IBAAS 2026 Conference & Exhibition

September 9-11, 2026

Mayfair Hotels and Resorts, Jharsuguda, Odisha (India)

Application of Artificial Intelligence in the Aluminium Industry

Integrated Red Mud Pond Management Using Digitalization and Artificial Intelligence

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ABSTRACT

Red mud ponds are among the most safety-critical assets in alumina refineries, with their long-term integrity directly dependent on the interaction of material behavior, water balance, pore pressure development, phreatic line position, bund geometry, and changing operational conditions. Traditional management practices—based on manual instrumentation, periodic inspections, and snapshot-based stability assessments—have been effective for compliance but remain largely reactive. These limitations become increasingly significant under higher rainfall variability, aging infrastructure, and growing regulatory, ESG, and community expectations, where early warning and proactive risk management are essential.

This paper presents a practical digital and AI-enabled framework for red mud pond management that builds on proven geotechnical practices rather than replacing them. Recognizing the poor reliability of online sensors in caustic red mud environments, the approach deliberately retains manual piezometers and inclinometers while digitizing data collection, integration, and visualization through mobile applications and centralized dashboards. Digitized field measurements are spatially integrated to continuously track pore pressure evolution and phreatic line movement across the pond and bund. Using existing design assumptions and historical stability models, these data are converted into a dynamic Factor of Safety (FoS), providing continuous visibility of stability margins and early warning of deterioration well before visible signs of distress. The framework integrates drone-based surface inspection, computer-vision-assisted crack and erosion detection, high-precision DGPS deformation monitoring, AI-driven dust suppression, operational mud inventory assessment, and storm water management for supernatant liquor ponds. All real-time and historical datasets are consolidated into a unified digital platform that functions as a living digital twin of the red mud pond. By enabling predictive analytics, scenario modeling, and structured insight-to-action

decision workflows, the proposed system transforms red mud pond management from a reactive compliance activity into a proactive, predictive, and risk-based governance process, supporting improved safety, regulatory compliance, ESG performance, and long-term operational resilience.

Keywords: ***Red Mud Pond, Digital Twin, Pore Pressure, Phreatic Line, Slope Stability, AI, Dam Safety, Geotechnical Monitoring.***

Transforming Effluent Treatment through Automation, Analytics, and Circular Resource Recovery

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ABSTRACT

Water scarcity poses a critical operational challenge for Hindalco Belagavi, a specialty alumina refinery located in a water-stressed region with no perennial river source and complete dependence on monsoonal rainfall. Ensuring a reliable supply of high-quality water is essential for specialty alumina production, which demands stringent water quality standards. While increasing reuse of treated process water is imperative for sustainability, conventional Effluent Treatment Plant (ETP) operations—based on manual controls, fixed chemical dosing, and periodic intervention—have proven inadequate due to persistently high Total Dissolved Solids (TDS), colour, odour, and biological growth caused by caustic contamination and large-volume storage conditions.

Building on earlier process optimization efforts that successfully eliminated colour and odour through improved coagulant–flocculant systems and controlled biocide application, this paper presents a fully automated, sensor-driven, and AI-enabled ETP framework for specialty alumina operations. The proposed system integrates automated acid dosing for real-time neutralization of process water, dynamic coagulant and flocculant dosing based on online turbidity measurements, and ORP-based biocide control. Machine-learning algorithms analyze historical and real-time data to optimize chemical dosage, minimize consumption, and prevent under- or over-treatment. Automated sludge-level monitoring enables controlled and timely sludge withdrawal, ensuring stable hydraulic and treatment performance.

To achieve complete circularity, the withdrawn sludge is processed through a thermal dryer to achieve greater than 90% solids, enabling its utilization in cement industry co-processing and eliminating dependence on traditional TSDF disposal routes. The

integration of automation, real-time sensing, and AI-based optimization significantly improves treated water quality, enhances system reliability, and reduces freshwater intake, chemical usage, operational variability, and environmental risk. This study demonstrates a scalable and cost-effective pathway for autonomous ETP operation in water-scarce, compliance-intensive industrial environments.

Keywords: ***AI-Enabled Automation, Water Reuse, Sensor-Driven Dosing, Circularity.***

Predictive Modelling of Alumina Trihydrate Particle Size Using Machine Learning

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ABSTRACT

As demand for specialty alumina continues to grow, consistent control of alumina trihydrate particle size distribution (PSD) during precipitation has become increasingly critical for meeting customer-specific quality requirements and ensuring stable refinery operation. Many alumina refineries continue to operate ageing precipitation circuits, where any meaningful process adjustment typically requires 15–20 days to manifest in the final product. This delay significantly increases the risk of quality drift, particularly in the formation of excessive fines or coarse material, for different customers. The challenge is further compounded by the need to supply multiple customers with distinct PSD targets, placing strong emphasis on effective production planning, sequencing, and process stability.

Traditional precipitation control relies predominantly on delayed laboratory measurements and operator judgement, limiting the ability to anticipate PSD deviations and intervene in a timely manner. In this study, a data-driven predictive framework is developed to estimate the median particle size (d_{50}) of alumina trihydrate directly from real-time process variables, while remaining anchored in established precipitation chemistry. The model is based on three years of continuous plant operating data, comprising 25,404 hourly observations and 36 key variables related to liquor chemistry, seed characteristics, super saturation, and temperature profiles. A major challenge was the high sparsity of laboratory PSD measurements, with approximately 85–90% missing

data, which was addressed through Bayesian iterative imputation and time-lagged feature construction over 1–24 hour intervals.

Key mechanistic indicators, including super saturation, Tschamper ratios, seed specific surface area, and temperature gradients, were combined with statistical descriptors, with multi collinearity controlled using variance inflation factor analysis. A Light GBM ensemble model delivered the best performance, achieving an R^2 of 0.727, MAE of 3.55 μm, and RMSE of 4.63 μm. With a predictive horizon of approximately 14 days, the framework allows early identification of PSD drift, supporting stable quality delivery, reduced switching losses, and improved customer confidence in specialty alumina supply.

Keywords:* *Digital Twin, Process Digitalization, Predictive Analytics, Precipitation Control, Particle Size Distribution, Machine Learning.

AI-Enabled Bauxite Yard Management Using Online Analyzer, Intelligent Stacking–Reclaiming, and Real-Time Laser-Based Volume Control

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ABSTRACT

Efficient bauxite yard management is critical for ensuring consistent feed quality, optimized inventory utilization, and improved downstream process performance in alumina refineries. This paper presents the concept of an AI-based bauxite yard management system integrating an online bauxite analyser, intelligent stacker control, grade-wise segregation, optimized reclamation and blending, and real-time volume monitoring using terrestrial laser scanning (TLS).

This method utilizes an online bauxite analyser installed on the conveyor feeding the stacker to continuously measure key quality parameters such as Al_2O_3, SiO_2, Fe_2O_3, and moisture. These real-time inputs are processed through AI and machine learning algorithms to dynamically determine stacking strategies, enabling grade-wise segregation and formation of optimized stockpiles. The stacker operation is

automatically guided to place material in designated zones based on predicted quality trends and blending requirements.

For reclamation, the system integrates AI-driven reclaimer scheduling and control, ensuring best-blend extraction by combining material from multiple stockpiles and layers to achieve target quality specifications for refinery feed. Historical analyser data, stockpile quality models, and process requirements are used to generate optimal reclaimer paths and reclaim rates, minimizing quality variability and reducing manual intervention.

Additionally, terrestrial laser surveying can be employed for real-time, volume-based yard management. High-resolution 3D stockpile models generated from TLS data provide accurate measurements of stockpile volume, shape, and reclaim progress. These models are continuously synchronized with the AI system, enabling precise inventory tracking, reconciliation, and decision-making in real time.

The integrated solution can enhance operational transparency, quality control, and inventory accuracy, while reducing blending losses, operational delays, and dependency on subjective judgment. The adoption of AI-based bauxite yard management with real-time analysers and laser scanning represents a significant step toward digitalization and smart material handling in the aluminium industry.

Keywords: ***AI-Based Yard Management, Online Bauxite Analyzer, Grade-Wise Segregation, Intelligent Stacker Control, Optimized Reclamation, Best Blending Strategy, Terrestrial Laser Scanning (TLS), Real-Time Volume Measurement, Digital Stockpile Management, Alumina Refinery Feed Optimization, Machine Learning in Bulk Material Handling, Smart Mining and Industry 4.0.***

AI-Guided Optimization of Last Growth Tank Temperature in the Precipitation Circuit of Utkal Alumina International Limited (Alumina Refinery)

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ABSTRACT

In the precipitation circuit of an alumina refinery, precise temperature control across tanks is critical for hydrate crystal growth, size distribution, impurity incorporation and

process efficiency. Conventional operation of manually controlled inter-stage coolers (ISCs) often governed by fixed SOPs that lack sensitivity to dynamic process and environmental condition, failing to dynamically adjust to ambient fluctuations and radiation losses, thereby causing variability in the final (last growth) tank temperature. The control philosophy is basically a backward feed control.
A common operational constraint is maintaining the last growth tank temperature above 54°C (50% of time), leading to conservative cooling strategies and consequent loss in precipitation productivity. Furthermore, the lag between operator action and measurable impact at the last tank — approximately 7–8 hours — limits effective feedback control.

To address these limitations, this study investigates data-driven strategies to model ambient cooling between the last operational ISC and the last growth tank, reduce temperature control lag by adopting forward feed control to dynamic conditions, enable dynamic target setting for last operational ISC inlet temperatures using predictive models and quantify the resultant gains in precipitation productivity and refinery throughput.

This paper outlines an AI/ML-based framework to optimize last growth tank temperature by modelling ambient cooling and operational behaviour of ISCs across the precipitation train. Using a Random Forest model and a regression-based ambient cooling equation trained on plant data (June 2024–August 2025), the study establishes the link between last operational ISC inlet temperature, ambient temperature, and target last growth tank temperature. The proposed framework enables real-time target setting of ISC inlet temperature to achieve consistent last tank temperature within 54–54.5°C.

Implementation trials demonstrated can have an average improvement of ~0.4 gpl in precipitation productivity (~0.46% throughput increase), by maintaining the target last growth temp, 90% of time. The work demonstrates the potential of intelligent control frameworks in modern alumina refining operations for enhancing process consistency, productivity, and energy efficiency.

Keywords: ***Artificial Intelligence (AI), Machine Learning (Random Forest), Forward Feed Control, Ambient Cooling Modelling, Process Optimization, Temperature Control, Precipitation Productivity, Hydrate Crystal Growth, AI-Driven Process Optimization, Machine Learning, Last Growth Tank Temperature, Inter-Stage Cooler (ISC) Optimization, Refinery Throughput Improvement and Energy efficiency.***

Real Time Condition Monitoring of Transformer

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ABSTRACT

Power transformers are critical assets in continuous process industries, where unexpected failures can cause prolonged outages, significant production losses, and even plant-wide blackouts. At Hindalco Industries' Muri complex, two 8 MVA generation transformers operate continuously, with physical inspection feasible only during major shutdowns scheduled every four to six years. Conventional manual monitoring resulted in delayed detection of abnormal conditions such as low oil levels, temperature rise, dissolved gas generation, oil quality degradation, and mechanical vibrations, thereby increasing the risk of catastrophic transformer failure.

To mitigate these risks, an AI/ML-enabled, IoT-based real-time transformer health monitoring system was implemented to ensure continuous condition assessment and early fault prediction. The solution integrates multi-domain sensing across thermal, mechanical, chemical, and electrical parameters. A network of IoT sensors captures twenty-three critical indicators, including oil level, case temperature, dissolved gases (hydrogen and moisture), oil quality indices, vibration, and key electrical parameters. All sensor data are consolidated into a centralized AI-driven monitoring platform that provides real-time visualization, anomaly detection, and predictive insights through an intuitive dashboard.

The system generates actionable alerts through dashboards, email notifications, WhatsApp messages, and control-room hooters, eliminating dependence on periodic manual inspections and significantly reducing response time. Advanced analytics and trend-based intelligence facilitate early identification of insulation degradation, thermal stress, and mechanical anomalies, enabling a transition from reactive maintenance to predictive and condition-based maintenance practices.

This initiative represents the first deployment of comprehensive online transformer health monitoring at Hindalco CGPP and delivers a true 360-degree view of transformer condition by integrating electrical, thermal, chemical, and mechanical indicators within a single platform. The modular and scalable architecture allows easy replication across additional transformers and other Aditya Birla Group facilities. Quantifiable benefits include reduced unplanned downtime, avoidance of potential plant blackouts, lower maintenance costs, improved power reliability, and an estimated financial benefit of ₹1.2 crore per prevented incident. Qualitative benefits include enhanced operational safety, faster decision-making, improved workforce efficiency, and strong user confidence through accurate alerts and continuous asset visibility.

Keywords: ***Real-Time Transformer Monitoring, Internet of Things (IoT), Artificial Intelligence (AI), Predictive Maintenance, Anomaly Detection.***

Smart Boiler Tube Leakage Detection System

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ABSTRACT

Boiler tube leakages are a major cause of unplanned outages, energy losses, and production disruptions in cogeneration power plants. At the Muri Power Plant, which operates three 140 TPH IJT make CFBC boilers and two 15 MW steam turbine generators to ensure uninterrupted power and steam supply, frequent tube leak incidents resulted in low mean time between failures (MTBF) of approximately six months and significant operational losses.

This project presents an AI-driven Smart Boiler Tube Leakage Detection System that integrates Condition-Based Monitoring (CBM), predictive maintenance, and prescriptive analytics to enable early detection of tube leakages and enhance boiler reliability and availability. The solution consolidates real-time data from Distributed Control Systems (DCS), water chemistry, coal quality, and laboratory inputs into the OSI PI platform. Advanced feature engineering using more than 20 process parameters and Principal Component Analysis (PCA)–based condition monitoring rules form the core of the detection logic. Real-time health monitoring, intelligent alerts, and decision-support dashboards are deployed through PI Vision to assist operators and maintenance teams.

The system is the first AI-based boiler tube leakage detection solution implemented at Hindalco CGPP and is fully developed in-house, resulting in a one-time capital expenditure saving of ₹2.2 crore compared with commercially available solutions. Quantifiable benefits include reduced forced outage hours, avoidance of production losses estimated at ₹39 lakhs per event, maintenance cost reduction of ₹3 lakhs per event, and an annual benefit of approximately ₹42 lakhs per boiler. Qualitative benefits include improved safety, centralized asset health visibility, improved planning, and a shift from reactive to predictive maintenance practices. The solution is scalable across other Aditya Birla Group power plants and supports future expansion with additional sensing technologies.

Keywords: **AI-Based Predictive Maintenance, Boiler Tube Leakage Detection, Condition-Based Monitoring (CBM), Principal Component Analysis (PCA), Industrial IoT (IIoT), Power Plant Reliability & Optimization.**

Towards Operator-Actionable Early Warning of Anode Effects: A 60-Minute Horizon Prediction System in Aditya Potlines

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ABSTRACT

Anode effects in aluminium smelting potrooms are among the most energy-intensive and operationally disruptive events in the Hall–Héroult electrolysis process. Intrinsic to alumina electrolysis, an anode effect occurs when the concentration of dissolved alumina locally drops below a critical threshold in the cryolite bath. Even with well-designed and properly functioning alumina feeding systems, achieving perfect concentration uniformity across a large industrial electrolytic cell is physically impossible, making localized alumina starvation unavoidable. Frequent or prolonged anode effects in potlines lead to sharp increases in specific energy consumption and greenhouse gas emissions, particularly perfluorocarbons (PFCs). They also reduce current efficiency and accelerate cell degradation, resulting in higher operating costs and reduced overall productivity.

Early detection of anode-effect onset and proactive reduction of anode-effect frequency is critical for achieving efficient, stable, and sustainable potline operation. Most existing approaches either rely on rule-based threshold triggers few seconds prior or require expensive per-anode current monitoring hardware not universally available across smelter fleets. With the advent of advanced analytics and machine learning, data-driven approaches can be leveraged for early detection of anode effect (AE) onset and proactive control.

Our work presents a pilot-scale, real-time AI-based predictive framework developed using standard plant historian data. The model incorporates pot-specific alumina feeding behaviour and resistance dynamics and explicitly addresses the severe class-imbalance characteristic of anode-effect prediction. A machine-learning classifier is employed to provide early warnings with a prediction horizon of up to 60 minutes.

The model has been developed and evaluated using walk-forward validation to reflect real operating conditions, demonstrating stable and consistent performance. In its current form, the model detects approximately 48% of anode-effect onsets with an

average lead time of 23 minutes and a precision of 15%. Ongoing work focuses on continuous model refinement and performance improvement.

The proposed approach enables timely operator intervention without requiring additional hardware or per-anode sensing infrastructure. By leveraging existing data systems, the framework supports improved energy efficiency, potline performance, and operational safety, and represents a practical step toward Industry 4.0 implementation in aluminium smelting operations.

Keywords: **Hall-Héroult electrolysis, AI-driven predictive model, Early prediction of anode effects, Machine Learning, Industry 4.0**

Development of a Vision AI based solution to distinguish between Bauxite and Laterite at Samri Bauxite Mines

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ABSTRACT

Accurate identification of bauxite and laterite ores is essential for effective mining and beneficiation, yet it remains challenging under real-world conditions due to ore heterogeneity and reliance on subjective visual inspection. This study presents the development and field deployment of a Vision AI–based system designed to distinguish between bauxite and laterite ores in real time. The system leverages deep learning–driven computer vision, augmented with domain-specific geological knowledge, to replicate and enhance expert-level visual assessment.

Key discriminative features—including colour variation, surface texture, degree of weathering, silica presence, moisture indication, and structural compactness—were encoded into the model during training. A continual learning framework enables the system to improve dynamically through ongoing image capture and retraining, allowing adaptation to site-specific variables such as lighting conditions and ore variability. To ensure reliability and sustained performance, a human-in-the-loop validation mechanism was incorporated, whereby field supervisors review model predictions and provide corrective feedback for subsequent learning cycles.

The model was deployed on tablet-based devices used directly in mining operations, enabling seamless integration into existing workflows without additional infrastructure requirements. Field results demonstrate strong classification performance and operational robustness, with minor accuracy degradation observed in cases involving highly mixed ores. Ongoing research focuses on extending the system to stack-level ore

analysis to support bulk material assessment and improved inventory management. Overall, the study demonstrates the viability of Vision AI as a scalable, adaptive, and consistent solution for real-time ore classification in mining environments.

Keywords: Vision AI, Continual Learning, Human-in-the-loop, Corrective Feedback, Mining Operations, Scalability.

AI-Enabled Soft Sensors and CBM for Driving Operational Excellence in Bauxite Mining

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ABSTRACT

Bauxite mining operations face growing pressure to enhance safety, improve asset availability, and reduce operating costs while managing geographically dispersed and capital-intensive assets. Conventional maintenance practices—largely reactive or time-based—offer limited visibility into asset health and often fail to detect early degradation. The objective of this work is to demonstrate how AI-enabled soft sensors integrated with Condition-Based Monitoring (CBM) can provide real-time operational transparency, enable predictive maintenance, and drive measurable improvements in asset performance across large-scale bauxite mining operations. A scalable, enterprise-ready AI-driven CBM framework is designed and being deployed across Hindalco's Lohardaga Division. The solution integrates PLC and SCADA data with sensor retrofitting, AI-based soft sensors, machine-learning algorithms for anomaly detection, and AI machine vision for continuous visual inspection and action by the system automatically. The deployment covers critical assets including ropeways, crushers, conveyors, DG sets, power transformers, and Heavy Earth Moving Machinery (HEMM). A layered architecture was adopted to minimize incremental capital expenditure while enabling centralized analytics, automated alerts, real-time dashboards, and actionable insights for operations and maintenance teams. Empirical results from pilot and scaled deployments indicate a significant improvement in predictive maintenance performance. The system will achieve 10–15% reduction in unplanned downtime, driven by early detection of abnormal operating patterns. Maintenance response time will be reduced by approximately **20 %**, and dependency on manual inspections decreased by over **60%**. Equipment availability improved by **3–5%**, and continuous real-time monitoring will enhance asset health visibility and operational safety. These findings validate the effectiveness of AI-enabled soft sensors and CBM in transitioning mining operations from reactive to predictive maintenance regimes. The results demonstrate a successful transition from reactive maintenance to predictive, data-driven operational

management, with strong alignment to safety and reliability objectives. The distinguishing feature of this initiative is the digital enablement of legacy and brownfield assets, converting conventionally operated equipment into smart, connected assets through sensitisation and AI-driven analytics. Existing infrastructure—often not designed for digital monitoring—is being upgraded to capture and record operational data in real time, generate automated reports, and trigger intelligent maintenance actions. By combining physical sensor data with AI-enabled soft sensors, the solution extends asset life, improves safety and reliability, and maximizes return on existing infrastructure without large-scale replacement. The framework delivers integrated visibility across mechanical, electrical, and safety domains and is scalable across mining and metals operations. This represents a "Smart Brownfield Transformation: Making yesterday's assets intelligent for today's operational challenges.

Keywords: Predictive Maintenance; AI-CBM, Soft Sensors, Smart Mining, Brownfield Digitalization, Asset Health.

Re-imagining the Aluminium Value Chain through Digitalization

Digital Transformation in a 60-Year-Old Industrial Plant: A Practical Approach

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ABSTRACT

Ageing industrial plants operate within constraints such as legacy equipment, soloed data, and manual processes that limit energy efficiency, reliability, and decision speed. This paper presents a practical, phased digital-transformation model implemented in a 60+ year old aluminium smelter, beginning with the establishment of a secure, real time operational data backbone using the Data Management System. On this foundation, targeted high impact analytical applications were deployed across operations and maintenance. The programme includes a Maintenance Analytics tool that delivers MTTR and MTBF based reliability insights along with spare consumption intelligence, enabling faster decisions and more efficient asset management. Complementary solutions include CBM Analytics for vibration, thermography, air leakage and oil diagnostics; Cooling Water Analytics for chemistry and ΔT control; a Pot Digital Twin

that predicts pot temperature and recommends AlF_3 dosing; Anode Cover Analytics to minimize heat loss and guide operator upskilling; VC Analytics to track the transition from open to closed crucibles; and Auto Reports that cascade Macro→Micro insights (Potline→Room→Zone→Pot) to accelerate daily and chronic abnormality resolution. Governance and safety enablers—Cyber secure OT/IT/CCTV, Layered Process Audits, Third Party Inspection compliance, and a unified Digital Landing Page—further strengthened transparency, discipline, and operational control. Collectively, these interventions reduced manual workload, improved energy stewardship, accelerated abnormality detection, and enhanced reliability, offering a replicable blueprint for transforming legacy brownfield plants into data driven "Plants of the Future."

Keywords: Legacy Plant Modernization, Industrial Digitalization, Data-Driven Operations, Operational Intelligence, Predictive Maintenance.

Optimization of Green Anode Density (GAD) & Electrical Resistivity (ER) through AI/ML

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ABSTRACT

The anode quality for aluminium manufacturing is influenced by operating parameters and ingredients during the making of green anodes. Pitch, coke, butt, ball mill fraction & green scrap is some of the key ingredients which controls the quality of anode which is represented by Green Anode Density (GAD). Some of the constraints of anode making includes a specific height, weight and flexural strength of the anode. These green anodes are baked in bake oven. The baked anodes are used in potlines for primary manufacturing of molten Aluminium through Hall–Héroult process. Electrical resistivity (ER) plays significant role in the process. Problems identified through quality checking of anode influenced by the above parameters has been done so that the electrical resistivity (ER) is minimum. This helps in reducing the voltage drop and increasing the current efficiency by reducing ER. It is required to optimize mass fractions of green anode ingredients within the feasible ranges to attain the best anode quality through Machine Learning (ML) algorithms. Multi-objective/RSM (response surface methodology) optimization method has been used to identify the suitable combination of the pitch and blending percentage of above-mentioned ingredients.

Keywords: Green anode density, electrical resistivity, anode baking, Machine Learning.

Predicting Keyholes in Additively Manufactured Aluminium using a Multiphase Physics Model of AM PravaH®

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ABSTRACT

This manuscript presents the prediction of melt pool behavior and a more critical aspect of melt pool dynamics, i.e., keyhole formation in pure aluminium. A physics-based approach is used for modeling the pure aluminium welding process at 500 W laser power and 1.2 m/s. The model is an advanced physics-based numerical simulation tool, AM PravaH ®, which has been developed and introduced by Paanduv Applications; it is specifically designed for high-fidelity analysis of Additive Manufacturing processes. The model is highly sensitive to the thermo physical properties, laser characteristics such as emissivity, absorption coefficients, and Fresnel coefficients. The tool aims to predict the defects in additively manufactured parts by a high-fidelity computational fluid dynamics approach involving multi physics coupling in laser-assisted AM processes. It captures the complex interplay of multi physical phenomena, such as a laser heat source for the melting of the solid alloys, particle distribution using Discrete Element Modeling, along with heat, mass transfer, and Marangoni convection for elaborate surface tension effects. The solver's accuracy is deployed by minimizing the assumptions and incorporating a dedicated vapour phase to capture vaporization effects along with the Fresnel reflections, to predict the interfacial optical interactions. Furthermore, the model validation with experimental results is presented here, reinforcing the model's reliability and predictive capability.

Keywords: Aluminium alloys; Additive Manufacturing; LPBF; keyhole.

IBAAS 2026 Conference & Exhibition

September 9-11, 2026

Mayfair Hotels and Resorts, Jharsuguda, Odisha (India)

Green Aluminium

The Next Cycle of Aluminium Growth and its Carbon Consequences

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ABSTRACT

Since 2000, the global aluminium industry has undergone a profound geographical shift in primary smelting capacity from Western regions to Asia and the Middle East. This relocation has significantly altered the sector's carbon footprint due to differences in regional power-generation mixes.

Between 2000 and 2015, a substantial share of new smelter capacity in China and India was powered predominantly by coal-fired electricity, while new capacity in the Middle East relied largely on natural gas. As a result, industry-wide direct and indirect carbon emissions rose by approximately 200% over this period, equivalent to a compound annual growth rate (CAGR) of 7.5%. Over the same timeframe, global primary aluminium output grew at a slower pace of 6.5% CAGR, underscoring the sector's increasing dependency on fossil fuel–based power and the associated carbon intensification of supply.

Following COP21 and the adoption of the Paris Agreement in 2015, global awareness of climate risks increased markedly, prompting aluminium producers to embark on decarbonisation initiatives. Although China, the Middle East, and several Asian economies continued to add fossil-fuel-powered smelting capacity, the broader industry began implementing carbon-reduction strategies. These included relocating capacity to hydro-rich provinces in China, integrating renewable energy sources into power portfolios, and signing renewable power purchase agreements. Collectively, these efforts contributed to a stabilisation—or plateauing—of sector-wide emissions despite continued production growth.

As the industry enters its next growth cycle, a critical question emerges: Which regions will dominate future smelter additions, and how will their respective power-generation profiles influence the aluminium sector's decarbonisation trajectory? Understanding this dynamic is essential for anticipating whether global emissions will resume an upward.

This paper presents Wood Mackenzie's projections of future aluminium supply growth, assesses the likely energy sources underpinning new capacity, and quantifies the expected impact of these developments on the global decarbonisation pathway for primary aluminium production.

Keywords: ***Aluminum Smelting, Decarbonization, Carbon Emissions, Energy Mix, Global Supply Shift.***

Green and Low-carbon Aluminium Technologies

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ABSTRACT

In the Aluminum industry there are different challenges like achieving energy consumption, complying with environmental standards, achieving quality demands, and facing the market challenges. Linde's Ox fuel technology helps address these challenges by reducing fuel consumption and emissions in aluminum melting furnaces. Through this technology, in melting furnaces various benefits can be achieved like power saving, refractory saving, operation safety improvement, reducing operation and maintenance costs and increasing yield. Other benefits can be achieved like reduction of fuel consumption up to 35-40%, homogeneous heating in the furnaces, higher thermal efficiency and heat transfer and less Nox emissions due to reduced nitrogen ballast and recirculated flue gases which effectively lowers flame temperature.

Keywords: ***Aluminum Industry, Oxy-Fuel Technology, Linde plc, Energy Efficiency, Fuel Consumption Reduction, Emission Reduction.***

Non-Metallurgical Bauxite–Alumina Applications

Challenges in Designing Equipment for Small Speciality Alumina Refineries

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ABSTRACT

India is seeing a surge in small capacity Specialty Alumina refineries coming up or under advance stage of planning. Specialty alumina production at modest capacities (10,000 – 60,000 tons per year) presents unique engineering challenges. Unlike large-scale alumina refineries, small plants must adapt liquid/solids separation equipment such as Deep Bed® Decanters, Deep Bed® Washers, Disc filters, Pan filters, and Security filters to achieve high product quality, process efficiency, and economic viability. This paper explores the technical, operational, and integration challenges of designing small-scale process equipment, highlighting the trade-offs between scale, efficiency, and flexibility.

Keywords: Speciality Alumina, Liquid/Solids separation, Deep Bed®Decanters, Deep Bed®Washers, Disc filters, Pan filters, Security filters.

Sustainable Refractory Engineering: Performance Optimization and Shell Temperature Minimization by Using Dense Bauxite in ASC brick

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ABSTRACT

The growing demand for low-carbon refractory solutions has accelerated the exploration of alternative raw materials to energy-intensive fused corundum. Dense Bauxite offers a promising pathway toward carbon footprint reduction due to its significantly lower calcination energy requirement and reduced associated CO_2 emissions. In our earlier development work, a customized refractory formulation

utilizing fused corundum and High Dense Bauxite, balanced with binders and additives, was introduced for hot-metal ladle linings. The modified composition effectively achieved the customer's primary requirement—a measurable reduction in ladle shell temperature, driven by improved thermal insulation characteristics. However, field trials revealed that the overall refractory performance, especially in terms of wear resistance, thermal shock stability, and service life, did not meet operational benchmarks. In response to these performance gaps and upon customer expectations for both enhanced lining durability and further shell-temperature minimization, the present work focuses on transitioning to an optimized Alumina–Silicon Carbide–Carbon (ASC) brick system incorporating a refined balance of fused corundum and High Dense Bauxite. The revised formulation strategically increases the proportion of engineered bauxite fractions and introduces a controlled SiC-C matrix to improve slag resistance, thermal conductivity tuning, and microstructural bonding. This fine-tuned recipe not only strengthens the thermomechanical performance of the lining but also continues to displace a higher percentage of energy-intensive fused corundum, thereby reducing CO_2 emissions. Comprehensive evaluation through thermal profiling, microstructural analysis, and operational trials indicates that the optimized ASC design enhances hot-face stability, limits heat transfer to the shell, and significantly improves campaign life compared to the earlier corundum-dominant mix. The study demonstrates that carbon-optimized refractory engineering—leveraging High Dense Bauxite as a sustainable raw material—can deliver both environmental benefits and superior functional performance. This work thus positions optimized ASC refractories as a viable next-generation solution for steel plants aiming to balance energy efficiency, reduced thermal losses, and sustainability-driven material selection.

Keywords: ***High Dense Bauxite (HDB), Carbon Footprint Reduction, Thermal Efficiency, Microstructural Optimization***

Selective Removal of Iron Oxide from Bauxite Ore

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ABSTRACT

The progressive depletion of high-grade bauxite reserves in India has necessitated the development of effective beneficiation technologies to reduce iron and titanium impurities in low-grade ores. Conventional de-ironing techniques, such as hydrochloric acid leaching, suffer from major environmental drawbacks and economic penalties due to excessive alumina loss and reagent consumption.

The Gharda Scientific Research Foundation (GSRF) has developed and successfully demonstrated a novel, sustainable, and economically viable selective chlorination route for bauxite beneficiation. The process is based on single-step carbo-chlorination of bauxite in a fluidized-bed reactor using calcined petroleum coke as a reductant. Following extensive laboratory & Kg Scale studies, the process was scaled up and validated at the pilot/demonstration-plant level.

Pilot/Demonstration-scale trials achieved selective conversion of iron and titanium oxides while preserving alumina integrity. The process reduced Fe_2O_3 content in beneficiated bauxite to 2.5% ± 0.2%, with approximately 5-7% loss of Al_2O_3. High selectivity was observed, with substantial conversion of iron and titanium oxides to volatile chlorides and minimal chlorination of alumina. The recovery of valuable by-product ferric chloride further improves process economics and resource efficiency.

GSRF process establishes the techno-economic feasibility of the selective chlorination process at pilot/demonstration scale and demonstrates its potential as an environmentally cleaner and industrially viable solution for upgrading low-grade Indian bauxite for non-metallurgical applications.

Keywords: ***Selective Chlorination, Bauxite beneficiation, Carbo-chlorination, Pilot-plant validation.***

Impact of Trace Impurities on Properties and Cost of High-Purity Alumina for Advanced Applications

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ABSTRACT

High-purity alumina (HPA) is a critical material for advanced applications such as sapphire substrates, LEDs, semiconductors, and lithium-ion batteries, where performance is highly sensitive to impurity levels. The present study provides a comprehensive comparative evaluation of 3N (99.9%) and 4N (99.99%) purity alumina, with emphasis on impurity profile, structural characteristics, and techno-economic viability.

Both 3N and 4N alumina were synthesized through controlled chemical processing routes, with 4N alumina produced via an optimized alkoxide method involving multi-stage purification of aluminum isopropoxide to achieve ultra-low impurity levels.

Elemental analysis indicates that total impurity content in 3N alumina lies in the range of ~500–1000 ppm, whereas 4N alumina exhibits impurity levels below 100 ppm, with critical elements such as Fe and Si reduced to <10 ppm. X-ray diffraction analysis confirmed the formation of phase-pure α-Al_2O_3 in both cases after calcination, indicating that differences in performance arise primarily from trace impurity variations rather than phase composition.

The comparative assessment reveals that while 3N alumina is suitable for conventional applications such as refractories and ceramics, 4N alumina demonstrates superior optical, electrical, and chemical properties required for high-end applications such as sapphire crystal growth and electronic substrates. A notable cost disparity was observed, with 3N alumina estimated at ~₹100/kg, whereas 4N alumina produced via the alkoxide route incurs a significantly higher cost of ~₹500–600/kg at laboratory scale due to stringent purification steps.

The study highlights that upgrading alumina from 3N to 4N purity involves substantial increases in processing complexity and cost but delivers disproportionately higher functional value. These findings underscore the importance of impurity control and process optimization in developing cost-effective, high-purity alumina for next-generation technological applications.

Keywords: ***High-Purity Alumina, 3N vs 4N, Alkoxide Process, Impurity Control, XRD, Techno-Economic Analysis.***

Sustainable Alumina Solutions for Innovative High Alumina Refractories in Iron and Steel Applications

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ABSTRACT

The continuous development of steel producing technology is a main driver for the innovations of high alumina refractories. The steel industry consumes between 60 and 70% of the refractories, and taking into account synthetic alumina based aggregates such as tabular alumina, the share of consumption in the steel industry is even higher at around 80%. The relevant trends in steel technology directly influences the innovative developments in alumina refractories. The paper briefly discusses the trends in steel secondary metallurgy and how modern alumina refractories provide innovative solutions for challenging conditions in the evolving steel making processes. The specific developments and innovations especially in high purity alumina refractories and the roles of synthetic alumina raw materials are discussed.

The examples of modern innovative high alumina refractories demonstrate the contribution of refractories to modern steel making, both technically and sustainability wise. When considering the sustainability of modern innovative refractory solutions, it is important to also take refractory related operational cost into equation, and not only focus on the directly spend refractory costs. The improvements in refractory performances must also satisfy the demands on other sustainability factors, such as, steel quality, energy losses, yield losses, environmental impacts, health and safety aspects, etc. The flexibility required in modern steel making processes requires performance reserves in refractories supported by innovative developments in refractories and refractory raw materials in the field of high alumina are touched up on in this paper.

Keywords:* *High Alumina Refractories, Sustainable Alumina Solutions, Steel Secondary Metallurgy, Synthetic Alumina Aggregates, Refractory Performance Optimization, Energy Efficiency and Sustainability.

Process–Structure–Performance Relationships in Specialty Aluminas for Non Metallurgical Applications

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ABSTRACT

Specialty aluminas play a critical role in a wide range of non-metallurgical applications, including refractories, technical ceramics, abrasives, catalysts, and batteries. Unlike smelter grade alumina, the performance of specialty aluminas is determined by a tightly coupled relationship between processing conditions, resulting microstructure, and functional properties. This paper examines the fundamental process–structure–performance relationships that govern the behavior of specialty aluminas and highlights how tailored processing routes enable application specific product design.
The study focuses on the influence of combination of feedstock, calcination profiles, and post treatment steps on key structural attributes such as phase composition, crystallinity, particle size distribution, morphology, surface area, porosity, and impurity levels.

Linking structure to performance, the paper discusses how these attributes directly impact densification behavior, mechanical strength, chemical purity, thermal stability, and reactivity in representative non metallurgical applications. Case examples illustrate how optimized specialty aluminas enhance refractory corrosion resistance and thermal shock behavior, improve sintering and microstructural homogeneity in advanced

ceramics, and provide high surface area and stability for catalyst and functional material applications.

In addition, the paper briefly addresses emerging requirements for low carbon and resource efficient specialty alumina production, showing how process optimization can align high material performance with reduced energy consumption and environmental footprint.

Keywords: ***Process–Structure–Performance Relationship, Specialty Alumina, Microstructure Engineering, Non-Metallurgical Applications, Calcination and Processing Optimization, Sustainable Alumina Production.***

Bauxite–Alumina

Navigating Resource Depletion and Geopolitical Volatility through Technological Agility

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ABSTRACT

The global alumina industry is currently facing a dual challenge: the tightening supply of high-grade bauxite and an increasingly precarious geopolitical landscape. While traditional corridors remain vital, current market dynamics are driving a strategic shift toward a more balanced global supply matrix, fostering deeper engagement with multiple bauxite-producing jurisdictions. However, resource securitization is only one side of the equation. The progressive exhaustion of low-silica bauxite is forcing a shift toward "non-conventional" and lower-grade ores. In this new operational paradigm, the ability to manage reactive silica has transitioned from a technical preference to the primary determinant of cost competitiveness. Effective mitigation of impurities is now critical to controlling caustic soda consumption and energy intensity. Refinery performance is no longer a function of throughput alone, but of "process agility." Finally, this technological evolution is colliding with a critical generational skills gap. As senior technical expertise exits the industry, the focus must shift to structured knowledge transfer (mentoring) to ensure operational continuity and to maintain margins in an era of unprecedented mineralogical complexity.

Keywords: ***Bauxite multi-sourcing, reactive silica management, Bayer process agility, bauxite beneficiation, knowledge transfer, OPEX optimization.***

Geological controls on critical mineral enrichment in Indian Lateritic Bauxite

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ABSTRACT

Lateritic bauxite profiles in India have developed over compositionally diverse parent rock formations significantly influencing their geological and mineralogical characteristics. Deposits along the eastern ghat are predominantly derived from

Khondalites, and associated granulite-facies lithologies, whereas those in central India developed predominantly over Deccan Trap basalts, with additional contributions from Archaean granites and gneisses. The primary aluminium mineral phases predominantly gibbsite, with subordinate boehmite and diaspore define the alumina bearing minerals in bauxite zone, while accessory phases including zircon, ilmenite, and Fe-oxyhydroxides (goethite, hematite) serve as the principal hosts for rare earth elements (REEs), scandium (Sc), gallium (Ga), and vanadium (V). The lithomarge clay horizon exhibits elevated concentrations of heavy REEs (HREEs) and Sc, reflecting retention in resistate phases, while LREEs show upward redistribution and co-precipitation with Fe-oxyhydroxides under fluctuating pH–Eh conditions. These findings underscore the importance of integrating detailed geological, lithological, and geochemical characteristics in the identification and sustainable exploitation of critical mineral resources within lateritic terrains of peninsular India. In the present study, representative lateritic bauxite profiles from the central Indian and east coast region were examined to understand the distribution and enrichment patterns of critical minerals. The study further explores the potential for recovering critical minerals and REEs using physical separation techniques, highlighting an opportunity for value addition to existing bauxite resources. These findings underscore the importance of integrating geological and lithological characteristics in the identification and sustainable exploitation of critical mineral resources within lateritic terrains.

Keywords: Lateritic Bauxite profile, Geology, Parent rocks, Critical minerals.

Bauxite–Residue

Red Mud to Aluminium and Silica Separation Technology Demonstration Unit

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ABSTRACT

Bauxite residue (Red mud), a by-product of the Bayer process for alumina extraction, represents a major environmental challenge while simultaneously containing significant quantities of recoverable aluminium, silica, and trace valuable metals. Effective valorisation of red mud is therefore critical for sustainable aluminium production, circular resource utilisation, and reduction of industrial waste liabilities.

Keywords:* *Environmental challenge, recoverable aluminium, silica, trace valuable metals, circular resource utilisation

IBAAS 2026 Conference & Exhibition

September 9-11, 2026

Mayfair Hotels and Resorts, Jharsuguda, Odisha (India)

Aluminium Smelting

Special Session

Cathodes for Energy Management and Pot-Life Extension

Cathodes for Energy Management and Pot Life Extension

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ABSTRACT

Aluminium Smelting is very high energy intensive process and shell life and energy consumption are the key cost driver for the modern aluminium shell. In the modern aluminium production, optimizing energy consumption is a critical and continuous operational priority due to its substantial influence on overall production cost and environmental impact. Among multiple factors affecting efficiency and energy consumption, Cathode plays a vital role in entire pot life in determining efficiency. The global aluminium industry is trying to reduce its carbon footprint, in line with climate change policy, and great strides are being made in the use of hydropower, solar, and geothermal electricity, as opposed to fossil-fuel powered electricity.

This paper discusses the critical role of prebaked carbon cathodes in enhancing energy efficiency and extending pot-life in aluminium smelting operations. In high-amperage Hall–Heroult cells, cathode performance directly affects current distribution, metal flow, heat balance, and overall specific energy consumption. Cathode wear mechanisms—including sodium penetration, graphitization, and sidewall erosion—contribute to increased voltage losses and premature end-of-life for pots. Modern cathode technologies aim to mitigate these degradation pathways while improving operational stability.

Advances in cathode formulations, such as optimized anthracite–graphite blends, improved pitch quality, and nanomaterial-reinforced carbon composites, have demonstrated reductions in cathode voltage drop (CVD), better resistance to chemical attack, and improved thermal shock tolerance. Additionally, ramming paste

innovations with low reactivity and optimized permeability support a more stable cell bottom profile. Controlled cathode block microstructure enhances sodium resistance, reducing swelling and limiting metal pad instabilities that can elevate energy consumption.

Energy management strategies increasingly emphasize cathode design alignment with targeted heat balance. High-density blocks and improved insulation layouts reduce heat losses while maintaining adequate freeze thickness. These measures support lower operating voltages and reduce anode effects. Extending pot-life, often from 2,000–2,500 days to more than 3,000 days, is achieved through optimized current loads, stable cell bottoms, and predictive monitoring of cathode wear using thermal imaging and impedance-based diagnostics. Longer pot-life significantly reduces shutdown frequency, refractory replacement costs, and overall energy per tonne of aluminium produced.

In conclusion, cathodes are a pivotal lever for energy efficiency and long-term stability in modern smelting plants. Continued development in materials engineering, digital monitoring, and pot control systems will further enable lower specific DC energy consumption and improved asset life, supporting operational excellence and sustainability goals across the aluminium industry.

Keywords: Cathode Voltage Drop, Sodium penetration, graphitization, energy efficiency, sustainability.

Continuous Developments/Improvements in Cathode Lining of Low Amperage Pots (Hirakud Smelter) to Improve Pot Life and Energy Efficiency

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ABSTRACT

Hirakud Smelter (HKD), a unit of Hindalco Industries Limited and part of the Aditya Birla Group (ABG), is one of India's oldest aluminium smelting facilities. Established in 1959, the Hirakud Aluminium Plant is an integrated smelting complex that employs GAMI Technology for aluminium production. In 2009, half of the existing Soderberg potline was successfully converted to a prebake system. This conversion, while beneficial, also brought inherent challenges associated with retrofitting an older potline to modern prebake technology. The smelter utilizes the Hall–Héroult Electrolysis Process to extract aluminium from alumina. Since aluminium production is a continuous operation, overall productivity is closely linked to the number of operating pots. Over the years, Hirakud has significantly enhanced its performance in terms of energy efficiency and pot life through strategic modifications, particularly in cathode lining design. The combined impact of these initiatives has been substantial. Pot performance is now comparable to that of modern high-amperage smelters in terms of energy efficiency. Most notably, pot life has increased from an average of 1000 days to approximately 1800 days, marking a major operational milestone. This document aims to provide a detailed overview of the comprehensive improvements undertaken at the Hirakud Smelter, with particular emphasis on innovations in cathode and collector bar design, which have been pivotal in achieving the enhanced performance metrics.

Keywords: Cathode, Collector bar, Pot life, Lining materials, Energy Efficiency, Ramming.

Evolution of Pot Stoppage Philosophy: From Run-to-Fail to Data-Driven Predictive Planning Based

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ABSTRACT

Aluminium smelting is a continuous and energy-intensive process in which cathode life directly governs pot performance, operational stability, and relining frequency. Traditionally, Renukoot smelter has followed a “run-to-fail” approach for pot stoppage, where pots are allowed to operate until failure or severe deterioration. While simple to implement, this reactive practice often leads to unplanned failures, higher operational risk, and inefficient utilization of pot life.

Over the years, Renukoot smelter has undergone significant changes in cathode sourcing and cell design, which have had a pronounced impact on cathode life behaviour. The plant transitioned from SGL (European supplier) cathodes to Chinese suppliers. While earlier Chinese suppliers delivered comparable life (>2800 days), later supplier changes resulted in a reduction of average cathode life to around 2300 days.

This study focuses on redefining the pot stoppage philosophy from a reactive “run-to-fail” approach to a proactive, data-driven strategy. Detailed analysis of historical plant data, including supplier-wise cathode performance, life trends, and stoppage records, was carried out to understand variability in cathode life. The analysis clearly establishes that cathode life is strongly dependent on supplier quality and design conditions and therefore cannot be managed using a uniform life criterion.

Based on these insights, a predictive and practical framework for pot stoppage has been developed using supplier-specific life benchmarks. Pots are evaluated based on their expected life and categorized to identify for planned shutdown before failure. This approach enables systematic relining planning, reduces the risk of sudden pot failures during power fluctuations, and improves overall potline stability.

In addition, techno-economic analysis indicates that selective use of higher-life cathode blocks, despite higher initial cost, is beneficial in the long term due to extended pot life. The study demonstrates that combining historical data analysis with a structured decision framework can effectively transform pot stoppage philosophy, leading to more reliable and optimized potline operation.

Keywords: Aluminium smelting, Cathode life, Pot stoppage, Relining strategy, Data-driven analysis.

General Smelter Papers

Improvement in Anode Quality by Collaboration & In-house Process Optimization

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ABSTRACT

The Carbon Division at the ADITYA Plant plays a critical role in aluminium production by manufacturing high-quality anodes required for the electrolysis process in the pot-room. These anodes are not only utilized in the ADITYA Smelter but are also supplied to the HIRAKUD Smelter, ensuring a reliable and consistent supply across both operations.

To enhance operational efficiency and ensure superior anode performance, several initiatives have been implemented focused on optimization of parameters and improving overall anode quality.

At the ADITYA Plant, the anode manufacturing process encompasses the entire raw material and process chain—from the receipt of Calcined Petroleum Coke (CP Coke) to the final forming and baking of the anode blocks. Recognizing the critical impact of grain size distribution on anode quality and pot-room efficiency, a series of strategic initiatives have been undertaken.

Key among these is close collaboration with the raw material suppliers to optimize incoming CP Coke Sizing. Also design of experiments to optimize the parameters at anode forming stage. These proactive approaches ensured that the final anodes are of high quality and meet the stringent pot-room quality standards which has led to significant power savings.

Keywords: Carbon, Anodes initiatives, Coke Sizing.

From Reactive to Predictive: Data-Driven Reliability Enhancement of Rectifier

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ABSTRACT

Hirakud Smelter (HKD), a unit of Hindalco Industries Limited is a part of Aditya Birla Group (ABG). Hirakud Aluminium is an integrated aluminum smelting complex which uses ABB PEC controller Technology for high power Rectifiers, and one of the oldest Smelter in India established in the year-1959.

This project establishes an analytics-driven reliability framework for rectifier cooling systems, shifting from reactive troubleshooting to a predictive, data-centric model.

The initiative began after frequent nuisance tripping caused by intermittent analog signal disturbances. Analysis revealed limitations in the existing monitoring approach—single sensor dependency, instantaneous protection logic, and standard SCADA trends, which cannot capture millisecond-level signal spikes or transient instability. Although hardware corrections and sensor redundancy reduced immediate tripping, long-term reliability required deeper system visibility and advanced analytics.

cooling-system instrumentation—including DM water temperatures, pressure, conductivity, transformer temperatures, pump status, Heat exchange Delta T/Delta P, Rectifier Cubical temperature and other analog signals was digitally integrated into a unified automation platform, enabling end-to-end monitoring of thermal performance across rectifier units.

A weightage-based Cooling System Health Score (0–100) was developed to convert multi-parameter data into a single actionable reliability indicator, allowing operators to quickly identify degrading conditions and pinpoint mechanical, electrical, or sensor-related issues.

Integration with OSI-PI Historian added a high-resolution analytics layer, where Event Frames automatically detect spikes, drift, and abnormal stability patterns, generating early predictive alerts and enabling faster root-cause diagnosis.

This integrated framework—IOT based sensor digitization, health scoring, and historian analytics—has delivered zero nuisance tripping, improved rectifier availability, faster diagnostics, and more stable operating current, while creating a scalable digital reliability model for rectifier operations.

Keywords: Predict, Detect, Diagnose, Prevent, Stabilize.

Revolutionizing Aluminum Furnaces with Precast Pre-Fired Refractory Technology

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ABSTRACT

Primary aluminium smelters operate under highly aggressive thermal, chemical, and mechanical conditions that demand robust and reliable refractory systems, particularly in aluminium holding furnaces. Conventional monolithic and castable refractories often face challenges such as inconsistent quality during application at site, prolonged installation and dry out time, susceptibility to thermal shock, and reduced service life. In response to these limitations, precast pre-fired refractory shapes have emerged as an innovative and next-generation solution.

This study explores the application of precast pre-fired refractory shapes in aluminium cast house furnaces within primary smelters, focusing on their performance, durability, and operational advantages. These factory-engineered components offer superior dimensional accuracy, controlled microstructure, and enhanced resistance to molten aluminium attack, oxidation, and thermal cycling. The pre-firing process ensures minimal on-site drying and eliminates risks associated with improper curing, thereby significantly reducing commissioning time.

Furthermore, the modular nature of precast shapes enables faster installation, improved maintenance practices, and reduced downtime. Comparative analysis with conventional refractory systems demonstrates notable improvements in thermal efficiency, lining longevity, and overall cost-effectiveness. The study also highlights the potential of these advanced refractory solutions to contribute to sustainability goals through energy savings and reduced material wastage.

The findings suggest that precast pre-fired refractory technology represents a paradigm shift in refractory design and application for aluminium cast house furnaces, offering a reliable pathway toward enhanced performance and operational excellence in primary aluminium smelters.

Keywords: ***Precast Pre-Fired Refractories, Aluminium Cast House Furnaces, Thermal Shock Resistance, Refractory Lining Optimization, Molten Aluminium Corrosion Resistance, Energy Efficiency & Sustainability, Modular Refractory Systems.***

Performance Optimisation of Pre-Cast Ceramic-Steel Composites in Aluminium Smelter Environments

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ABSTRACT

Industrial aluminium production subjects structural and process components to a relentless combination of thermo-mechanical stresses, including rapid thermal cycling, aggressive chemical attack from fluxes and dross, and mechanical abrasion from molten metal flow. Traditional engineering material selection often forces a compromise between the high-temperature resistance of brittle refractories and the structural toughness of steelwork, which remains susceptible to high-temperature corrosion and loss of structural integrity. This paper examines the application of Fiberstone™, a proprietary pre-cast ceramic-steel composite designed to bridge the performance gap between these two material classes.

Fiberstone™ is manufactured by infiltrating a high-volume stainless steel fiber network (up to 35% by weight) with a high-alumina ceramic slurry. Unlike conventional fiber-reinforced Castables limited by mixing constraints, this composite utilizes advanced manufacturing to achieve a fully isotropic, dense matrix. The ceramic phase provides necessary refractoriness and hardness (1175 kg/mm^2), while the interlocking metallic network provides fracture toughness energy (50 J/m^2) and flexural strength (45 MPa at 20°C) approaching metallic levels.

In aluminium casting operation (melting cum holding furnace), the material's dual toughening mechanism is a critical differentiator. Under stress, energy is absorbed through fiber debonding and progressive frictional pull-out, alongside plastic deformation of the fibers bridging the crack plane. Technical evaluations demonstrate that Fiberstone™ reaches a peak load approximately 3.5 times greater than standard 4% stainless steel fiber Castables, sustaining load over a 5 mm deflection where conventional materials suffer near-instantaneous failure. This fracture toughness effectively arrests crack growth initiated by rapid temperature differentials, which is vital for aluminium-specific applications such as door blocks, launders, and tap blocks.

Furthermore, the material exhibits exceptional chemical resistance to molten aluminium and “Fluoride/Chloride” based fluxing agents; coveralls used in metal treatment in cast house furnaces. Its chemically neutral slurry reduces the risk of metal contamination, while its superior dimensional stability ensures reliable sealing in high-temperature zones. Tested Modulus of Rupture (MOR) values of 27.5 MPa at 600°C and 12.3 MPa at 1000°C confirm its suitability for continuous high-temperature service.

By replacing vulnerable steel or refractory components—such as lintels, jambs, stirrers, and thermocouple protection tubes—with bespoke pre-cast Fiberstone™ shapes, operators can realize a significant reduction in total Life Cycle Cost. The integration of these high-performance composites facilitates extended campaign lives, reduced unplanned downtime due to catastrophic part failure, and simplified maintenance through precision-engineered retrofitting. This paper concludes that the adoption of ceramic-steel composites represents a transformative shift in the engineering of aluminium related components, providing a structural advantage over standard materials at elevated temperatures.

Keywords: Fiberstone™, dual toughening mechanism, door blocks, launders, and tap blocks, lintels, jambs, stirrers, and thermocouple protection tubes.

Design and Development of Integrated High Pressure Oxygen Lancing System with Manifold and Lance Holder for Emergency Aluminium Potline Operations

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ABSTRACT

In aluminium smelter pot rooms, emergency conditions such as multiple pot shutdowns often result in large-scale solidification of molten metal within pots. When tapping is not feasible, rapid removal of frozen metal becomes essential to restore operations and recover valuable material. Conventional methods such as pneumatic jack hammering are time-consuming and ineffective for thick metal sections, while oxygen lancing using a single cylinder suffers from rapid pressure depletion, leading to frequent interruptions and unstable cutting conditions.

To address these challenges, an integrated high-pressure oxygen lancing system has been developed. The system consists of a multi-cylinder manifold connecting twelve oxygen cylinders in parallel, ensuring continuous oxygen supply at 90–140 bar. A dual-line manifold configuration enables uninterrupted operation. Additionally, a copper lance holder with an inbuilt non-return valve (NRV) provides localized safety at the point of operation.

The system incorporates multiple safety layers including NRVs, flashback arrestors, pressure monitoring, and oxygen leak detection with alarm. A failure analysis of backfire and flashback scenarios has been conducted, and the implemented design demonstrates significant risk reduction. Field application shows a ~10× increase in lancing duration, improved pressure stability, and enhanced safety performance. The system provides a reliable and efficient solution for emergency aluminium potline operations.

***Keywords:** Smelter pot rooms, Metal Tapping, Oxygen lancing system, Dual-line manifold, Non-return valve (NRV).*

Impact of Refractory Health in Anode Baking Quality at higher Age

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ABSTRACT

The production of aluminium from alumina through the Hall-Héroult process requires carbon anodes as a key input. These anodes are made of calcined petroleum coke, coal tar pitch, and reusable anode butts. Anode production involves three critical stages: green anode manufacturing, anode baking, and anode rodding. Anode baking process is the most critical step in anode production. It has strong impact on anode quality in terms of baking level, anode heat-up rate, physical defects such as cracks or air burn and it affects performance of anodes in electrolysis cells. Therefore, it is utmost priority to have good baking process control and operation.

Anode baking takes place in Anode Baking Furnace made of high Alumina Refractory Bricks inside a Concrete casing. Refractories play a crucial role in anode baking furnaces used in the aluminium smelter. During baking the hot gas flows inside the flues (Flue wall) on both sides of the pit loaded with green anodes and bakes the anodes by indirect heating. These flue walls are composed of high-alumina refractory bricks that are exposed to chemical (high temperature corrosion), mechanical (creep, walls, anode loading and unloading), and thermal (high temperature, thermal shock) conditions. The compressive and tensile stress during heating and cooling of flue walls during operating cycle of ABF generates chemical and physical changes across the wall's width. The collapse, cracking, and bending of flue walls are common indicators of this stress.

This paper investigates and finds the key factors affecting the life of the refractory bricks and corresponding impact on baking process as baked anode quality. This paper also investigates the challenges and solutions associated with improving the performance of aging baking furnaces. As Anode Baking furnaces age, their efficiency tends to decline, leading to increased energy consumption, higher operating costs, and inconsistent product quality. This study identifies key factors contributing to the degradation of furnace performance, such as wear and tear of components, unstable control systems, and suboptimal maintenance practices. To address these issues, this paper proposes a comprehensive approach that integrates advanced diagnostic techniques, modern control technologies, and predictive maintenance strategies.

Keywords: Anode Baking, Refractory Bricks, Anode Quality, Baking Performance.

IBAAS 2026 Conference & Exhibition

September 9-11, 2026

Mayfair Hotels and Resorts, Jharsuguda, Odisha (India)

Special Session

Value Recovery from Aluminium and Power Plant Wastes

Sustainable Recycling of Raw Materials and By- Products of Smelters with Reference to Carbon, and Carbon Dust for Operation of Greener Aluminium Smelters

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ABSTRACT

The Aluminium smelters consume raw materials like fresh alumina, petroleum coke, pitch, aluminium fluoride, and calcium fluoride. Petroleum coke and pitch are used for the manufacturing of carbon anode, and cathode blocks. The fresh Alumina, Aluminium Fluoride, and Calcium Fluoride are used for electrolysis operation to manufacture prime metal Aluminium. The other inputs are miscellaneous cathode sealing materials, miscellaneous lining materials, new cast iron, additives, refractory bricks, alloying elements and electric power. The smelters generate bath, spent anodes, coke particles, spent pot linings, spent cathode bars, cast house dross, rejected cast iron, lining scrap, iron scrap, miscellaneous scrap and spent refractory materials in solid form including the prime metal Aluminium. The prebaked Aluminium smelters technology has attempted to recycle the bath, spent anodes, spent pot linings, spent cathode bars, cast house dross, rejected cast iron, lining scrap, and iron scrap through different units within the smelter or through outside agency. The smelter emits carbon monoxide, carbon dioxide, sulphur dioxide, gaseous fluorine, fluorine dust, gaseous tar, recycled carbon dust, and clean air. The spent refractory materials composition is complex to segregate to reuse as refractory input material and is uneconomical.

Although the present practice of recycling spent anodes is most effective and highly economical for the operational cost of smelters, there is lots of carbon dust within the smelters. This loss draws attention of management to review periodically. The paper proposes few innovative steps to capture the carbon loss in solid and in gaseous forms. The carbon particles will not be allowed to stockpiled on ground to avoid the contamination of sand and iron. The various steps in handling and storage will improve the reuse of the carbon particles and dust. The carbon concentration is very less to process and capture. It is uneconomical to collect although the pots generate carbon in

large quantity of exhaust gases. This carbon is smaller as compared to loss of carbon particles and dust within smelter carbon area.

Keywords: Raw materials, bath, spent anode, spent cathode, dross, carbon particle, carbon dust, iron, silica.

Aluminium Alloys – Sustainable and Smart Engineering Solutions

A Compressible Multiphase Volume of Fluid Model for Aluminum Powder Production using Inert Gas Atomization

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ABSTRACT

A new compressible multiphase model is developed by Paanduv Applications for producing aluminum metal powders using an inert gas atomization process. This process is known to produce metal powders with high purity and sphericity under the influence of a supersonic gas jet to break apart the molten liquid into droplets and its subsequent solidification into spherical metal powder particles. The model executes the compressible flow of gas at Mach number 4. High-quality metal powders exhibit excellent physical properties such as composition, controlled particle size, flowability, and high purity, along with metallurgical behavior. The metallurgical behavior is attributed to the solidification rate during the atomization process, which depends on the undercooling rates achieved by the metal droplets before solidification, which in turn depends on the particle size. The supersonic gas atomization process is widely used across the industry for metal powder manufacturing. The size of the metal droplets depends upon the atomizer configuration. CFD can help understand the effect of different nozzle designs and other process parameters on the atomization of metal droplets. The compressible VOF method is used for capturing the discontinuities, including shock waves and interfaces.

Keywords: Metal powder, Atomization, Compressible flows, Mach number

Aluminium Downstream

Valorization of Aluminium Extrusion Leachate for Detergent Grade Zeolite Production via Controlled Crystallization

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ABSTRACT

The disposal of aluminium extrusion die cleaning liquor, rich in sodium aluminate, poses significant environmental and economic challenges for the aluminium industry. In the present study, an integrated approach has been developed for the valorization of leached caustic liquor through the synthesis of detergent-grade zeolite. The process involves controlled reaction of the leachate with sodium silicate followed by gel formation, ageing at ambient conditions, and subsequent crystallization to yield zeolite. The conversion of aluminium present in the leachate into zeolite was evidenced by the reduction of Al_2O_3 concentration in the spent liquor to below detectable limits after crystallization. This was achieved through optimization of synthesis parameters, resulting in a product with desirable physicochemical properties. The synthesized zeolite exhibited a Si/Al ratio of ~1.34, high BET surface area, and whiteness of 96.5%, making it suitable for detergent applications. Chemical composition analysis further confirmed compliance with detergent-grade zeolite specifications. Further, the process enables recovery and recycling of spent caustic liquor, reducing fresh caustic consumption and minimizing waste generation. The developed methodology demonstrates technical feasibility offering a sustainable and cost-effective solution for industrial waste utilization. This approach not only addresses disposal issues but also contributes to the circular economy by converting waste streams into value-added products.

Keywords: Zeolite synthesis, Aluminium extrusion leachate, Sodium aluminate liquor, Circular economy, Waste utilization, Detergent grade zeolite.