Optimizing Aluminium Reduction Cell Start-up- A Semi-Conventional Approach at Sohar Aluminium

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Abstract

Sohar Aluminium ensures non-stop development, especially in minimizing greenhouse gas emissions through boosted cell performance. Perilous to achieving this target is the continuous development of the procedures for the aluminium reduction cell start-up, as this will enhance greatly the performance, life longevity, productivity and environmental footmark. This paper outlines a novel semi-conventional methodology developed at Sohar Aluminium to enhance cell preheating, start-up, and early life operation, addressing both performance and safety concerns.

Traditional dry start-up and preheating methods, while effective, normally results in non-homogenous temperatures across pot and are labour intensive, which represent safety risks. To reduce these challenges, Sohar Aluminium improved its cell start-up process by implementing a group of changes, focused on minimizing manual intervention and achieving a uniform preheating process. This new approach, branded by a "semi-conventional" strategy, bonds the gap between well-known practices and innovative enhancements.

The paper evaluates the effectiveness of these changes by analysing key performance indicators (KPIs) for preheating and start-up. It details the technological and procedural advancements as well that led to a safer, more efficient, and sustainable cell start-up, ultimately extending cell life and improving operational excellence.

Keywords: Aluminium reduction cell, Dry Start-up, Homogeneous preheating, Work practices, Sustainability.

1. Introduction

1.1 Sohar Aluminium Facility Overview

The Sohar Aluminium smelter runs with a single potline consisting of 360 reduction cells. The potline is divided into two pot rooms and utilizes AP40/42S technology, supporting a maximum annual production capacity over 400 kt of primary aluminium. In addition to the reduction lines, the facility holds an integrated carbon plant that manufactures baked anodes required for the electrolysis process. A dedicated cast house is also on-site, where the liquid aluminium is sent for casting into various product forms, including standard ingots and sows, ready for domestic and international markets.

Sohar Aluminium is equipped with state-of-the-art process control systems and aligns with global operational best practices. Supporting its smelting operations, the company operates a dedicated

1000 MW natural gas-fired power plant, ensuring a stable and efficient energy supply. The facility also benefits from direct access to a port terminal located within the Sohar Industrial Port area, allowing for all-in-one logistics, raw material imports, and product exports. This integrated process outlines the reliability and efficiency of the overall operation [1].

As part of its broader industrial impact, Sohar Aluminium has actively contributed to the growth of the local aluminium company. The company has played a foundational role in the founding of four downstream aluminium processing facilities, in which all are operational and utilize metal produced at the Sohar Aluminium [2].

1.2 Primary Aluminium Electrolysis Process

Hall–Héroult process is the only industrial process for smelting aluminium on industrial scale. The process starts by extracting of (Al_2O_3) through the Bayer process by purifying bauxite. The alumina then dissolves in the cryolite solution (Na_3AlF_6), under an excessive temperature in electrolytic cell. A direct current then passes through the pot, where the alumina is electrochemically reduced, yielding metal that is "Aluminium" and oxygen ions that directly bond with carbon of the anodes, that produce CO_2 carbon dioxide. As of denser molecular weight of aluminium metal, it sinks and accumulate in the pool of the pot and is regularly tapped for extra handling. Simultaneously, carbon dioxide is produced below the anodes as of side reactions of the process, which is extracted thru GTC duct system.

The pot cell structure is a large, rectangular steel vessel lined with a refractory material and carbon blocks. Inside this container, a carbon anode block suspended at top and acts as positive pole, while the negative pole cathode block is setting at bottom of the pot. The space between the two blocks is filled with an electrolyte, mainly composed of cryolite (Na_3AlF_6) with the alumina dissolving inside. Readiness of this type of cell is complex, as this presents a key stage for the effective process of aluminium cell, beginning with shell construction and a precise and layering of refractory and insulation materials. The process starts with delining the old shell then followingly rebuilding it at a dedicated lining workshop. The ready new shell, will be shifted to the new pot location in which it will undergoes preparation for energization and preheating, in which the pot will spend time in this phase to be ready for the start-up were bath will be added alongside metal after 24 h. The final step arrives to normalize the pot in the early life stage, to bring it to full production.

This start-up method has technical difficulties, as well holds substantial influence over the enduring performance and efficiency of the pots. Therefore, the continuous improvement and finetuning of start-up procedures is a main priority, and dominant for better long life, productivity, and environmental effect.

1.3 Preheating and Start-up in Aluminium Smelters: A Critical Foundation for Cell Life and Performance

Preheating and start-up first phases are essential for the operational long life and efficiency of aluminium cells. The cells overall performance and lifespan are influenced by these critical early stages, contributing a considerably 25 % to aspects affecting cell life, a proportion comparable to that of normal operation and exceeding the impact of materials (10 %), construction (20 %), and design (20 %). The sole purpose of preheating is to cautiously and gradually prepare the cathode, ensuring a steady temperature to avoid damages before the addition of molten bath. Numerous approaches of starting cells have been used over time, some early methods with no preheat, but using preheat has been more reliable, successful and remains the prime method today. Throughout these complex stages of cell preparation, energisation, preheating, start-up, and early life operation strict control over voltage, temperature, and bath composition is indispensable [3].

Preheating and start-up methodologies alongside their parameters and the overall impact on cell performance will be further examined. While the comprehensive cell cut-out activity involves numerous critical stages, from lining decommissioning and reconstruction to early operational normalization, this paper will specifically focus on the pivotal phases of cell preheating and start-up. This approach allows for an in-depth testing of the latest and optimized practices used to improve the quality and effectiveness of these crucial initial operations.

This paper presents Sohar Aluminium's experience with the implementation of the ***Semi-Conventional Start-Up methodology*** and its effectiveness in stabilizing cell conditions throughout the various phases of the start-up process. Additionally, the methodology aimed to reduce manual handling and improve safety standards associated with start-up operations. To maintain a concise scope and avoid excessive length and complexity, this study will not explore into other aspects of the cell cut-out process, nor will it cover broader operational improvements undertaken, thereby ensuring a concentrated analysis on the vital area of cell preheating and start-up.

2. Start-up Methodologies

2.1 A Review Around the Globe

Various preheating techniques have been used, including crash start (adding a liquid bath directly) and cathode preheating using burners or short-circuiting the resistor bed. When using the resistor bed method, two main approaches are available: a dry start, where the bath is generated during the heating process, or the conventional method, where the bath is added after the preheating phase. The efficacy of the preheating process is thoroughly measured through various key parameters: the final average cathode surface temperature, the uniformity of this temperature distribution, vertical temperature gradients within the cathode materials, the rate of preheating, and the anodic current distribution. Continuous innovations, such as reducing coke bed thickness, employing coke strips, optimizing anode flexible connectors, and wisely monitoring preheating rates and times have demonstrably improved cell lives, alongside reductions in energy and improved current efficiency in normal operation [4].

Many experts now agree that essential start-up methods, such as adding bath or metal without cell preheating, should be abandoned. This consensus stems from clear evidence of cathode damage, premature cell failures, and significantly reduced cathode lifespan associated with such practices.

2.2 A Review of Sohar Aluminium Start-up Methods

Since its inception, Sohar Aluminium has continuously improved its cell preheating and start-up processes, adopting various methods to enhance performance and efficiency. The preheating phase focuses on achieving uniform cathode temperature to prevent thermal shock and reduce electrolyte freezing during molten bath addition.

Each method features distinct material use, heating rates, and procedures. Based on these innovations, Sohar Aluminium has adopted, developed, and implemented the following start-up methodologies.

2.3 Dry Start-Up Procedure

The Dry Start-Up method at Sohar Aluminium uses electrical resistance heating with a coke and/or graphite bed. Around 28–30 tonnes of crushed bath material fully cover the sidewalls, tap holes, and centre channel. Unique to this approach, the entire bath melts during the three-phase preheating process. The coke and graphite enable a higher heating rate, averaging over 40 °C/h. In some cases, 2 to 3 tonnes of liquid bath may be added externally.

The preheating process follows three structured phases, gradually transforming the solid bath into a fully molten state to ensure thermal readiness for start-up. Flexes (expansion bellows or flexible joints) are also installed to manage thermal expansion and preserve structural integrity during operation.

2.4 Conventional Start-Up Procedure

The Conventional Start-Up, unlike the Dry method, uses a smaller amount of crushed bath – around 15 tonnes applied mainly over the anodes and sidewalls, without covering the central channel. This results in a slower average preheating rate of 25 °C/h and a more gradual thermal build-up.

The slow preheating rate is further impacted by the pad resistor design, particularly the diameter, thickness, and resistivity of the pure graphite used. Unlike the Dry Start-Up, no liquid bath forms during preheating, requiring a large post-start-up addition of 15 to 16 tonnes of liquid bath using a crucible. This demands precise planning designating holding cells, preparing the crucible in advance, and ensuring skilled operators carry out the bath transfer without metal contamination. Coordination is essential so that the crucible is ready while the launder is being preheated. Additionally, crucible and crane availability must be secured, with a backup crane and crucible on standby in case of unexpected issues. Similar to the Dry Start-Up, flexes are installed as part of the cell preparation to manage thermal expansion.

3. The Case for Change

3.1 Optimization of Cell Preheating, Start-up and Early-Life at Sohar Aluminium

The entire cell cut-out activity, from decommissioning to a cell's return to normal operation, is a highly critical and collaborative endeavour, demanding close coordination among reduction services, start-up teams, operations, maintenance, and technical departments. Within this complex process, the continuous improvement of start-up methodology holds immense importance. Any enhancement in these initial phases directly translates to substantial operational and economic benefits. Therefore, achieving such improvements necessitates a highly structured and meticulously planned approach, involving detailed analysis, controlled implementation, and rigorous evaluation across all involved departments to ensure optimal performance and to mitigate risks in the long term. A stable and efficient normal operation of a cell is directly linked to a successful start-up, which validates the correct chemistry, alumina concentration, and effective side protection during its early life. In turn, a good start-up is a direct consequence of thorough preheating.

Homogeneous preheating is vital, as it allows cathodes and lining materials to heat gradually, preventing damaging thermal shocks and cracks during the start-up phase. This is why maintaining a balanced temperature gradient between the corner and centre anodes is essential to achieve uniform preheating. A higher temperature gradient between centre to corner position leads to thermal shock to the cathodes and may cause damage to the cathodes at very early stage of preheating and start-up. This effective preheating, characterized by a uniform cathode temperature maintained throughout the 48–54-hour process, fundamentally depends on the quality of workmanship during cell preparation before energization. Consequently, cell preparation itself stands as the foundational step in process optimization. Recognizing this critical link, a detailed review, monitoring, and evaluation of cell preparation practices have been initiated to continuously enhance preheating quality and, by extension, overall cell performance.

3.2 Dry Start-up at Sohar Aluminium

Despite long experienced and established methodology, the Dry Start-Up method presented several significant challenges and inefficiencies that necessitated continuous improvement efforts. These issues spanned both the preparation and preheating phases, as well as the subsequent critical start-up phase. Initially, dry start-up methods were favoured for their simplicity and reduced setup time, making them the typical choice during rapid potline restarts, However, during steady-state operations, the standard practice preferred by Sohar Aluminium (SA) is the conventional start-up method.

During the preparation and preheating phases, Dry Start-Up methods often required extended heating times and high energy input, resulting in elevated temperatures at start-up. This approach was also highly labour-intensive, especially during phases 2 and 3, where significant manual effort was needed to melt the solid bath. A key challenge was the non-homogeneous preheating—this typically began at end of phase 1 and became more pronounced in phase 2, when the bath started to generate or melt. During this critical period, achieving uniform bath melting was highly unlikely, often leading to excessive temperature rises in the centre while the corners remained cold. In the worst cases, corner anodes would draw very low or even zero millivolts. This behaviour was evident in all the cells with dry start-up method and ended up with premature start-up of cells, challenged to have a smooth bath addition while start-up of the cells. Additionally, cell temperatures frequently surpassed 1040 °C before metal addition, causing thermal instability and further operational fluctuations like high cell instability and high resistance in the first 24 hours of start-up. These conditions reduced process reliability and combined with the high dependency on manual intervention, significantly increased the risks of human error, safety concerns, and operational hazards.

Specific technical inefficiencies identified with the dry start-up method included:

- **Uneven preheating ACD (Anode Current Distribution, corner vs. centre):** Corner anodes frequently exhibited lower or almost null current (mV) once central anodes started drawing significant current in phase 2 (Figure 1).

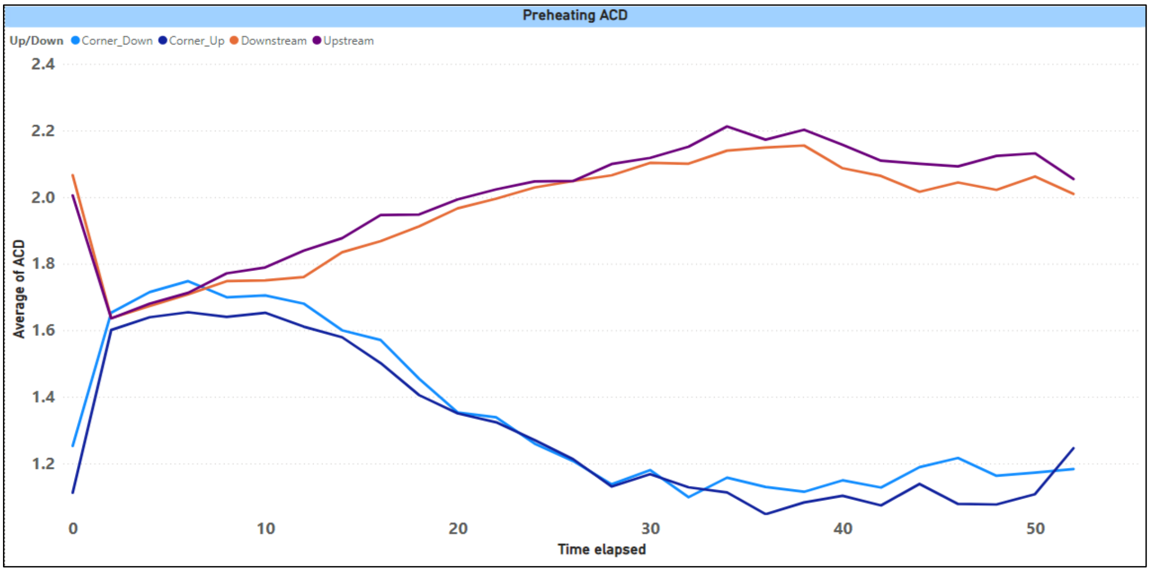

Figure 1. Preheating ACD (anode current as drop in stem mV) vs preheating time (Hours).

- **Uneven preheating ACD (overall):** All the corner anode positions 1, 10, 11 and 20 showed much less current load compared to centre anode and same leads to uneven cathode temperature over the elapsed preheating duration (Figure 2).

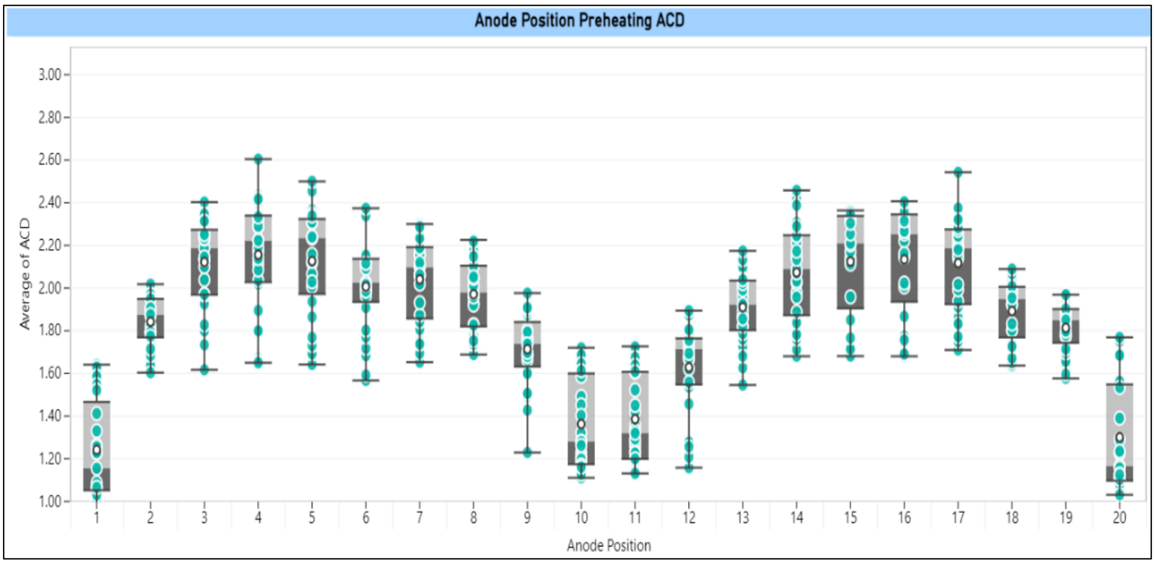

Figure 2. Anode position-wise current (mV in stem) for preheating.

- **High ACD covariance:** The covariance of ACD often exceeded 20 % by the end of Phase 1 preheating, sometimes reaching 50 %, indicating considerable spatial variations in current distribution (Figure 3).

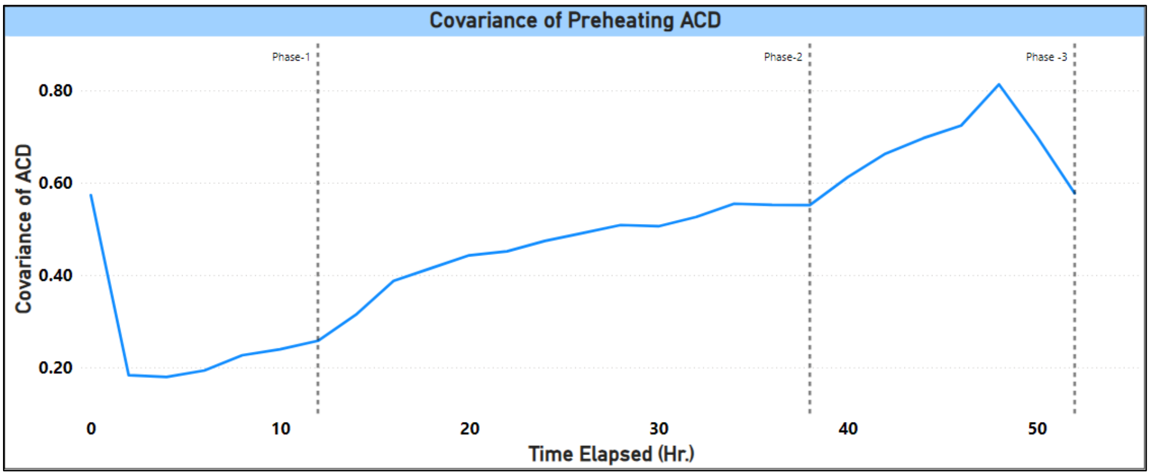

Figure 3. Covariance of preheating ACD over the preheating time.

- **Cell-to-cell variation:** Poor insulation and the use of a coke–graphite mix in the resistance pad led to significant differences in preheating resistance, heating rates, and bath formation. These inconsistencies made start-up more complex, requiring a dedicated team to closely monitor and enforce operational standards (Figure 4).

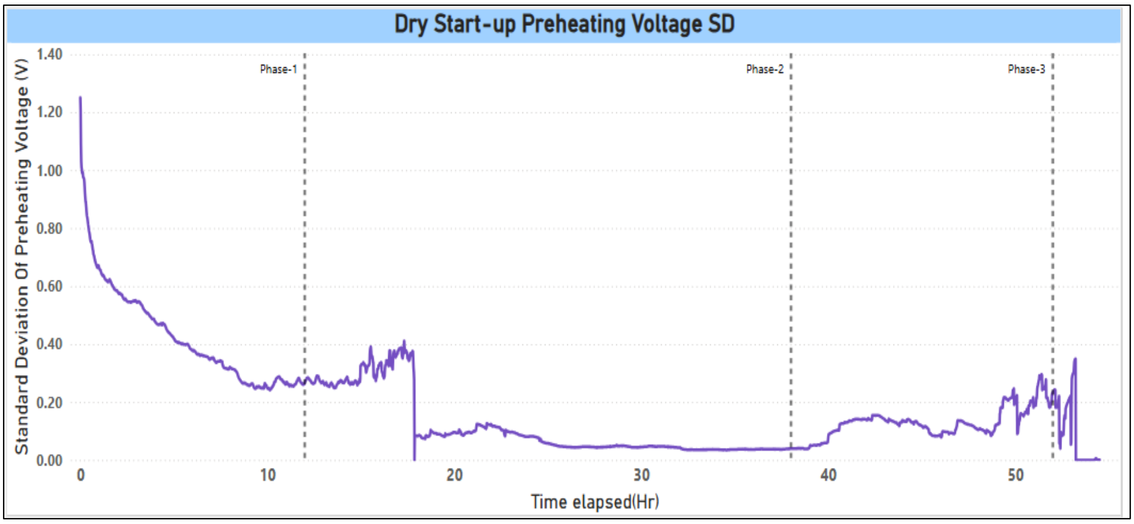

Figure 4. Standard deviation of preheating voltage (cell to cell).

- **High temperature gradient:** Corner anode positions consistently showed very low current loads compared to central anodes, exacerbating temperature gradients of over 250 °C (Figure 5).

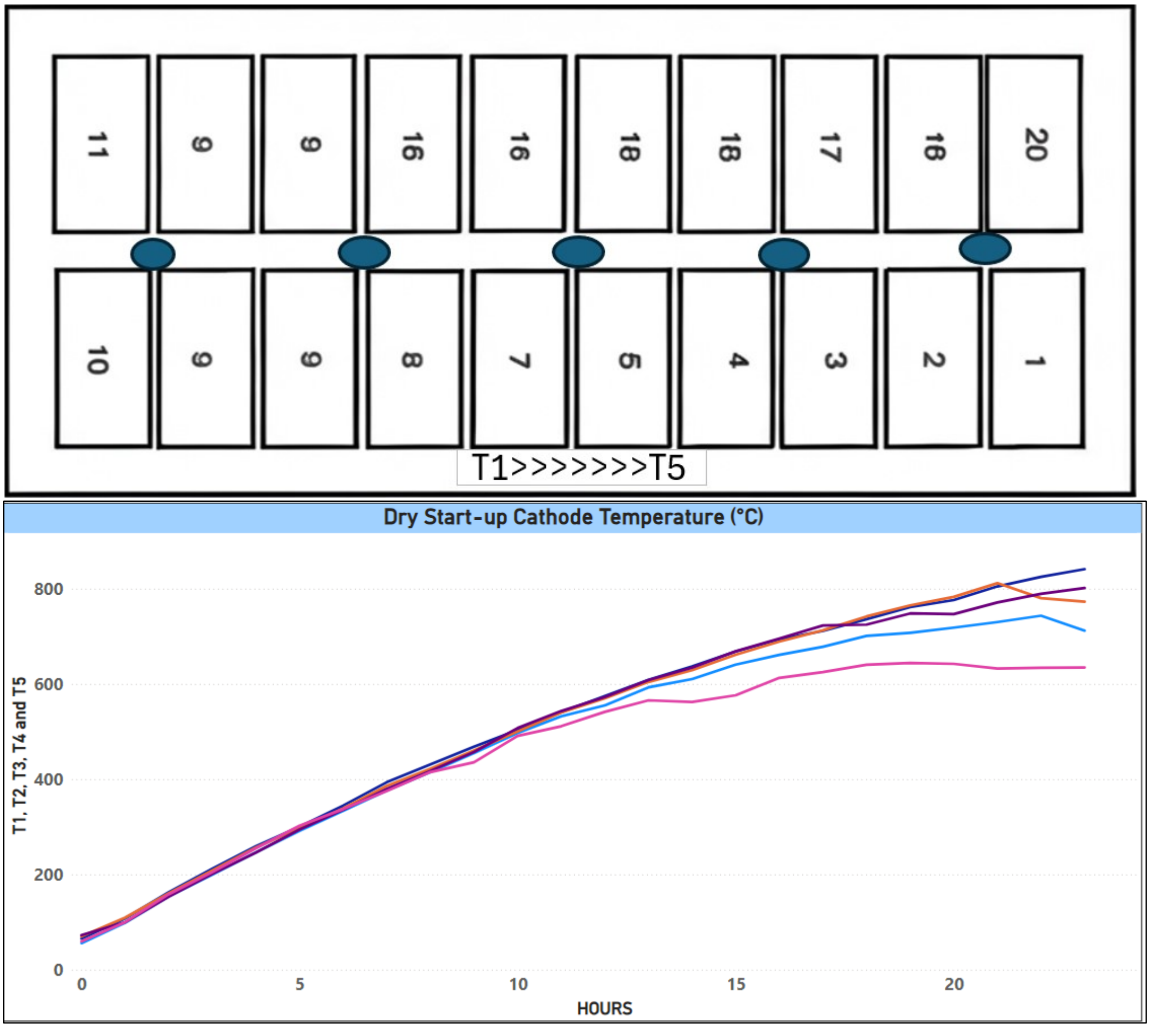

Figure 5. Cathode temperature, T1 >>> T5.

- **Localized Hot Spots:** Uneven cathode temperatures during preheating typically hotter centres and cooler corners resulted in persistent hot spots at central anode positions. Conventional methods, like isolating high-draw anodes, proved ineffective when hot spots were dispersed, revealing the limitations of traditional temperature control.

- **Limited Temperature Monitoring:** Beyond the first 24 hours post-bath formation, temperature data was lacking, restricting thermal assessment during later start-up stages. As a result, adjustments relied solely on anode mV readings after Phase 1 (Figure 5).

- **Unclear Energy Distribution:** The specific energy split between heating the cathode blocks and generating the bath was unknown, making it difficult to evaluate energy efficiency and total preheating duration accurately.

- **Labour Intensive Process:** Tasks such as pushing solid bath and installing flexes required high skill and manual effort. Several follow-up steps were also manually performed, critically affecting overall preheating quality (Figure 6).

Figure 6. Manual interventions (flex installation/big bath crucibles).

Optimizing the dry start-up became a key Continuous Improvement (CI) initiative. Through predictive planning, refined practices, advanced controls, and ongoing procedural updates, we enhanced energy efficiency, reduced costs, and ensured safe, reliable, high-performance operations from the cell’s start. By identifying gaps, tailoring solutions, testing, and fine-tuning, we evolved the dry start-up into a hybrid "Semi-Conventional" methodology combining the best of dry and conventional approaches.

4. Start-Up Methodology; A Transformative Shift to Semi-Conventional - How?

Sohar Aluminium’s start-up process has evolved from dry to conventional, and now to a semi-conventional method, reflecting a commitment to improving efficiency, safety, and cell performance. The semi-conventional approach integrates key conventional elements like partial preheating and targeted thermal management while simplifying procedures to cut preparation time and labour. Building on the conventional foundation with tailored refinements, it aims to boost preheating efficiency, ensure uniform temperature distribution, and reduce thermal and mechanical stresses. This method also lowers early start-up instability, accelerates cell stabilization, and reduces manual effort, enhancing safety and minimizing operational risks.

4.1 Key Changes in Cell Preparation

This evolution unfolded in clear phases, starting with cell preparation and progressing through start-up. The earliest major improvements were made to the resistor pad.

4.1.1 Resistor Pad

The improvement journey began by replacing traditional **coke graphite** resistor pads with **fully graphite** templates. This change addressed inconsistencies caused by variable coke-graphite blends, which had led to unpredictable voltages and uneven preheating rates in the critical first six hours. Switching to all-graphite pads improved thermal conductivity and preheating uniformity, stabilizing the preheating rate and allowing focus on other operational factors.

Alongside material upgrades, trials tested different bed configurations by varying pad diameter and thickness under **centre and corner** anodes. The goal was to find the optimal setup for consistent heat distribution, structural integrity, and stable anode mV (ACD) during start-up. These experiments helped Sohar Aluminium develop a tailored "best recipe" suited to its cell design and operational needs (Figure 7).

Figure 7. Resistor pad trials - centre vs corner. “Best recipe”.

4.1.2 The Use of Normal Clamps Instead of Flexes

Replacing flexes with standard clamps during preheating was a key improvement (Figure 8). This allowed controlled anode movement for thermal expansion and alignment while preserving structural integrity. Routine inspections every four hours involve selectively loosening or tightening clamps to relieve mechanical pressure and maintain proper anode positioning.

Figure 8. Flex to normal clamp in preheating.

This smooth preheating without flexes resulted from simultaneous improvements enhancing uniformity. With no bath generation needed during this phase, the risk of high voltages or localized millivolt spikes melting the bath was removed, reducing manual intervention and improving overall consistency.

This approach significantly reduced crane and vehicle activity around the cell, improving safety and easing operational congestion. It also cut manual labor and minimized workers heat exposure. Standard clamps enabled quick installation and removal for about 1.5 hours each matching the time for flexes. Crucially, it eliminated the need for operators to work near suspended loads, greatly enhancing safety and lowering incident risks. Overall, the method proved efficient, robust, and aligned with safety and operational goals.

4.1.3 Anode Quality

After replacing flexes with standard clamps, ensuring anode quality became crucial. We focused on achieving strong contact and maintaining flexibility without damaging the anode pad by strictly enforcing the perpendicular alignment of anode stems (Figure 9). This was essential for optimal anode-to-beam contact while allowing necessary movement during preheating.

To ensure these standards, we implemented strict audits for anodes used in cell preparation, checking stem straightness, cast iron quality, and defect absence. Anode integrity is crucial for current distribution and load stability during start-up. By enforcing these criteria, we improve contact and flexibility without harming the anode pad, boosting cell performance and reducing electrical imbalances and early anodic issues.

Figure 9. Anode alignment and anode placements.

4.1.4 Anode Placement on Resistor Pad

The in-house "Anode Bell" was redesigned for precise, gentle anode placement on the graphite bed (Figure 10). This ensures accurate positioning, protects the template from damage, and maintains uniform anode leveling critical for correct Anode Current Distribution (ACD). Proper leveling prevents localized hot spots, uneven preheating, and operational inefficiencies.

Figure 10. Checks on the anode placement on top of graphite template.

4.1.5 Improved Insulation to Restrict Heat Loss

To tackle uneven corner cathode temperatures caused by heat loss, insulation of corner anodes was significantly improved before applying the cover bath (Figure 11). Multiple trials focused on isolating these anodes to reduce heat loss, building on earlier resistor pad enhancements.

To enable precise, data-driven adjustments, additional thermocouples were installed at key corner points, linked to a data logger for continuous temperature monitoring. This setup allowed real-time tracking essential for fine-tuning insulation on sides, tops, and between anodes. Emphasis was also placed on optimizing cover bath granulometry to ensure effective insulation and prevent localized cathode overheating during preheating, maintaining uniform conditions critical for start-up.

Figure 11. Insulation along long, short sides and centre.

4.1.6 Cell Banking Practices

An insulating cover bath was applied over the anodes and cell sides to reduce heat loss and stabilize temperatures. Additionally, rockwool was placed between anodes and in the central channel to prevent bath or debris from entering, preserving cell integrity during preheating.

Granulometry standards were set for the cover material to ensure optimal performance, keeping alumina content below 5%. Initially, bagged cover material was used, but this made flow control difficult and posed safety risks when bags fell during handling.

To resolve these issues, purpose-built bath hoppers were introduced for cell banking (Figure 12). They enable controlled, uniform cover material distribution, enhancing safety, efficiency, and minimizing spillage and workplace hazards.

Figure 12. Cell cover practices - bags to hoppers.

4.2 Key Changes in Start-up and Early Life

At preheat completion, liquid bath is added to start the cell unless already formed during dry start-up, which is a complex process requiring skill and care. Optimization efforts extended into the critical first 24 hours, known as soaking time, essential for stabilizing cell conditions before molten metal addition. This delay allows low-excess AlF_3 bath to fill cathode cracks and enables sodium penetration, preventing melting at normal operating temperatures.

The dry start-up method faced issues like cell temperatures often surpassing 1040 °C before metal addition, causing thermal instability, higher electrical resistance, and performance fluctuations. It also required heavy manual intervention, raising safety risks. The shift to the "Semi-Conventional" start-up method introduced key changes to overcome these challenges:

4.2.1 Controlled Bath Introduction

Unlike dry start-up, which melts all bath during preheating, the semi-conventional method adds about 15 to 16 tonnes of bath at start-up using Bath Tapping Vehicles (BTVs) (Figure 13). This gradual addition allows better control of bath chemistry. Procedural changes included replacing a single large crucible fill with staged transfers of 2 tonnes each.

Cell preparation improvements include limiting anode movement during bath addition, applying soda ash to high-draw anodes, optimizing bath transfer speed, and refining donor cell setups. Enhanced insulation and thermal distribution during preheating prevent bath freeze and support a stable start-up. In the semi-conventional method, achieving uniform cathode temperatures above 900 °C helps keep bath temperatures below 1000 °C during early operation an important start-up goal that was challenging in dry start-up due to high energy input and longer preheating times.

Figure 13. Use of Bath Tapping Vehicle (BTV) for bath transfer.

4.2.2 Review of Procedures and Practices for Start-up to Early Life

In dry start-up, high initial voltages (20–30 V for 30 minutes to 2 hours) were used to offset poor preheating, causing prolonged anode effects and high PFC emissions. With improved preheating, uniform cathode temperatures, and better bath chemistry, the goal is now minimal or weak anode effects, keeping voltages at 8–12 V and significantly cutting emissions by optimizing polarization duration.

Enhanced start-up procedures now allow cells to be hooded immediately by avoiding high voltages and controlling energy input. This prevents melting or collapse of the solid bath cover along the cell sides, improving emission control and cell stability advantages not possible with dry start-up. Optimized energy use enables rapid power reduction, helping cells quickly reach normal liquid levels. Better cover conditions support effective cell tending within 20–24 hours after metal addition, stabilizing bath chemistry and reducing early adjustments. Many additional improvements during early cell life and normalization at Sohar Aluminium are beyond this paper scope.

4.3 Summary of Key differences of Semi-Conventional Method to Conventional Methods

The Semi-Conventional Start-Up blends features of previous methods with key differences. It uses about 15 tonnes of bath like the Conventional method but applies partial coverage insulating anode tops and sidewalls while leaving the central channel clear to ensure thermal consistency. The bed templates are made entirely of graphite for improved thermal conductivity and durability. This approach delivers a balanced preheating rate of 30–35 °C/h, between the faster Dry and slower Conventional methods.

A key change is the deliberate removal of flexes, simplifying the process and reducing manual labour and logistics. Bath is added during start-up using BTV crucibles, enabling more controlled and efficient liquid bath handling similar to Dry Start but unlike the conventional large crucible method.

5. Evaluation the Quality of Preheating and Start-Up Process in Semi-Conventional Methodology

Though preheating and start-up span just 2 to 3 days at relatively low temperatures, their success is critical for long-term cell stability and performance. This short, foundational phase requires precise and careful execution.

To monitor this, bottom cathode temperature sensors track cathode and shell heating as well as electrical energization during and after start-up. Combined with incident logs and post-start-up data, these tools provide key insights into early cell behaviour. Long-term performance is assessed during planned shutdowns or autopsies, usually around five years post start-up.

Preheating quality is evaluated by factors such as initial and final average cathode temperatures, anode current distribution, temperature gradients, localized hot spots, and manual intervention levels. The following sections outline improvements in preheating and start-up phases.

5.1 The Cell-to-Cell Voltage Variation

Cell-to-cell voltage variation has notably decreased, shown by a reduced preheating voltage standard deviation. This reflects more consistent and uniform cell behaviour during the Semi-Conventional Start-up, especially compared to the higher variability seen in the Dry Start-up method (Figure 14).

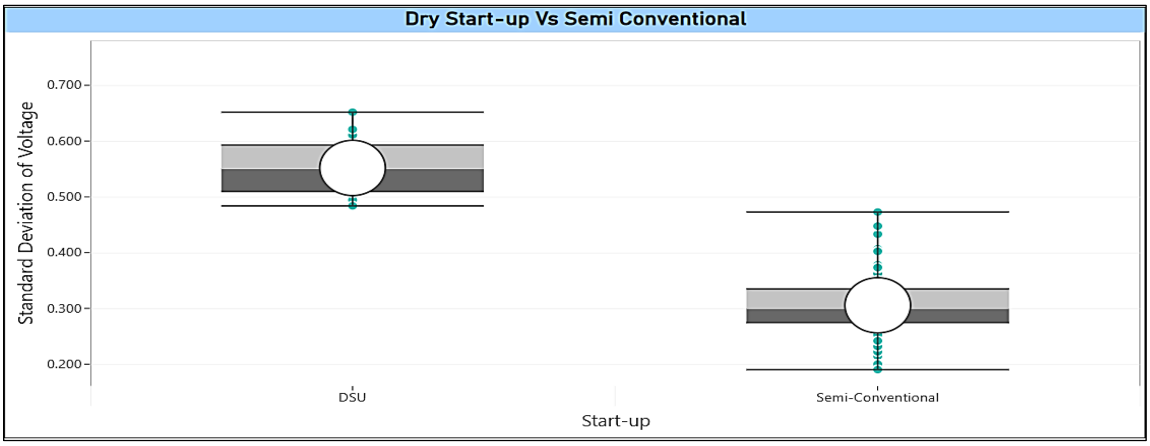

Figure 14. Cell to cell standard deviation of preheating voltage. Left: DSU, Right: Semi-conventional.

5.2 Preheating Rate

The cathode preheating rate in the first five hours is optimized to 24–32 °C/h (Figure 15), enabling a controlled, gradual temperature rise and more uniform heat distribution across the pot lining. This reduces thermal stress, lowering the risk of lining damage and enhancing cell stability. The improved heat-up rates also promote higher ramming paste density, further supporting cell longevity and reliability.

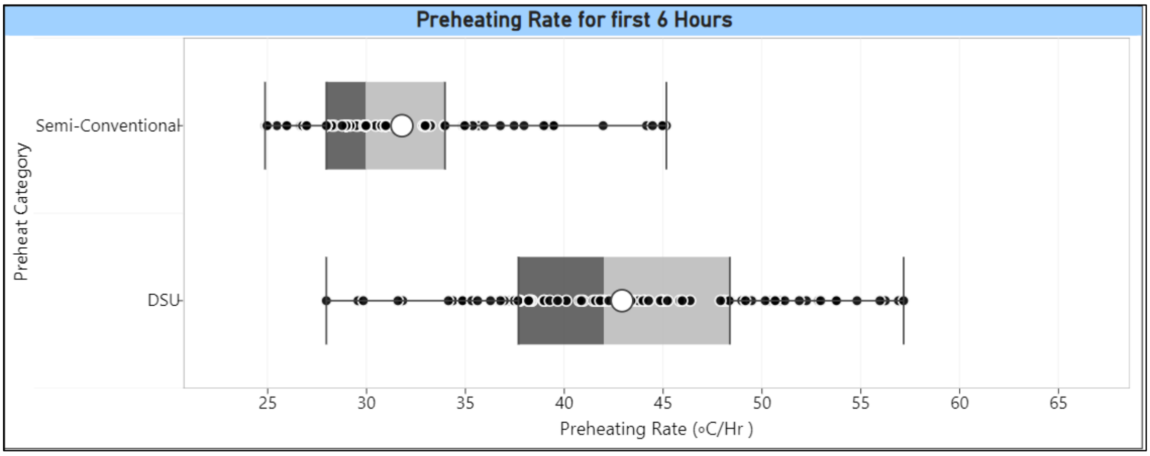

Figure 15. Preheating rate (°C/h) for the first 6 hours.

5.3 Improved Anode Current Distribution, Cathode Temperature

Anode current distribution was better regulated in the semi-conventional start-up compared to DSU (Figure 16). Cell measurements showed average cathode surface temperatures of 850–900 °C with a low 5% relative standard deviation by preheating's end, demonstrating high uniformity. Maximum temperatures ranged between 840–920 °C, with no hot spots or elevated millivolts detected. This reduced temperature variation and minimized gradients reflect excellent contact among the resistor bed, anodes, and cathode blocks, laying a strong foundation for extended cell life.

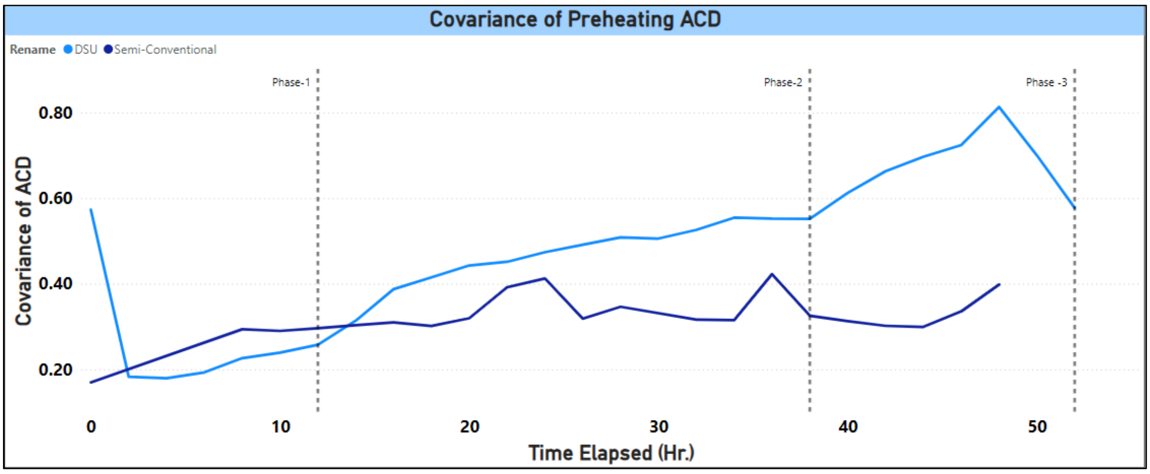

Figure 16. Dry start-up vs Semi-Conventional - covariance of anode current distribution (ACD) over preheating in hours.

5.4 Preheating Hours and Energy

The semi-conventional method delivers notable energy efficiency improvements and better thermal uniformity. Enhanced insulation, uniform anode current distribution, and consistent preheating enable cathodes to reach target temperatures faster (Figure 17) while consuming significantly less energy (Figure 18). By eliminating the energy-intensive bath melting required in dry start-up, this approach achieves superior overall efficiency.

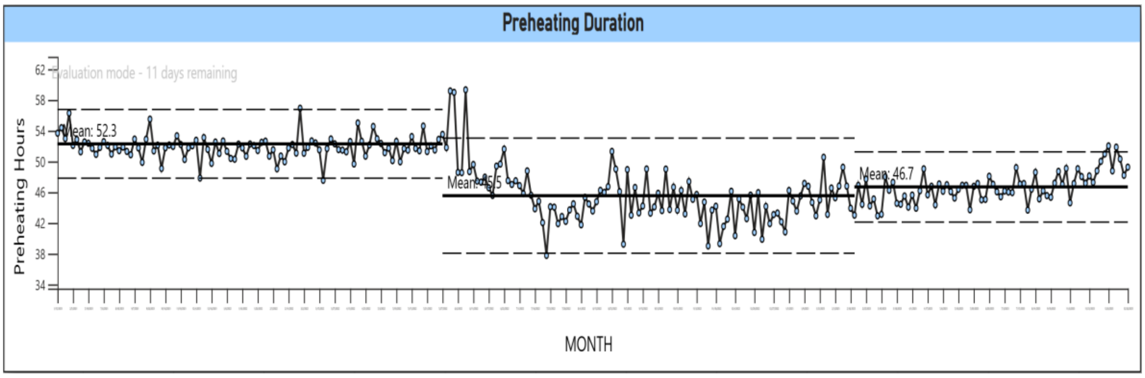

Figure 17. Preheating duration from Dry Start-up to Semi-Conventional start-up.

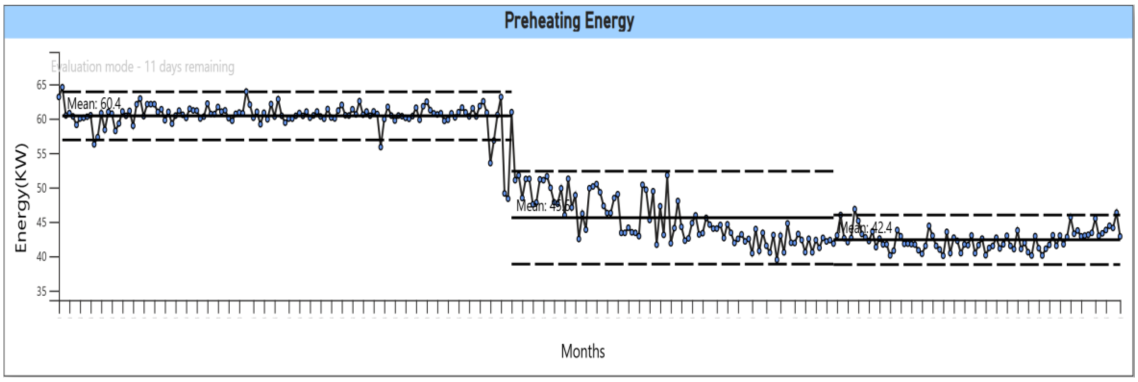

Figure 18. Preheating energy from Dry Start-up to Semi-Conventional Start-up.

5.5 Operational Advantages: Reduced Manual Intervention

A key benefit of the semi-conventional method is the significant reduction in manual intervention. Phase 2 no longer requires pushing solid material to melt the bath or frequent adjustments of the cell cover to manage hot spots. Additionally, manual loosening and tightening of anode clamps has been nearly eliminated. This reduces reliance on skilled labor and continuous supervision, streamlining operations and improving safety.

5.6 Improved Alumina Dissolution and Reduced Anode Effect Energy and Frequency

This approach boosts alumina dissolution efficiency, cutting anode effect frequency and energy use, while enhancing start-up stability.

5.7 Reduced Temperature in Soaking Time

Bath temperature before start-up has been optimized from around 1040 °C to a controlled 900–1000 °C (Figure 19), enhancing thermal balance for greater stability and efficiency. This lower temperature reduces thermal shock, extending lining life, stabilizes the electrolyte by minimizing crust issues, and cuts heat loss to improve energy efficiency. The steadier thermal conditions also enable smoother start-up with fewer voltage and current fluctuations, ensuring controlled alumina dissolution and lowering risks of sludge buildup and anode effects.

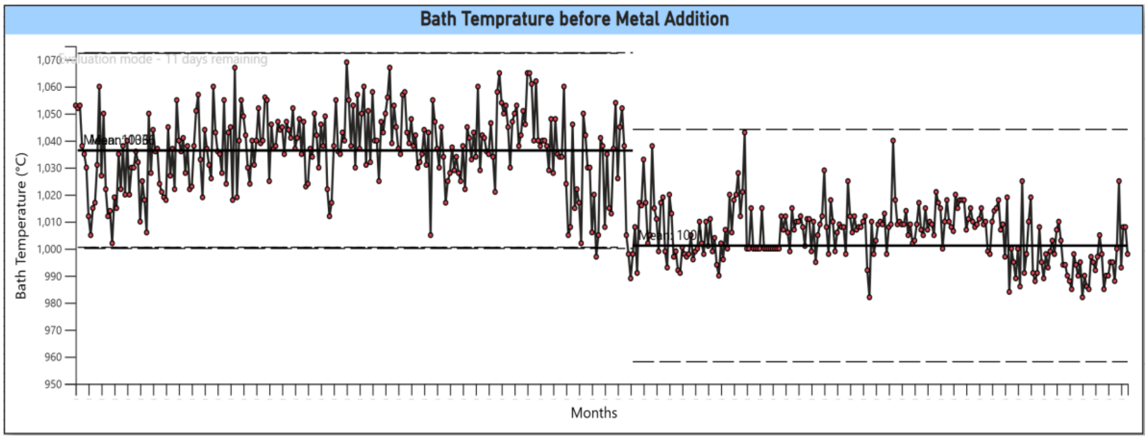

Figure 19. Bath temperature before metal addition in start-up cells.

5.8 Instability, Cell resistance and Improved Chemistry

Operational stability during the first 100 days showed noticeable improvement, attributed to the smoother preheating process along with enhanced voltage and current distribution across the cells (Figure 20).

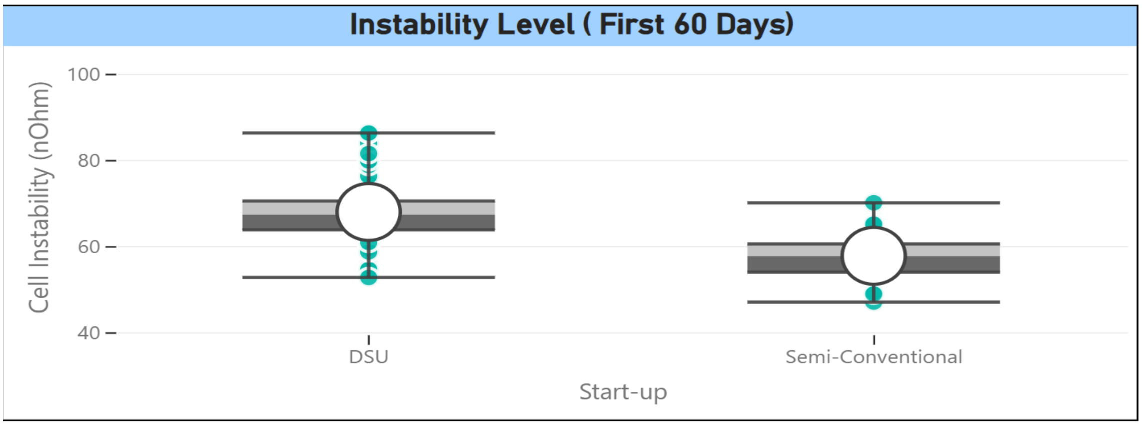

Figure 20. Cell Instability - Dry to Semi-Conventional start-up.

6. Challenges

6.1 Coactivity

Implementing the new approach demands precise coordination of co-activities, particularly during the bath-up/start-up phase. Using small 2-tonne crucibles requires 7–8 units, leading to high vehicle traffic. To optimize logistics, hold cells are positioned near the start-up area, facilitating efficient vehicle movement and controlled bath addition.

6.2 Cell-to-Cell Voltage Variability in Preheating

Voltage variability during preheating was observed due to differing tests on individual cells, causing inconsistent reactions across the cells.

6.2 Detailed Follow-up and Monitoring

Extensive testing across multiple cell preparations necessitated detailed monitoring sheets to track parameters such as temperature, materials, and procedural adjustments. Key performance indicators (KPIs) and dashboards were developed for real-time data visualization, enabling prompt identification of trends and informed decision-making.

6.3 Number of Cells for Test Conclusion

To ensure statistical validity amid variable test conditions, a minimum of five cells per test was adopted. Given the average start rate of five cells per month, test cycles extend over several months, increasing logistical complexity and emphasizing the need for meticulous planning and coordination.

6.4 Training of Start-up Team to Adopt MOC, SOP and RA of New Methodology

Training the start-up team on Management of Change (MOC), Standard Operating Procedures (SOP), and Risk Assessment (RA) is integral and iterative. Continuous refinement of procedures through feedback ensures safety and operational effectiveness during methodology implementation.

7. Key Learnings and Conclusions

Our organization has made significant progress in safety, workflow efficiency, and team confidence in managing change. Enhanced safety protocols have eliminated incidents like cladding failures and falling anodes, reflecting improved reliability and a safer work environment. This success stems from reduced manual handling and the removal of overlapping tasks, creating a more streamlined and secure process. Additionally, targeted procedural improvements, shorter preheating times, and better handling practices have improved team workflow, cut turnaround times, and optimized overall operations for smoother phase transitions.

These improvements have significantly boosted the team's confidence in managing change. The start-up team's positive feedback highlighting the new method's safety, simplicity, and ease of execution underscores this success. We remain committed to continuously monitoring and refining our start-up process, using data and team input to drive ongoing gains in consistency, efficiency, and overall performance at Sohar Aluminium.

To further enhance the start-up process, improvement opportunities can be considered, such as:

- Introducing periodic reviews and process audits to capture lessons learned and continuously refine SOPs and risk assessments.
- Have future autopsy for the cell started with this methodology to compare the lining condition to the previously used start-up methods.

These forward-looking actions will support sustained improvement, ensure safe and efficient operations, and solidify the benefits gained from the updated method.

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9. References

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