

## High Purity Aluminium Production at Mahan and Aditya Smelters

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### Abstract

Demand for high-purity aluminium is rising as it is essential for advanced applications in electronics, aerospace, and various specialized manufacturing setups. Its production at an aluminium smelter requires stringent process control and high-quality raw materials.

Over the last 5 years, Mahan and Aditya Aluminium have developed and implemented innovative operational practices to produce high purity aluminium within their existing electrolytic cells. This initiative enhances the value of the aluminium produced beyond commercial grade aluminium while maintaining cost competitiveness amid fluctuating LME prices and rising power costs. The production of high-purity aluminium has allowed both the smelters to maximize value and strengthen their position as a global leader in high purity smelter grade aluminium production. This paper presents the journey of Mahan and Aditya Aluminium towards high purity production and explores key factors influencing high purity aluminium production including the selection of right grade of raw materials. The operational focus and operating parameter setting is necessary to successfully implement and sustain high purity production. Data will be presented to show the impact, challenges in operational practice and how these are being managed to maintain high purity production economically.

**Keywords:** Aluminium smelting, High purity aluminium production.

### 1. Introduction

Hindalco Mahan and Aditya Smelters are two primary aluminium smelters operated by Hindalco Industries Limited, the metals flagship of the Aditya Birla Group. These integrated plants each house a 359 000 tonnes per year aluminium smelter, supported by a 900 MW captive power plant, positioning Hindalco among the leading aluminium producers in India.

Both smelters are equipped with advanced AP36 technology, featuring potlines with 360 cells. The smelters also include modern cast houses and carbon plants for anode manufacturing, forming a comprehensive production system.

The Mahan and Aditya smelters produce a wide range of aluminium products, including ingots, wire rods, billets, and sows. More than 40 % of their output is exported to global markets such as the USA, Japan, Korea, Mexico, and Israel. Their high purity grades of sow are particularly valued in international markets, serving critical applications in aerospace, advanced electronics, communications, and semiconductor industries.

Global demand in high purity aluminium has experienced incredible growth over the past few years and is likely to continue growing in line with the expansion of manufacturing industries. Technology advancements require ever-higher levels of purity for specific applications due to aluminium lightweight, corrosion resistance and superior conductivity in aerospace and military, semiconductors and electronic devices.

## 2. Hindalco's High Purity Journey

Since 2022, Hindalco's smelters have achieved a significant milestone by producing high purity 3N4 (99.94 %) aluminium resulting in an average potline metal purity exceeding 99.91 % (Figure 1). Both smelters have produced aluminium with purity level of 3N4 (99.94 %), marking the first instance of aluminium of such exceptional quality being produced in India. The achievement was the result of an in-depth, cross-functional initiative involving rigorous studies and collaboration across multiple departments to optimize key elements of the production process. This breakthrough not only underscores Hindalco's technological leadership but also positions the company at the forefront of high-end aluminium manufacturing on a global scale.

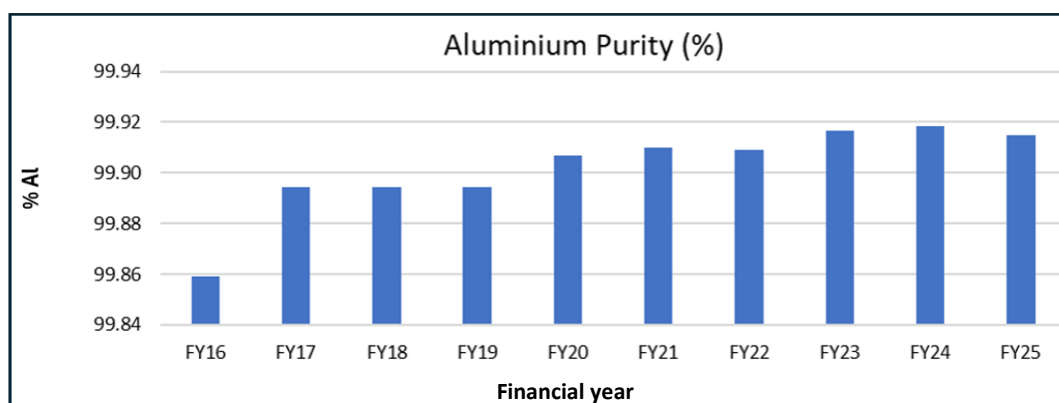


Figure 1. Trend of aluminium metal purity (%).

## 3. Raw Material Control: A Key Enabler for 3N4 (99.94 %) Aluminium Purity

Impact of raw materials in hot metal production is significant in terms of process stability and metal purity. Key raw materials in aluminium smelting are alumina, carbon anodes [1], anode cover mix, cryolite, and additives –  $AlF_3$  and  $CaF_2$ . Given the variability in raw material quality, it is essential to closely monitor incoming supplies and implement adaptive strategies to mitigate their impact.

Impurities in alumina ( $Fe_2O_3$ ,  $SiO_2$ ,  $Na_2O$ ,  $CaO$ ,  $TiO_2$ ) lead to higher impurity of molten aluminium. Carbon anodes are a mix of calcined petroleum coke, pitch and processed anode butts. Contaminants in anode coke or pitch (like sulphur, ash, or metals such as vanadium or nickel) can introduce trace metals into aluminium. As global oil reserves degrade [2], the quality of petroleum coke is also declining, making it increasingly difficult to source raw materials with lower impurity levels with increasing cost.

A critical factor in achieving high purity 3N4 grade aluminium production is the meticulous selection and segregation of raw materials. By carefully sourcing alumina, coke, and pitch with consistently low impurity levels – and ensuring strict segregation throughout handling and processing – the final purity of aluminium was significantly improved. This raw material strategy played a pivotal role in reaching high purity 3N4 aluminium quality benchmarks.

Procuring low-impurity raw materials has been challenging due to global supply variability, inconsistent material specifications, and ongoing cost pressures, which hinder the ability to maintain consistent quality standards. To overcome this challenge, the following approach was adopted:

1. Supplier qualification and auditing: Establish long-term relationships with verified suppliers with consistent impurity control.
2. Incoming quality inspection: Implement stricter quality assurance and quality control (QA/QC) for each raw material batch.
3. Digital procurement systems: Integrate with forecasting tools that consider impurity thresholds as key decision points.

Once raw materials enter the process, segregation becomes technically and operationally complex. Mixing or cross-contamination between cells leads to wider impurity spread. To segregate the impurities from high-purity cell zones, following approach was adopted:

1. Physically and operationally separate high-purity production cells from standard cells.
2. Monitoring by tagging and tracking raw material batches from delivery to usage.
3. Dedicated silos for special anode cover mix and alumina.
4. Monitor bath chemistry in high-purity cells more frequently and adjust anode cover mix, AlF<sub>3</sub> additions, and anode replacement schedules.

### 3.1 Special Anode Production for High-Purity Metal

A major source of silicon in anodes are pitch and coke, while iron impurities are primarily introduced through recycled butts. To address this and support high-purity aluminium production, a new blending approach was adopted to optimize pitch usage, significantly improving control over anode composition and enabling consistent production of high-purity anodes (Table 1). A dedicated Standard Operating Procedure (SOP) was developed to guide the segregation of standard anodes from special high-purity anodes, ensuring process discipline and traceability.

**Table 1. Fe and Si content in regular and special anodes.**

Anode	Fe (ppm)	Si (ppm)
Regular anode	450–500	140–170
Special anodes	400–450	90–120

### 3.2 Special Mix for Anode Covering and Taphole Closing

The standard cover mix, traditionally used for new anode covering and pot taphole closing after metal tapping, contains relatively high levels of impurities, with Fe<sub>2</sub>O<sub>3</sub> content in the range of 600–700 ppm and SiO<sub>2</sub> around 500–600 ppm (Table 2). To support high-purity 3N4 metal production, a special cover mix was developed through the careful selection and segregation of low-impurity raw materials.

This targeted approach significantly contributed to minimizing impurity introduction during both anode coverage and taphole sealing operations, thereby supporting the overall goal of producing high-purity hot metal.

**Table 2. Fe<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub> in regular and special cover mix.**

Cover mix	Fe <sub>2</sub> O <sub>3</sub> (ppm)	SiO <sub>2</sub> (ppm)
Regular cover mix	600–700	450–500
Special cover mix	350–450	250–350

### 3.3 Selection of High-Purity Alumina for Reduced Impurities in Liquid Aluminium

To support the production of high-purity aluminium, enriched alumina was selected based on its favourable impurity profile. This alumina contains fluorine (1.8–2.0 %), with low levels of Fe<sub>2</sub>O<sub>3</sub> (150 ppm) and SiO<sub>2</sub> (120 ppm) as shown in Table 3 and is delivered continuously to the pots via a hyper-dense phase conveying system. Mass balance assessments indicate that these impurity levels result in corresponding concentrations of Fe (200 ppm) and Si (100 ppm) in the final aluminium metal.

**Table 3. Fe<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub> in enriched and fresh alumina.**

Alumina	Fe <sub>2</sub> O <sub>3</sub> (ppm)	SiO <sub>2</sub> (ppm)
Enriched alumina	140–160	110–120
Fresh alumina	40–50	100–110

To further reduce contamination, an alternative alumina-feeding route was introduced, bypassing gas-treated alumina (GTA), which had elevated levels of Fe<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub>. This strategic shift significantly reduced iron and silicon concentrations in the molten aluminium, thereby increasing metal purity. However, the change also disrupted bath chemistry, resulting in a higher cryolite ratio (NaF/AlF<sub>3</sub>) and a less acidic bath. These shifts adversely impacted metal pad stability and current efficiency. Additionally, the introduction of fresh alumina led to a reduction in bath temperature and slower alumina dissolution, contributing to sludge formation in the pots.

To mitigate these effects, pot operating parameters like alumina feed rate, AlF<sub>3</sub> additions were adjusted in parallel to accommodate the characteristics of the new alumina source, ensuring process stability while maintaining high metal quality.

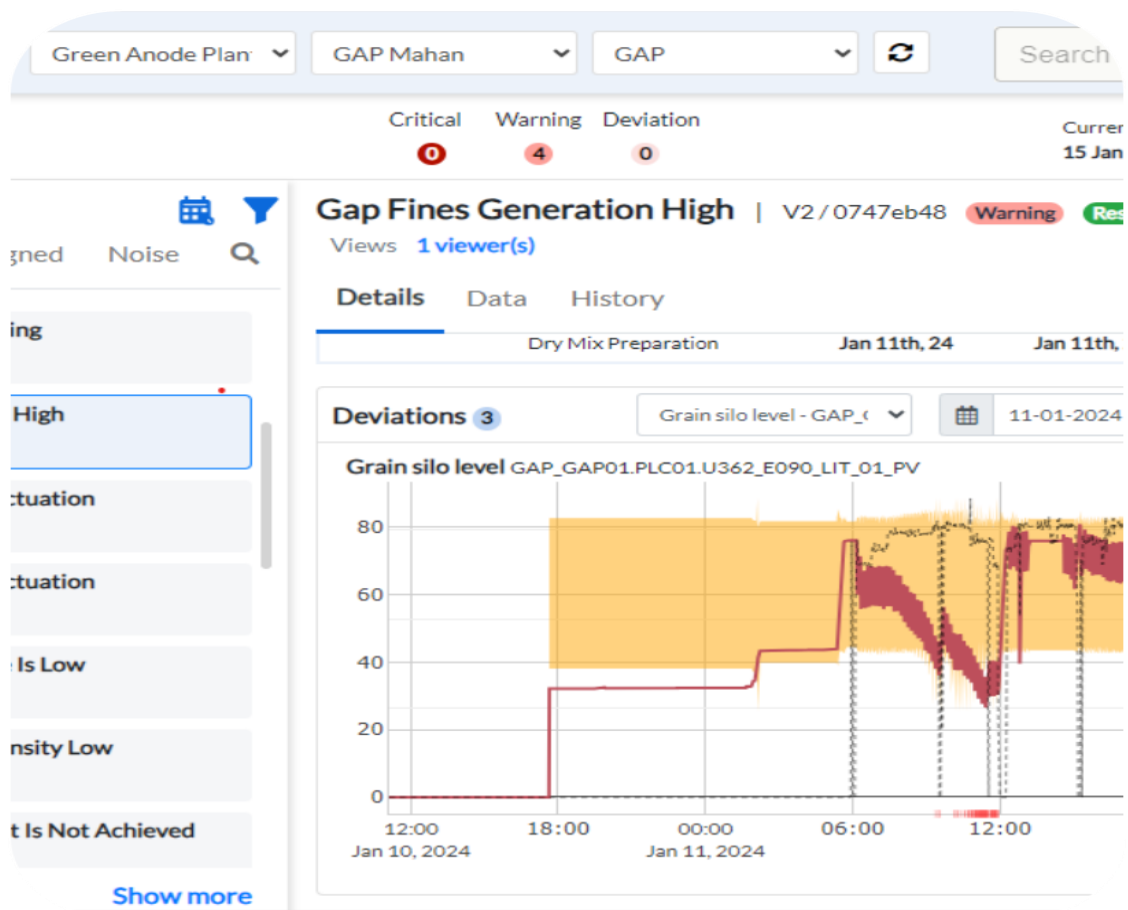
## 4. Process Optimization for High Purity Output

To support the production of high purity 3N4 aluminium, the smelting process was fine-tuned through the optimization of critical cell parameters. Key parameters such as cell temperature, voltage, bath height, and alumina feeding rates were carefully adjusted to maintain stable operations and reduce impurity generation during electrolysis. This systematic optimization played a vital role in minimizing contamination risks in the pot and increasing the overall purity of the metal produced.

Anode covering audit of pot and pot tending frequency increased to minimize air burn and stub exposure. Monitoring metal purity involves regular sampling and analysis of the aluminium produced in each cell. Data tracking systems are used to detect deviations in purity levels, enabling timely adjustments to the process to maintain desired quality standards. Enhancing the metal sampling process is critical to prevent introducing impurities. This includes using clean, dedicated sampling tools, minimizing exposure to contaminants, and implementing procedures that reduce the risk of impurity pickup during sampling.

## 5. Cross-Functional Collaboration and Digital Integration

The successful production of high purity 3N4 aluminium was made possible through seamless coordination among key departments, including production, quality control, and research and development. The integration of systems such as the Laboratory Information Management System (LIMS) enabled real-time data sharing, analysis, and traceability, supporting informed decision-making and driving continuous process improvements. A Digital Twin prediction model was developed to enhance process reliability in both the Green Anode Plant (GAP) and Anode Baking Furnace (ABF), with the objective of supporting the consistent production of high-purity metal (Figure 2). This model integrates real-time process data, historical trends, and machine learning algorithms to predict potential deviations in anode quality that could affect metal purity. By simulating various operational scenarios and their impact on downstream purity, the Digital Twin serves as a powerful tool for proactive quality control and continuous improvement in high-purity aluminium production.



**Figure 2. Prediction model for GAP and ABF process reliability.**

This achievement not only reflects Hindalco's commitment to technological excellence but also establishes its position as a frontrunner in the global aluminium industry, setting new benchmarks for purity and process innovation.

## 6. Operational Discipline and Monitoring: Sustaining Purity Standards

Achieving and sustaining high purity 3N4 aluminium production requires the implementation of stringent operational protocols and continuous monitoring of the smelting process. This disciplined approach is crucial in identifying potential sources of contamination in real time and enabling prompt corrective actions. Consistent oversight ensured process stability and played a key role in maintaining the high purity levels required for 3N4 purity aluminium. Key measures include:

1. Maintaining precise bath chemistry to prevent unwanted reactions and impurity dissolution.
2. Controlling anode effects, especially high-energy events, which can disturb bath stability and introduce contaminants.
3. Increasing the frequency of bath height measurements to ensure consistent operating conditions.
4. Impurities such as Fe and Si can be introduced from various sources, including the anode thimble, making it essential to control multiple process parameters. Proper anode setting practices are vital to minimize impurity pickup during the anode life in the pot. Preventing anodic incidents such as pin wash and pin melt, which increase impurity levels (Figure 3).



**Figure 3. Good butt with no air burn or pin exposed.**

To support these efforts, high-purity pots are monitored closely, with special attention given to:

1. Minimizing bath height variation,
2. Preventing air burning of anodes, and
3. Enabling early detection and removal of anomalies such as spikes, block drops, and other anodic disturbances.
4. Normal 80-shift anode change cycle was reduced to avoid chances of impurity pickup from stubs due to bath attack if exposed to bath.

This proactive operational strategy ensures that impurity input is minimized, and metal purity is maintained throughout the production cycle.

## 7. Results

The project aimed to reduce Fe and Si impurities in liquid aluminium by introducing a special alumina-feeding route and enhanced process monitoring in high-purity pots. As a result of the implemented changes on the selected high purity pots, Fe and Si content in metal reduced significantly (Figures 4–5), led to more consistent high purity 3N4 aluminium production Figure

6), and reduced the number of out-of-spec batches. The project demonstrated that precise raw material control and operational discipline can significantly impact metal purity.

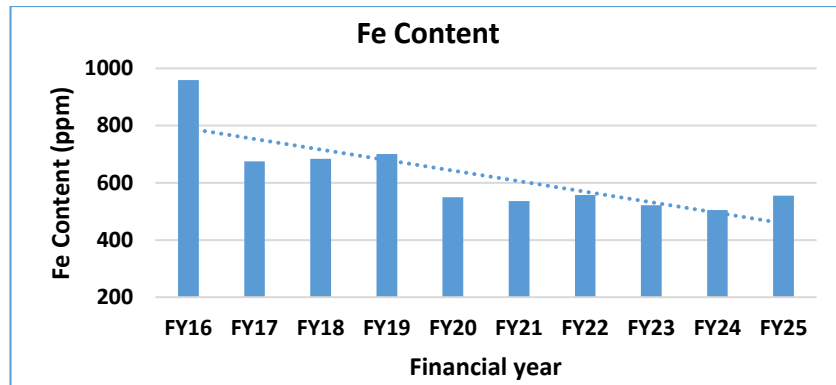


Figure 4. Fe trend of pot metal over the last 10 years.

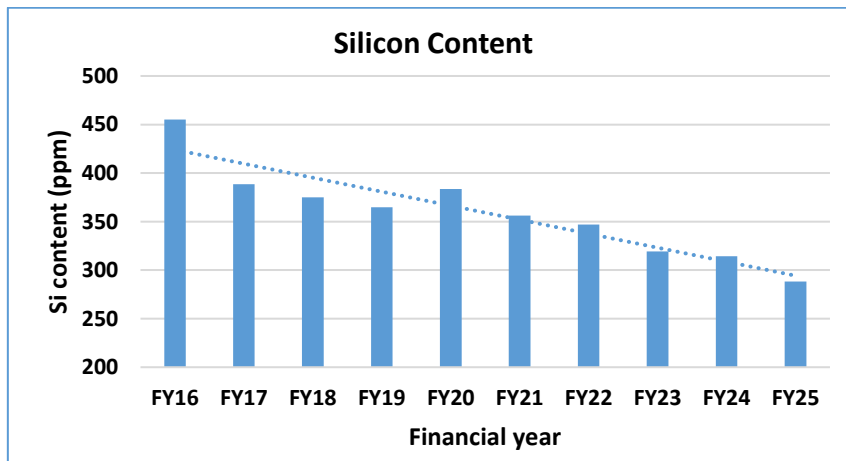


Figure 5. Si trend of pot metal over last 10 years.

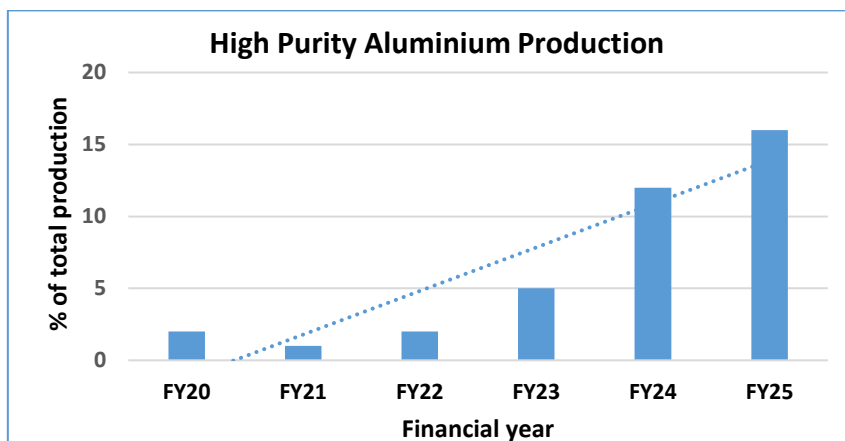


Figure 6. High Purity (3N1 to 3N4) metal production (%).

## 8. Conclusions

Effective segregation of raw materials is crucial to prevent contamination and ensure consistent metal quality. Implementing stringent delivery mechanisms, including proper storage and handling procedures, helps maintain the integrity of materials throughout the production process.

Stability in the smelting process is essential for efficient operation. This involves regulating parameters such as bath height, % excess  $AlF_3$ , bath temperature, and alumina concentration.

Consistent delivery of anodes and metal crucibles is achieved through synchronized scheduling and real-time monitoring to align with production demands.

## 9. References

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