Cost-Effective Transition to Larger Anodes - From Concept to Implementation

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https://doi.org/10.71659/icsoba2025-el017

Abstract

The Mahan Aluminium Smelter of Hindalco Industries Limited, located in Madhya Pradesh, India, operates using AP30 technology with a design capacity of 360 ktpa. To meet the growing demand for aluminium, manufacturers are increasingly adopting amperage enhancement as a cost-effective strategy to boost production. Higher amperage operation necessitates several modifications, including process optimization, busbar upgrades, anode area expansion, and cathode lining improvements etc.

Mahan smelter identified anode area expansion as the most viable approach to increasing amperage due to its favourable cost-to-benefit ratio. This paper presents a comprehensive study of the systematic efforts undertaken by the carbon plant to develop and implement larger anodes, from conceptualization to full-scale production, within the constraints of the existing infrastructure. Key process modifications and equipment upgrades in the green anode plant and anode baking furnace are discussed in detail. Additionally, the paper highlights the challenges encountered during the conversion process and the corrective measures taken to ensure a seamless transition. The successful implementation of larger anodes has contributed to increased amperage at the potline, enhancing overall smelter performance. With further potential for amperage growth, the study provides insights into the optimization of carbon operations for improved efficiency in aluminium smelting.

Keywords: Aluminium smelting, Amperage increase, Carbon anode, Design modification

1. Introduction

The Mahan smelter operates with AP36 pot technology. Initially commissioned at an operating amperage of 367 kA in 2013, the line continued to operate at this amperage until the end of 2021. To meet the increased aluminium demand, the potline amperage was successfully ramped up to 376 kA. In the potline, aluminium is produced through the electrolytic reduction of alumina in the presence of cryolite, prebaked carbon anodes, and cathodes. Mahan is an integrated smelter where prebaked carbon anodes are manufactured and supplied from a carbon plant located within the complex. The Carbon Plant is an integrated facility consisting of three units: the Green Anode Plant (GAP), Anode Baking Furnace (ABF), and Anode Rodding Shop (ARS). In the GAP, a dry aggregate mix comprising calcined petroleum coke and recycled anode is mixed with coal tar pitch. The homogenized paste is subjected to vibro-compaction to achieve specific dimensional tolerances, packing density, and mechanical strength necessary for downstream processing. The green anodes are then charged into the ABF. The ABF is a closed ring open-top furnace divided into four fires, each consisting of 3 preheating zones, 3 heating zones, and 4 cooling zones with 1 zone for unpacking of anodes. The furnace has a peak flue-gas temperature of 1130 °C at the burner zone. Energy required for raising the temperature of flue-gas mainly comes from pitch volatile matter combustion in the preheating zone and heavy fuel oil (HFO) combustion in the heating zone. Heat transfers from hot flue gases to refractory walls to packing coke to anode blocks. Thermal evolution during the baking cycle increases the anode temperature to almost 1080 °C, ensuring higher conductivity and compressive strength of anode blocks. Post-baking, anodes are transferred to the ARS. Here, carbon anode blocks are assembled with steel pins through a casted joint created using molten cast iron. This process ensures a low-resistance electrical connection between the carbon anode and the busbar system in electrolytic cells. The final rodded anodes are then subjected to quality inspection before being delivered to the potroom.

With amperage creep in the potline, anode current density rises linearly. To maintain a similar anode replacement schedule and ensure an optimum voltage drop across the carbon anode block, it is necessary to modify the carbon anode block design. Reducing the anode voltage drop can be achieved by increasing the current-carrying cross-sectional area of the anode and increasing slot height [1, 2]. Originally, the standard anode block dimensions are 1550 mm (length) × 650 mm (width) × 680 mm (height). Given the spatial constraints associated with increasing the anode width, the viable approach is to extend the length of the anode. The proposed design involves increasing the anode length by 30 mm, resulting in an additional surface area of approximately 18 360 mm^2 per anode. To facilitate a higher rate of gas dissipation, the anode slot height was increased by ~130 mm. Based on empirical correlations, these geometric changes lead to a reduction of approximately 24 mV in anode voltage drop. Moreover, this change does not necessitate significant alterations in the anode rodding process or pot cell configuration, ensuring compatibility with existing infrastructure. Upgrading the anode plant to produce larger anodes is a familiar approach in the smelting community, with many such efforts reported in the past [2]. Figure 1 shows the overall process flow of the smelter. Equipment modifications necessary for manufacturing larger anodes are presented against each process unit.

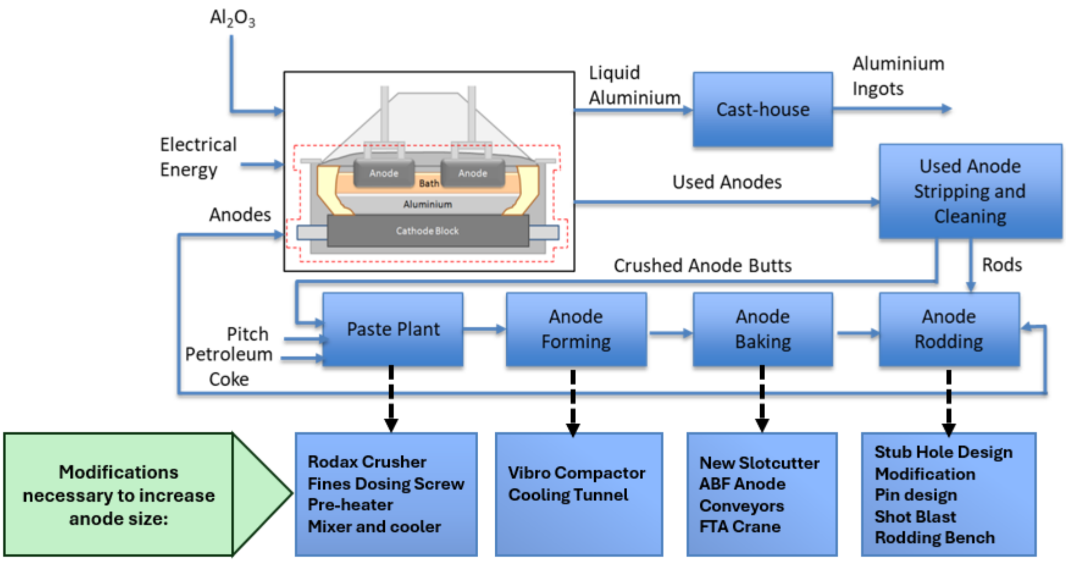

Figure 1: Process flow diagram of smelter and the necessary modifications in carbon plant.

2. Carbon Plant Upgradation

This section covers the process and equipment upgrades done in the carbon anode plant to enable it to produce larger anodes.

2.1 Green Anode Plant Modification

In GAP, the process flow remains the same; however, process parameters such as mixing residence time and vacuum were adjusted to achieve the desired green anode quality. The existing vibro-compaction mould and imprint mass were replaced to accommodate an anode block of increased dimensions. The intermediate paste feeding hopper was replaced to handle the increased paste mass per anode. The hydraulic power pack was upgraded to ensure the desired flow required to maintain compaction pressure for larger anodes.

2.2 Anode Baking Furnace Modification

2.2.1 Process Modification

To accommodate anodes with increased dimensions, an experiment was conducted to determine if the current baking furnace setup could effectively bake the anodes. Mahan's baking furnace consists of 2 tubs with 66 sections, where each section contains 8 pits. Each pit can house 21 anodes in the configuration of 3 rows and 7 columns, thus holding a total of 168 anodes per section and 11 088 anodes in the whole furnace. The flue walls are designed to hold the old 1560 mm long anodes, so the new anodes, when stacked, will have an excess of 90 mm above the direct baking zone. A visual presentation of this packing arrangement is shown in the figure. For baking larger anodes of 1580 mm length, an ABF feasibility analysis was conducted through (i) computational fluid dynamics (CFD) modelling (ii) experiments were conducted to analyze the impact of anode length increase on baking quality in the existing furnace (iii) measurement and calculations to check the fume treatment center (FTC) compatibility. Due to the increase in anode mass, pitch volatile mass, and HFO requirement will also increase. To ensure the availability of the required quantity of oxygen to burn this extra mass of volatiles and fuel, it is necessary to increase the gas flow. Effective flue gas flow was calculated and given as input to CFD computations. Draft requirement for baking 1550 mm long anodes and 1580 mm long anodes is compared in Figure 2. It was found that the draft increases by ~10 Pa and the zero-pressure point in the fire curve shifts by 1 peep hole.

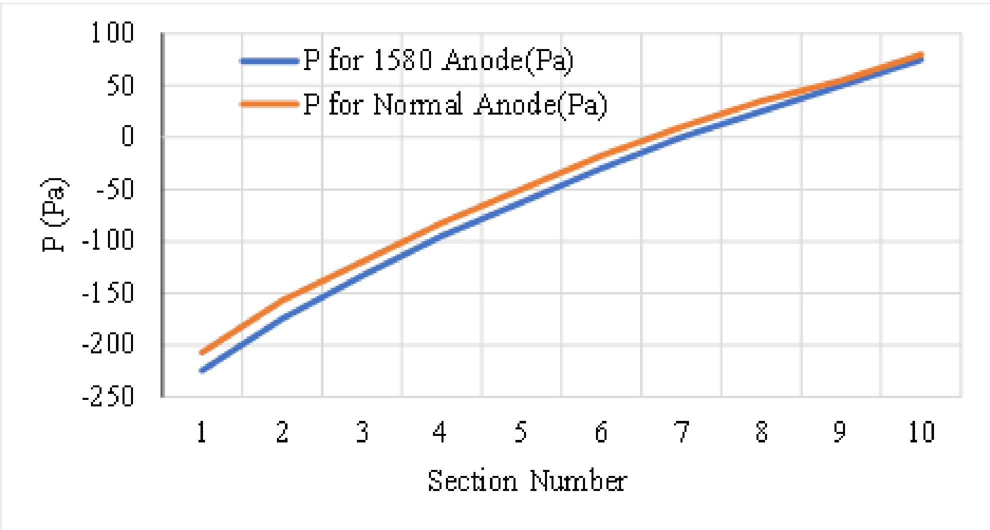

Figure 2. Difference in flue gas pressure (P) for the normal and longer anode.

To analyze the impact of anode length increment on the baking profile, an experiment was conducted. An additional layer of 100 mm thickness, comprising of packing coke was laid below the anodes to represent additional anode length of green anodes. The Figure 3 shows the schematic representation of the anode loading pattern during the experiment.

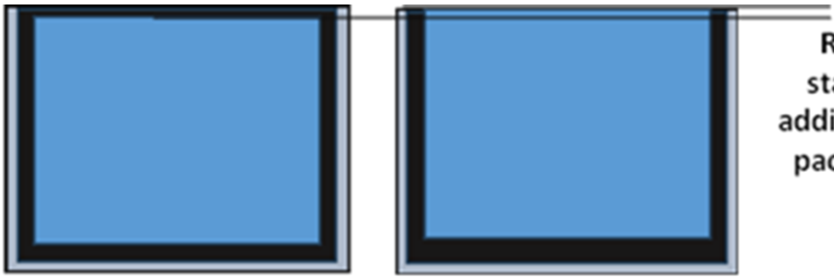

Figure 3. Difference in packing followed for the experiment with 1580 mm anodes.

A baking cycle was performed. Samples were drawn from various locations in the top layer of anodes. These samples were characterized, and their physical properties were compared. Table 1 shows the comparison of key anode quality parameters of these samples. To achieve the target Lc, the baking cycle time was increased to achieve the needed soaking time for the anodes. Critical design parameters of equipment in FTC were checked for their ability to handle higher gas flow. The residence time of gases in the conditioning tower, air-to-cloth ratio in the baghouse, and induced draft (ID) fan capacity were checked to ensure the availability of spare capacity to handle the extra flow.

Table 1. Measured parameters of normal and 1580 mm length increased anodes.

Properties	Sample from top 100 mm length of anodes (increased length)	Properties of anode sample centre to top layer anodes
Crystallite Size, Lc, (Å)	29.66	30.57
Geometrical Density, GD, (g/cm^3)	1.5692	1.599
Electrical Resistivity, ER, (µΩm)	59.8	59.7
Air Reactivity Residue, ARR, (%)	65.42	70.57
Carboxy Reactivity Residue, CRR, (%)	91.14	91.27

2.2.2 Equipment Retrofitting in ABF

On the ABF floor, central conveyor lines are provided between two furnaces to facilitate the movement of green and baked anodes. The green anode conveyor and baked anode conveyor are located side by side. When lifting and moving the green anode packet, the furnace tending assembly (FTA) grab should be lowered and lifted to a height that will be sufficient for clearing the anodes placed on the baked anode conveyor. To achieve this, the height of the FTA crane girders was raised by 200 mm. Graphical representation is shown in Figure 5. To support this modification, grab vertical car and suction and filling pipe stroke length was also modified accordingly.

Figure 4. Clearance between the anode packets placed on central conveyor line (One packet is in lifted position).

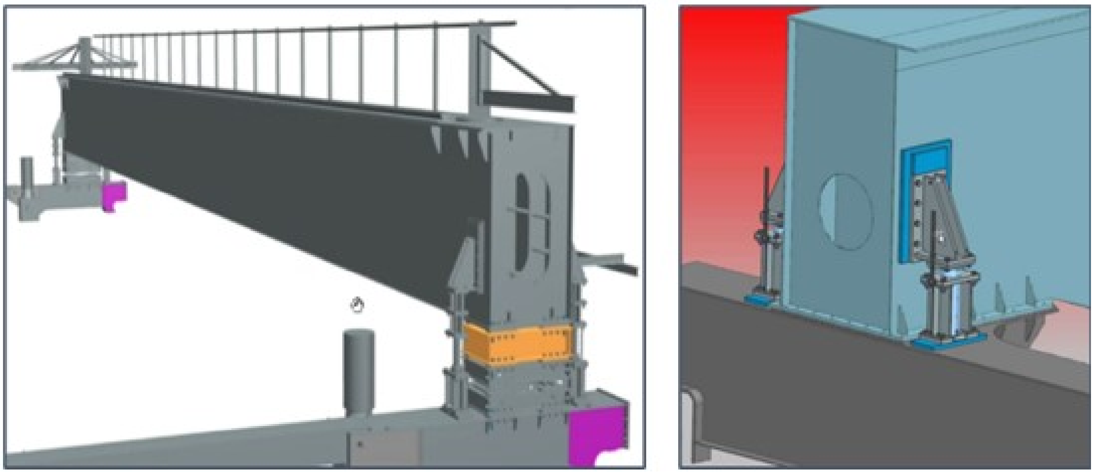

Figure 5. Left: FTA height increase, Right: Height increase via girder length increase.

2.3 Cost Effectiveness in the Modification Work and Its Financial Impact

A proper and thorough analysis of modification requirements helped to avoid major modifications in ABF and FTC. As discussed earlier, an increase in anode length by 30 mm translates to an overall increase of 100 mm in the height of stacked anodes inside the pit. To ensure similar flue gas flow distribution and volatile burning pattern, it was necessary to increase the height of the flue wall by adding an extra layer of bricks. This design modification also required some minor adjustments in baffle design, tie brick arrangement in the flue wall, and headwalls. The estimated cost of this modification was 3.4 crore INR. Experimental and CFD analysis provided insights that guided the team to bake the longer anodes without any design modifications in the flue walls, headwalls, and concrete tub. Baking levels were achieved with minor adjustments in process parameters. In addition, in-house expertise was utilized to conduct feasibility studies of the anode handling system to identify necessary modifications in conveyors, positioning sensors, and the rodding shop. Necessary modifications were made in an optimal manner to save costs.

3. Way Forward

While the amperage of the pots is being increased to 400 kA, the stem assembly design remains unaltered. The increased flow of current through the same stem and thimbles will result in an increase in voltage drop, due to increased current density. Thimble geometry also plays a crucial role in the volage drop in the block. Thus, the design of the anode block, stub hole, stems, brackets and pins will be modified to avoid increase in anode assembly voltage drop at high amperage operation.

4. Conclusion

To support the amperage increase in the smelter, three major modifications were made in the anode block design: (i) anode length, (ii) anode height, and (iii) slot height. The key process and equipment modifications made to achieve this goal are discussed in the paper. In the Green Anode Plant (GAP), the dimensions of the molds were adjusted to accommodate an extra 30 mm length during compaction. The hydraulic systems were also upgraded to meet the additional load requirements for producing larger anodes.

In the Anode Baking Furnace (ABF), the FTA height was increased to improve the clearance between the central conveyor and the suspended anodes. A feasibility analysis was conducted to determine if the existing fume treatment centre design was sufficient for handling the extra flue gas flow rate resulting from baking larger anodes.

5. References

1. Olivier Rival et al., Performance Improvement with Limited Expenditure and Baking Furnace Options, *Proceedings of the 40th International ICSOBA Conference*, Athens, Greece, TRAVAUX 51, 939–950.
2. Yvon Ménard and Vinko Potocnik, Anode Centre Modifications to Accommodate Potroom Amperage Increase–A Review and Practical Experience, *Proceedings of 42nd International ICSOBA Conference,* Lyon, France, 27 – 31 October 2024, *TRAVAUX* 53.
3. Mohsen Ahmed Shukralla et al., (2021, November). The Roadmap of AP-ALBA to 400 kA, *Proceedings of 39th International ICSOBA Conference, Virtual Conference,* 22 – 24 November 2021, *TRAVAUX* 50, 22–24.
4. Bastaki, M. et al. DUBAL cell voltage drop initiatives towards low energy high amperage cells, *Light Metals* 2014, 451–455.