furnaces and their impact on baked anode quality, it was decided in 2019 to adopt a two-way strategy: the in-situ replacement of critical flue walls and the rebuild plan of all the 7 kilns as per Figure 10. Depending on the availability of the refractory materials and supporting resources the rebuild plan was accelerated to minimise the impact of anode quality on smelter performance and optimise carbon working capital.

Prior to the rebuild program, 78 critical flue walls were identified. With passage of time, as more flue walls became critical, rebuild in-situ time (75 % more than the target) and the furnace rebuild time were accelerated by 6 months.
During the rebuild, the internal flue wall designs were modified to improve the temperature distribution across the flue walls with increased heights. In addition, the crossover designs were modified to single duct with only refractory insultation at Jebel Ali.

Furnace rebuilds activities were completed with 100 % compliance to safety and zero lost time incident (LTI) in both Jebel Ali and Al Taweelah sites.

Figure 10. Rebuilt completion schedule.

The benefits of accelerating the rebuild program included:

1- **Enhanced Furnace Performance:** The rebuild program involved refurbishing critical components of the ageing furnaces, such as refractory lining and burners. By addressing wear and tear, improving insulation, and optimising combustion systems, the furnaces' performance was significantly enhanced. This resulted in improved temperature control, better heat transfer efficiency, and reduced energy consumption.
2- **Increased Energy Efficiency:** Rebuilding the ageing furnaces allowed for the implementation of advanced technologies and energy-efficient practices. Upgraded insulation materials, optimised burner configurations, and improved control systems contributed to reduced heat losses and improved energy efficiency as per Figure 11. This resulted in lower energy consumption per tonne of aluminium produced and contributed to the EGA sustainability goal.

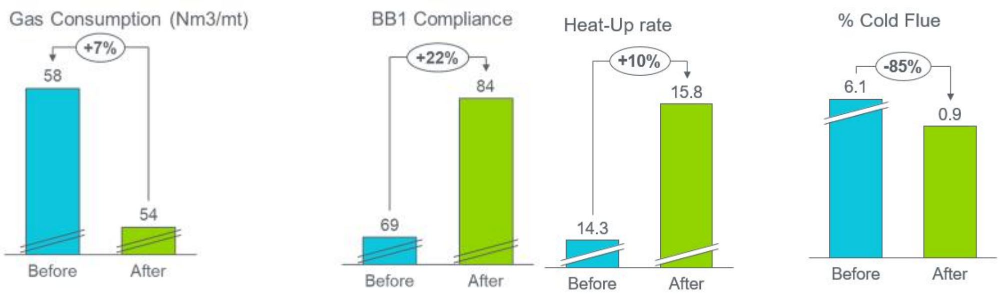


Figure 11. Improvement in baking kilns key performance indicators.

7.1 Continuous Monitoring and Feedback

Throughout the rebuild program, continuous monitoring of furnace performance and feedback from operators and maintenance teams were gathered. This allowed for timely adjustments and improvements to the rebuild process, ensuring the desired outcomes were achieved as per Figure 12.

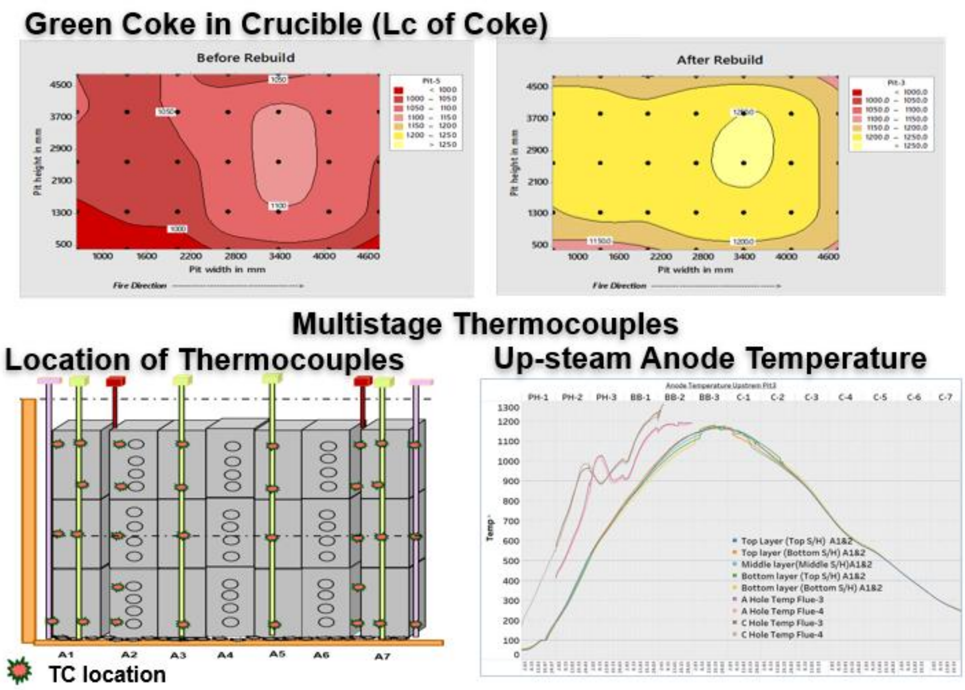


Figure 12. continuous monitoring of furnace performance.

The kilns were rebuilt to ensure their optimal performance and longevity. This involved refurbishing and upgrading the kilns to meet the desired operational standards. The rebuilds helped address any existing issues, improve energy efficiency, and enhance overall kiln performance.

The following issues were identified and addressed:

1- Furnace-rebuild height; in some cases, it increased to accommodate baking of longer anodes to facilitate amperage increase,
2- Flue wall design were changed to improve heat distribution in the cold zones of the pit,
3- New firing systems were introduced in two furnaces of Al Taweelah Phase 1 Plant,
4- Baking process parameters were optimised with the help of temperature distribution studies.

8. AT Phase 1 Fume Treatment Centre (FTC) Performance Improvement

In Al Taweelah Phase 1 the deterioration of refractory condition with increased furnace age resulted in higher draft demand and so immediate actions were taken during the critical time of the furnace operations before the rebuild to improve the FTC performance. These measures involved increasing the filter bag replacement with close monitoring of the pressure drop across the bag filters. Ring main duct frequency of cleaning was increased to improve the draft rate and ensuring regular maintenance of the FTC.

With the increased volumetric occupancy of anodes in Phase 1 and increased baking levels, the draft demand increased and is sustained. In Jebel Ali the same issue is being addressed via a CAPEX project of replacing the FTC with the consideration of additional capacity increase, Figure 13.

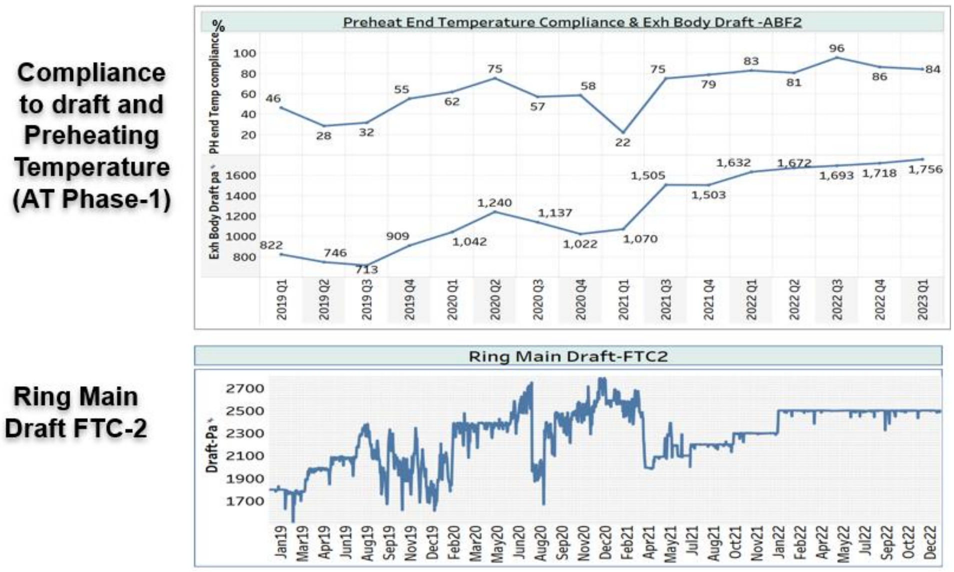


Figure 13. Preheat end temperature compliance and ring main draft.

9. Optimum Baking Levels

The baking curve, including the heat-up rate and the distance between anodes and the pit wall, was adjusted to optimise the baking process. The objective was to reduce the heat-up rate below the critical limit and maintain a uniform distance between anodes and the pit wall. This adjustment helped improve the overall baking process and resulted in more consistent and higher-quality anodes.

To standardise furnace operations and achieve consistent results, a 24-hour fire cycle was implemented for all kilns. Baking on a shorter fire cycle was found to increase electrical resistivity (ER) and decrease flexural strength (FS) while causing an increase in flue variation. By implementing a standardised fire cycle, EGA Carbon & Port aimed to ensure uniformity in the baking process and minimise variations in anode quality. In addition, 24-hour fire cycle is observed to be techno economically advantageous across all EGA furnaces, Figure 14.

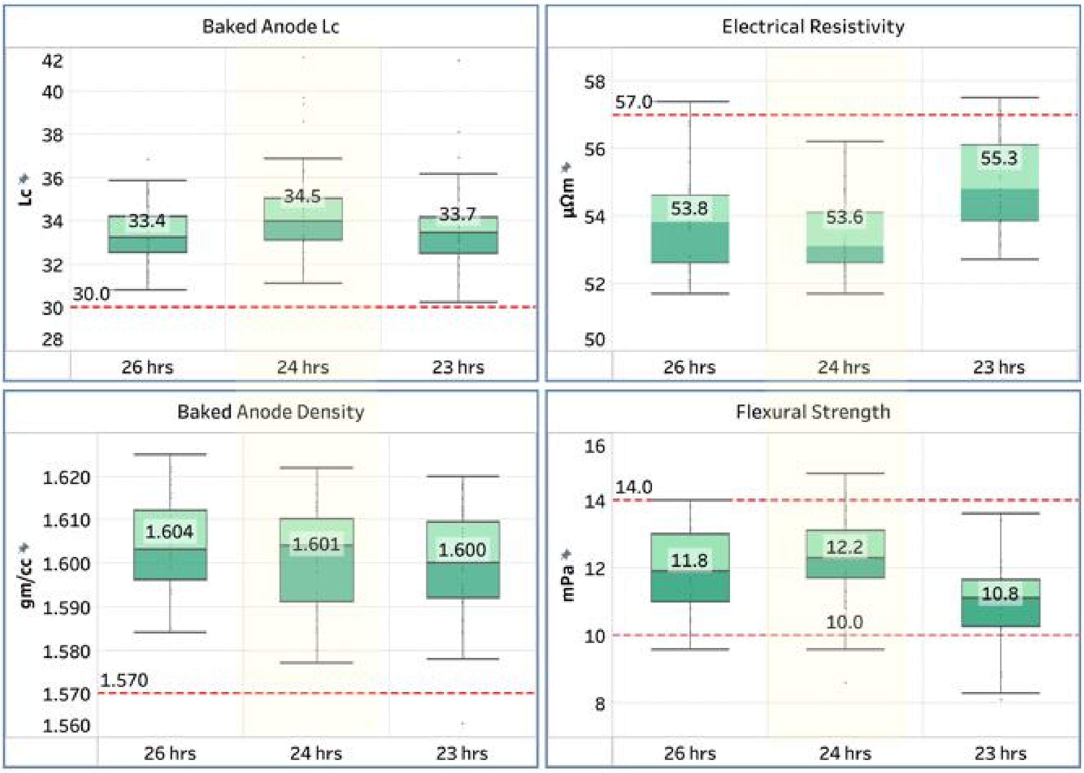


Figure 14. Study to establish optimum fire cycle and baked anode quality.

10. Butts Control Quality

Spikes and dust in the pots were the major issues in potrooms and therefore considerable emphasis was given to reduce the baked anode reactivity through reducing sodium content in butts. One of these major actions implemented in Jebel Ali and Al Taweelah was the discard of the dirty butts in the rodding plant since 2021; this was a costly step to break the cycle of increased anode problems.

Once the potline anode problems stabilised the resumption of dirty butts was restored in the rodding system in order to maximise the usage of butts and optimise the cost. Carbon plant took several initiatives in different units to ensure butt quality control is maintained:

1- Focused task force was created to ensure very good cleaning of butts across all rodding plants. Process of butt cleaning was assessed & additional checks as well as extra cleaning measures were introduced to handle special situations like uncleanable butts, poor equipment performance. Butt not meeting the cleaning criteria despite full compliance to cleaning process were removed for further offline processing.
2- The refurbishment of shot blast machines in Jebel Ali aimed to enhance the cleaning efficiency of carbon blocks, thereby decreasing Na in butts and thus improved CRD of anodes. The benefits included reduced anode variability in anode reactivity, and enhanced overall anode performance in potline. A detailed refurbishment plan was developed,

taking into account production schedules and downtime windows. Close collaboration between the carbon plant operations team and the maintenance department ensured effective planning, execution, and minimal disruption to the production process. This refurbishment was achieved without impacting butt quality (Na levels). Due to the successful implementation; a CAPEX was approved to upgrade the second cleaning machine.

3- An Online chemical analyzer (OCA) [2] was deployed in one site (Al Taweelah Phase 1) in order to have continuous status of butt quality for immediate action. Similar equipment is being widely used in cement and mining industry, however first of its kind in aluminium industry. Project team and the supplier worked closely to experiment and customise the equipment to fit needs of carbon material being analysed. A dashboard was developed to provide real-time data to the operator in the control room. The dashboard aggregated data to enable a quick response time, identifying patterns in the current trend of spent anode quality and providing warnings when necessary. This also reduced dependency on manual sampling and avoid delays in actions

Moreover, the improved potline performance has helped in reducing the anode problems and hence reduce the contamination of butts. Ultimately all of the above initiatives have supported the increase of recycled percentage of anode butts in the recipe while sustaining the level of CO_2 reactivity.

To further reduce the reactivity of baked anodes the de-dusting dust from the butts processing that is recycled back in the ball mill feed bin has shown elevated levels of critical impurities Na, Ca and F that has a negative effect on the reactivity of the anodes. Therefore, the fines fraction <0.25 mm was discarded from April 2021. Also, the FTC crane dust from Al Taweelah Phase 1 carbon plant was discarded due to high critical impurities from refractory.

Currently, a trial is ongoing in Jebel Ali to discard the dust from butts <0.3 mm, and the initial results of the trial are promising

11. Anode Quality Campaigns

EGA’s core values include innovation and continuous improvement. It is vital that these changes are embedded and aligned with the employees’ way of working to ensure that the full stream is captured from end to end. People engagement and involvement during the changes and implementation of these initiatives was a critical aspect that Carbon & Port took onboard. This was possible through the development of campaigns which focused on the anode quality at each step of the anode manufacturing process. The results of the campaign were successful.

12. Industry 4.0 Initiatives

Industry 4.0 is a subject of innovation and continuous improvement. This field aims to gain better insights and understanding of the process through various monitoring tools.

Carbon & Port have implemented the online chemical analyser in the rodding room butt conveyor to paste plant to monitor the Na in the butts. The decrease of Na reduces anode reactivity.

Other projects which are in process the pitch patch analysis on the green anode surface during the green anode manufacture for improved pitch control. Online measurement of ER at the green stage that should bring improvement in the anode manufacturing process. In addition, at the baking, the use of online robot to cover stub holes with cardboard to prevent the packing coke in the stub holes during the baking, was installed.

13. Results of the above Initiatives

The implementation of various initiatives focused on addressing plant productivity and continuous improvement in EGA Carbon plants resulted in significant performance improvements in both Carbon and Smelter. Key performance indicators (KPIs) were carefully monitored and analyzed to assess the effectiveness of these initiatives. The following KPIs were considered in the analysis:

13.1 Anode Quality

Anode quality indicators, including ER, CRD, and Lc, showed positive trends. The adjustments made in raw material specifications, screen modifications, vibro-compactor trials, fines content optimisation, and other initiatives in kilns contributed to improved anode quality characteristics, Figure 15.

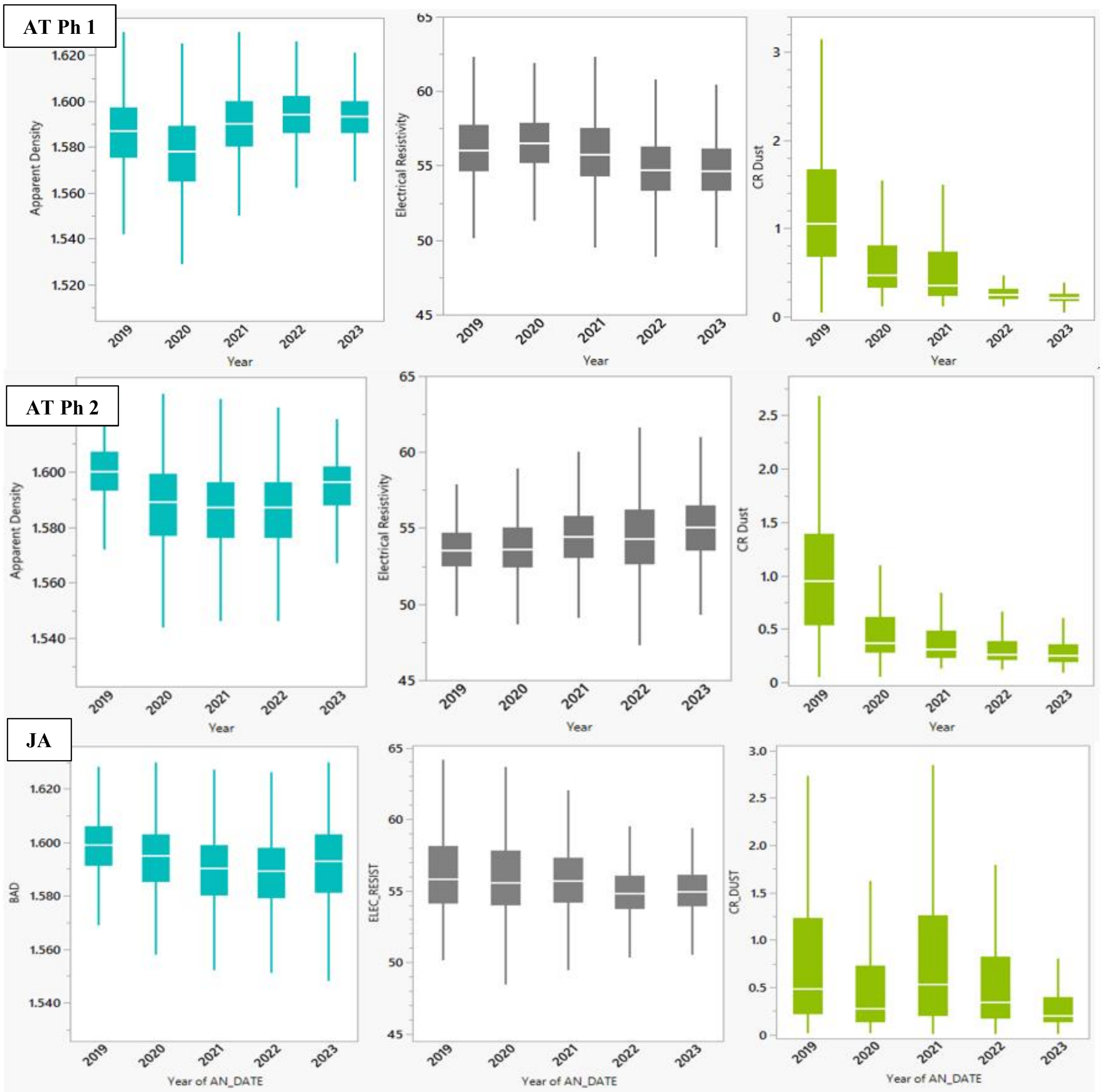


Figure 15. 5 years anode quality performance history.

13.2 Anode Performance

With the improvement in baked anode quality across EGA, all the potlines across EGA were able to increase amperage, and the total production capacity increased by ~6 % in reference to 2021 production.

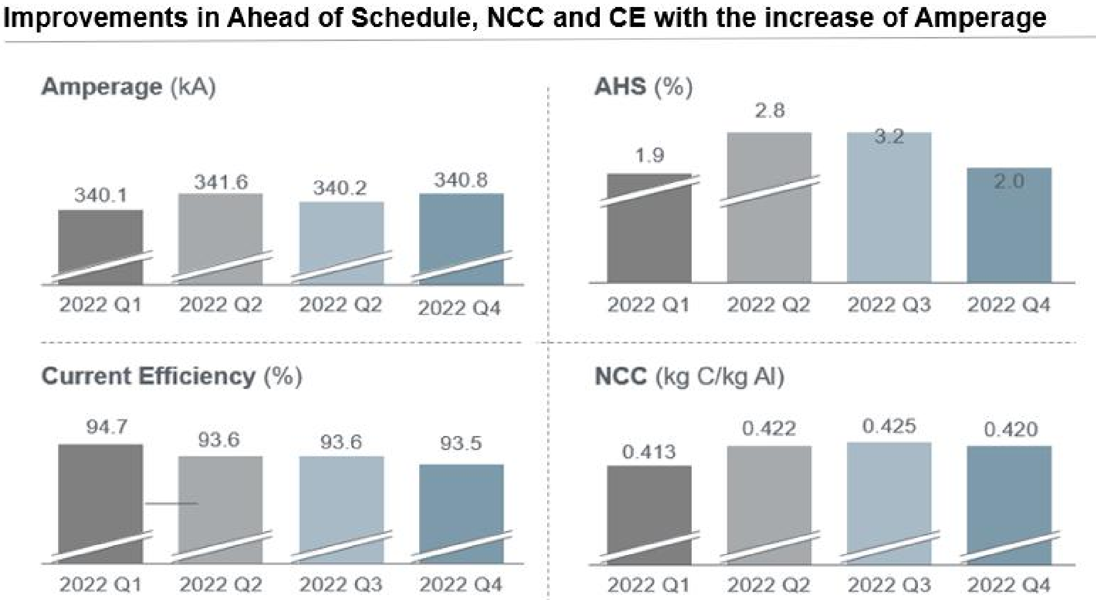


Figure 16. 2022 EGA Reduction KPIs.

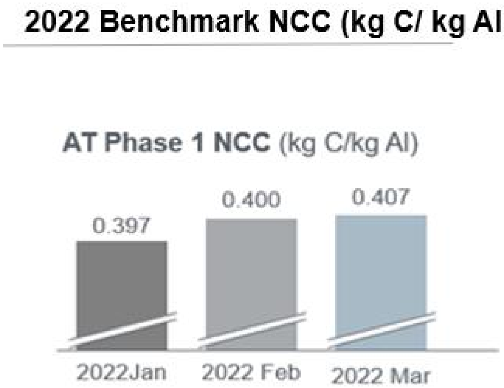


Figure 17. Al Taweelah Phase 1 best months of net carbon consumption, leading to an excellent 0.408 kg C/t Al for the whole 2022.

It was evident from the trends that the initiatives undertaken to drive process compliance and continuous improvement in EGA Carbon plants resulted in measurable performance improvements and contributed to achieving sustainable growth objectives.

14. Conclusions

Exploring new ways of improvement, adapting new technologies, defining effective measures, and debottlenecking the process challenges, lead to anode quality improvement and therefore improved smelter performance. The importance to the anode structure and integrity at each phase of the anode manufacturing, starting from the input raw materials to the rodding is key in making this journey successful.

15. Acknowledgement

We acknowledge our customers (Reduction team) for their support and patience to allow experimentation as well as for implementing good practices in the potrooms. The results are dedicated to ownership and teamwork of Technical & Operations teams of Carbon & Port.

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