AL07 - STARprobe™ Implementation in Sohar Aluminium Potline

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Abstract

Thermal regulation of aluminium reduction cells is essential for overall potline stability, cell performance and optimum metal productivity. It is currently difficult to instantly know the exact and complete status of a cell. Thermal regulation of cells is achieved by maintaining cell bath temperature and acidity near targeted set-point values. Therefore, any potline will always be looking for technology that provides better thermal regulation with more reliable and quicker results. The STARprobe™ has been adopted by Sohar Aluminium to measure all critical real-time information necessary for optimal cell control and effective thermal regulation.

Sohar Aluminium LLC is a pioneering greenfield aluminium smelter and a frontrunner in Oman's manufacturing sector. This paper will examine the successful STARprobe™ implementation in Sohar Aluminium by critically analysing the cell thermal behaviour, comparison of best practices integrated with ALPSYS thermal regulation, which has been recognised for achieving benchmark results. This report will present the experience of Sohar Aluminium in improving its thermal potline control by changing measurements and analysis methods from classical to modern technology through the STARprobe™ implementation.

Keywords: Aluminium reduction cells, Thermal regulation, Cell bath temperature and acidity, Classical method of cell control, STARprobe™.

1. Introduction

The Sohar Aluminium plant is operating a single potline of 360 cells, AP40 design, with a potential total metal production of 395 000 tonnes per year. It also has a carbon plant producing baked anodes and a cast house to cast the molten aluminium into final ingots and sows' format. Sohar Aluminium facilities include a smelter that utilizes advanced technology and employs best practices along with a dedicated power plant and port facility.

Sohar Aluminium has helped to establish and supply four downstream partners, of which three are currently in operation. Sohar Aluminium has its own state-of-the-art 1 000 MW power plant and a dedicated port facility situated in the Sohar Industrial Port area. Sohar Aluminium, Oman's sole aluminium smelter, aims to set a standard for comparable sectors and contribute to the nation's sustainable growth.

Modern primary aluminium production is based on the Hall-Héroult process. Many factors contribute to the behaviour of modern cells. Some parameters are defined by the cell design (cell lining thermal insulation, maximum amperage capacity, magnetohydrodynamic condition), while others are controlled automatically by a computerized-algorithm system like “ALPSYS” (cell resistance, alumina feeding, regulations), and still others are dependent on human interaction, or operations (anode changing, anode covering, bath corrections, metal tapping). Any incremental process improvement in industrial production might have a significant impact on energy consumption [1].

Currently, the thermal equilibrium of aluminium reduction cells is becoming increasingly constrained as operating current and energy-saving requirements increase, and anode-cathode distance (ACD) decreases. Therefore, fine-tuning the cell thermal balance is crucial and requires a more precise understanding, control, and prediction of the cell mass and energy balance, i.e., process control. Cell thermal equilibrium primarily entails sustaining a stable bath temperature, an appropriate superheat range, a solid ledge, etc. The cell heat equilibrium is the most important factor in maintaining its high efficiency, low energy consumption and prolonging cell life [2].

The temperature and composition of the bath must be controlled to ensure the process stability and efficiency. The basic criteria for regulating the composition and temperature of the bath are the excess AlF_3 in the bath, the bath temperature, the age of the cell, and cell operation. The addition of alumina had the most energy-intensive influence on electrolyte temperature. Alumina feeding caused a significant but temporary drop in electrolyte temperature and superheat. The superheat is critical for alumina dissolution in the bath and affects cell stability. So, precise, on-time, and consistent feedback on cell variables is critical for making control decisions.

While cell parameters such as bath temperature and excess AlF_3 must be measured manually on a regular basis, critical parameters such as superheat and free alumina are estimated or measured less frequently. These are the critical inputs for cell temperature regulation, and they necessitate the best industry sampling processes, process control experience, and standards [3,4].

Sohar Aluminium introduced an innovative bath chemistry measurement technology via STARprobe^{TM}, which provides simultaneous measurements of five cryolitic bath characteristics. The STARprobe^{TM}, which stands for Superheat, Temperature, Alumina concentration, and Ratio (STAR) analysis equipment, delivers real-time results that enable improvements on process control management.

In this paper we will cover the Sohar Aluminium experience in the implementation of the new measurement system and how the new thermal regulation methodology improved the cell performance and efficiency. The Sohar Aluminium trial approach was designed to gradually introduce new procedures, hence limiting potline disruption.

2. Conventional Measurement Method and Challenges in Process Control

The goal for the potline is to maintain stable cell conditions during normal operation. Maintaining a consistent bath temperature, an appropriate superheat range, a decent ledge, etc., are all aspects of cell heat balance that require careful attention during operation. Numerous studies have demonstrated the importance of heat balance in ensuring the cell continues to function at optimal efficiency while using as little energy as possible [5].

Bath temperature and excess AlF_3 have been seen to exhibit unpredictable behaviours, with rapid changes occurring even when prior AlF_3 additions were close to the average consumption. The traditional method of controlling bath ratio and temperature involves collecting bath samples for chemistry analysis and measuring bath temperature manually on a regular basis. However, these measures are usually taken independently. Furthermore, bath samples must be sent to a laboratory for analysis, and findings are typically available in approximately 8 hours. Due to this delay, control choices must be made primarily using cell actual consumption and bath temperature information. The classical approach, which is restricted in its ability to collect and analyse samples, encounters difficulties in establishing a correlation between bath chemistry and temperature, and the calculated superheat after analysing the updated samples is often unrealistic.

Several studies have looked at how alumina feeding affects the thermal equilibrium of the bath. The bath temperature fluctuates due to changes in feeding rates during underfeeding and overfeeding. There can be a large temperature discrepancy between the end of the underfeeding period and the end of the overfeeding period. Another key factor in subpar thermal regulation is the temperature variation that arises from varying feeding rates [6].

Superheat is another significant cell process characteristic that affects heat balance. The concentration of AlF_3, alumina and other additives in the electrolyte can significantly alter the superheat, which in turn affects the alumina dissolution. Since high superheat can melt the cell ledge and increase energy consumption, and too little can make dissolving alumina difficult and reduce the cell stability, it is important to maintain just the right amount of superheat for optimal operation [7]. At Sohar Aluminium, was determined that 8–12 ° C is an appropriate range for superheat. When controlling the cell process with classical thermal regulation, calculated superheat was unreliable due to their dependence on the bath temperature and the theoretical liquidus temperature at the respective excess AlF_3.

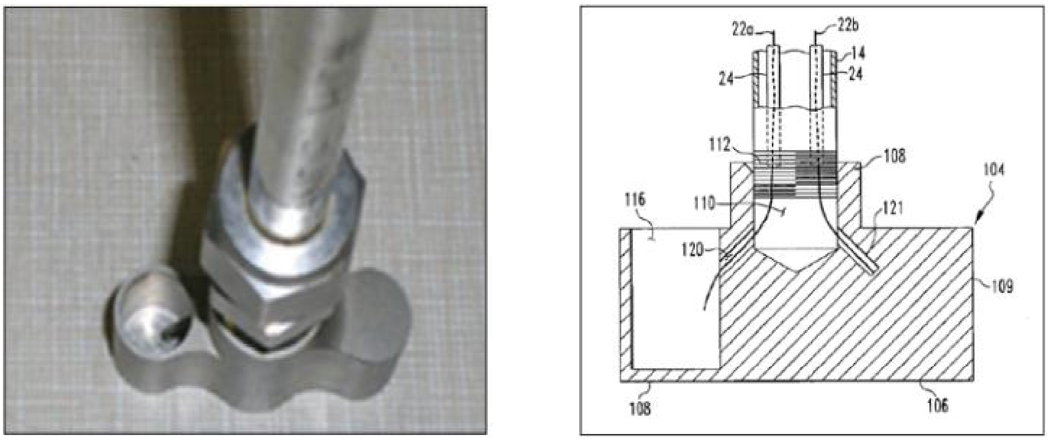
All these variables result in an unstable feedback control loop in which the cell is constantly under or overshooting the desired optimum settings and determined mostly on temperature. This over- or under-compensation generates fluctuations in excess AlF_3, which is harmful from both an operational and economic standpoint leading to sub-optimal cell performance.

3. STARprobe^{TM} Measurement Principle

The STARprobe^{TM} concept is straightforward and relies on the DTA (Differential Thermal Analysis) measurement technique, which examines the cooling characteristics of the cryolite melt to calculate the bath ratio. During the process of changing from liquid into solid, a cryolite melt undergoes a number of phase transitions. The amount of heat generated is directly related to the bath chemistry ratio since each transformation occurs in a distinct temperature range.

Two type K thermocouples are installed in the probe tip to monitor the temperature gradient and calculate the bath ratio (see Figure 1). The thermocouple on the left measures the rate at which the bath sample is cooling, while the thermocouple on the right measures the rate at which the probe metallic mass is cooling. With this probe, the ratio result is known after only a few steps: insert the probe tip into the molten bath to equilibrate with the bath temperature in the cell, withdraw the probe tip from the bath and allow it to cool down, and the STARprobe^{TM} analyses and records the cooling curve [4].

The temperatures were transmitted to the tablet PC using Wi-Fi. When the DTA results are ready, they are displayed on the tablet screen, saved to a file on the tablet, and sent to level 2. A specialized cart moves the portable computer around. Both STARprobe^{TM} assemblies, along with spare STARprobe^{TM} tips and a sizable backup battery to maintain the PC tablet, can fit in the cart. (Figure 2).



(a) (b)

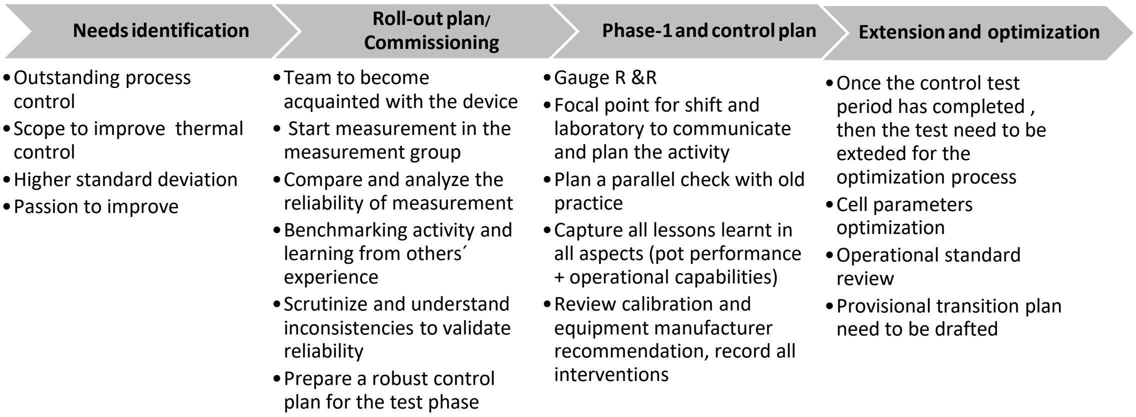
Figure 1. Probe tip (a). Schematic of probe with 2 K-Type thermocouples (b).

Figure 2. STARprobe™.

4. Cell Thermal Regulation Elements

Sohar Aluminium is driven to improve the traditional process of sampling and analytical methods, which had inadequate control and delayed actions on the cell thermal state. In addition, Sohar Aluminium is committed to enhancing cell thermal regulation to sustain productivity so that it could accommodate a further lower ACD operating zone, as would be necessary in a potential amperage increase project. Although triggering the transition and implementing new techniques requires consistent and targeted efforts, continuous advancement through best-in-industry current technology represents Sohar Aluminium intention to become a benchmark smelter.

The steps that were taken during implementation are shown in Figure 3. The improvement projects implemented by Sohar Aluminium all adhere to this standard methodology. The first step was a period of intensive training for a select number of technicians, operators, and shift supervisors. Starting with the selection of a pilot group (20-30 cells), measurements were taken using the STARprobe™ over the course of 32 hours, and a parallel measurement plan was established to compare the statistical results of the two methods. Through this process, Sohar Aluminium was able to build a more transparent, knowledgeable, and effective plan.



Needs identification

- Outstanding process control
- Scope to improve thermal control
- Higher standard deviation
- Passion to improve

Roll-out plan/ Commissioning

- Team to become acquainted with the device
- Start measurement in the measurement group
- Compare and analyze the reliability of measurement
- Benchmarking activity and learning from others´ experience
- Scrutinize and understand inconsistencies to validate reliability
- Prepare a robust control plan for the test phase

Phase-1 and control plan

- Gauge R &R
- Focal point for shift and laboratory to communicate and plan the activity
- Plan a parallel check with old practice
- Capture all lessons learnt in all aspects (pot performance + operational capabilities)
- Review calibration and equipment manufacturer recommendation, record all interventions

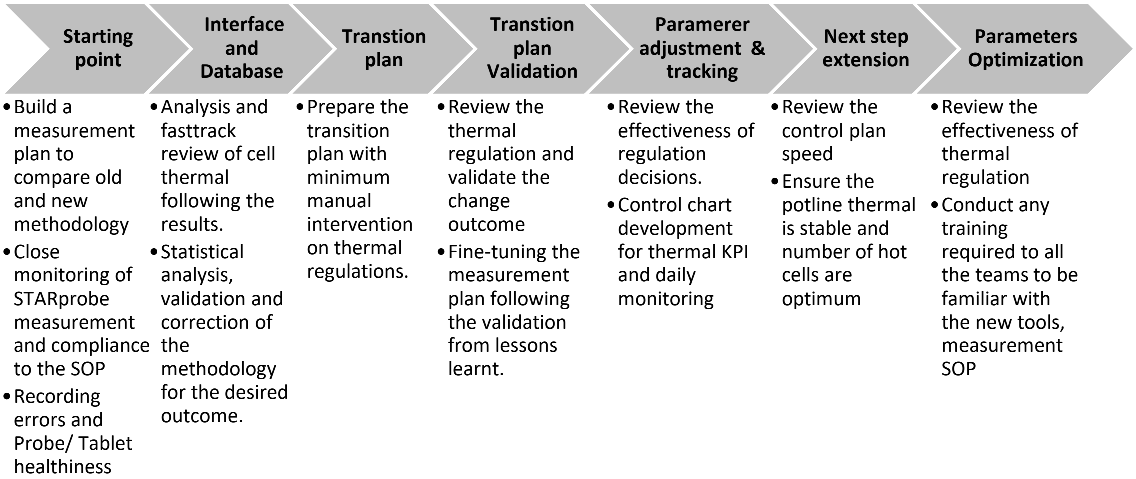
Extension and optimization

- Once the control test period has completed , then the test need to be exteded for the optimization process
- Cell parameters optimization
- Operational standard review
- Provisional transition plan need to be drafted

Figure 3. Decision-making and planning for STARprobe^{TM} measurement.

5. Main Stages of Implementation with Thermal Regulation Fine Tuning

After confirming the Phase-1 cells for the STARprobe^{TM} measurement, the next step was to capture and analyze the data. This data serves as a crucial indicator of the project success from the initial planning stages through the final stages of parameter optimization and continuous fine-tuning before its extension in the potline.



Starting point

- Build a measurement plan to compare old and new methodology
- Close monitoring of STARprobe measurement and compliance to the SOP
- Recording errors and Probe/ Tablet healthiness

Interface and Database

- Analysis and fasttrack review of cell thermal following the results.
- Statistical analysis, validation and correction of the methodology for the desired outcome.

Transtion plan

- Prepare the transition plan with minimum manual intervention on thermal regulations.

Transtion plan Validation

- Review the thermal regulation and validate the change outcome
- Fine-tuning the measurement plan following the validation from lessons learnt.

Paramerer adjustment & tracking

- Review the effectiveness of regulation decisions.
- Control chart development for thermal KPI and daily monitoring

Next step extension

- Review the control plan speed
- Ensure the potline thermal is stable and number of hot cells are optimum

Parameters Optimization

- Review the effectiveness of thermal regulation
- Conduct any training required to all the teams to be familiar with the new tools, measurement SOP

Figure 4. Key steps in planning a full implementation of STARprobe^{TM} measurement in the potline.

6. Insight in Sohar Aluminium Trial Methodology

According to the Sohar Aluminium experimental and testing method, a sample from the total potline population was needed to properly account for the test and reference groups. The calibration of the new equipment needed by the process team is another aspect of the laboratory result that must be accomplished on multiple occasions to fully grasp its operation.

We selected a control group with identical work schedules:

- 21 cells from one group served as test cells, while the remaining cells from the same group served as reference.
- Initial evaluations indicated that a length of two anode cycles and up (26.7 x 2 = 54 days) was optimal for testing purposes.

This study argues that once a suitable methodology has been selected, implementation is far more challenging and crucial to the methodology success within an organization. It covers how to plan for and manage the methodology execution, as well as how to establish clear and quantifiable goals. Some behavioural and technological concerns, such as how to harmonize the methodology, the structure, and the infrastructure, are also addressed.

7. Baseline Performance and Preliminary Validation of STARprobe™ (Statistical Analysis)

To establish a benchmark, we compared the results of the STARprobe™ measurement technique with those of the conventional laboratory analysis. We analyzed the multiple influences on the STARprobe™ four-step process and the laboratory results, and developed a mechanism for efficient thermal regulation. At Sohar Aluminium, by adopting statistical analysis we established a baseline for further simulation, validation and extension of the Phase-1 test.

7.1 Comparison of STARprobe™ and Laboratory Results

The following steps constitute the comprehensive measuring plan developed to enable an accurate comparison of the two approaches:

- Be sure to take a STARprobe™ reading and sample the bath at the exact same time.
- The tap hole must be skimmed properly before bath temperature measurement.
- No influences of other operations are considered.
- Only qualified personnel are to perform any and all measurements.
- Laboratory equipment is well calibrated and within the Sohar Aluminium specifications.

A comparison campaign was set up, and then the important findings were compared for the sake of clarity and accuracy before Phase-1 commenced:

- Paired t-test using Minitab hypothesis testing, to verify if there is a significant statistical difference between the normal method and the STARprobe™ method.
- Correlation between the laboratory´s normal analysis method and STARprobe™ method.
- Regression model for the laboratory´s normal analysis method and the STARprobe™ method.
- Gauge R&R test for the laboratory´s normal analysis method and the STARprobe™ method.

Table 1. Comparison between normal and STARprobe™ measurements

Statistical Method	*KPI*	*STARprobe™*	*Normal*	*Difference*
Paired t-test	Excess AlF_3 %_Mean	10.91	10.15	+0.76
	Excess AlF_3 %_STD	1.03	1.20	
Paired t-test	CaF_2 %_Mean	4.35	5.14	-0.79
	CaF_2 %_STD	0.18	0.16	

As the difference in AlF_3 % was negative and in CaF_2 % positive, they neutralize each other. Also, no statistically significant difference was observed for bath temperature and superheat. We looked at these numbers to have a starting point for our calibration and for future reference. Sohar Aluminium collaborated with equipment manufacturer to analyze the new equipment performance and identify the likely causes of the variations before moving forward with the implementation.

7.2 Determine Potential Causes for the Variation

The team held a technical discussion and brainstorming session to come up with better solutions for the confirmed sources of variations (Figure 5):

1. Confirming the STARprobe^{TM} first calibration parameters with the manufacturer.
2. Deepening in on the most crucial aspects of the STARprobe^{TM} measurement process.
3. Examining the STARprobe^{TM} implementation history of other smelters.
4. Using ALPSYS, to optimize the thermal parameters of the STARprobe^{TM} test cells.

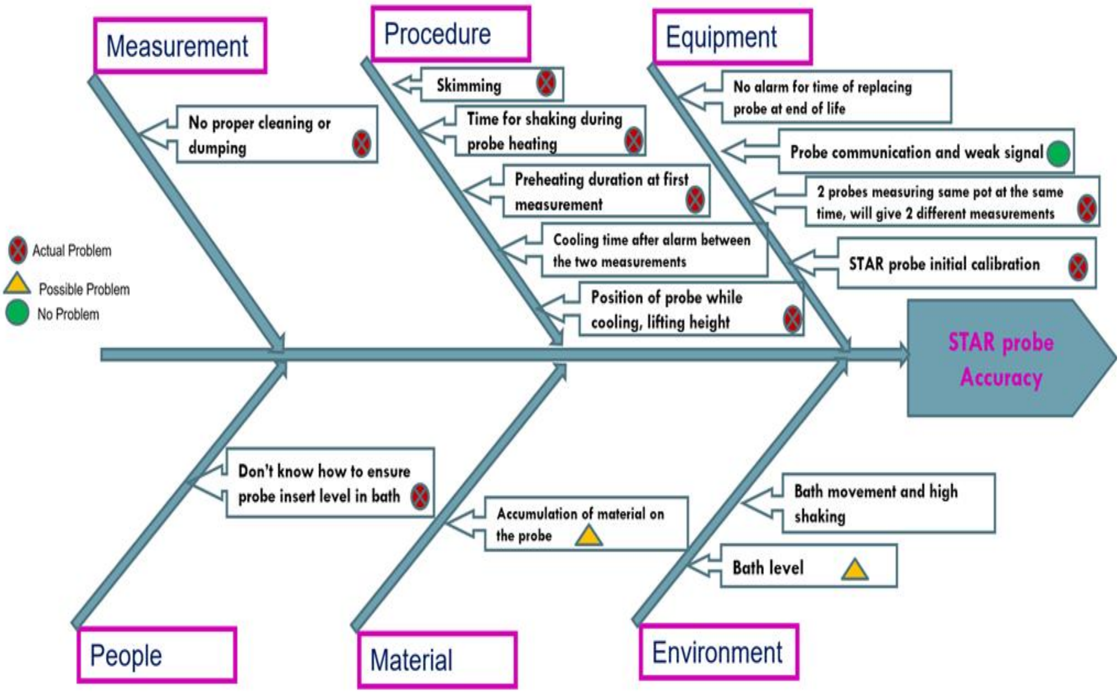


Figure 5. Fish bone diagram (cause and effect diagram).

7.3 Pilot the Solution in Phase-1 Test Cells

The examination of root causes reveals that fluctuations in measurement occur at each stage of the measurement process and that the cycle of these fluctuations can be partially explained in terms of the feeding interval. Overfeeding lowers bath temperature, while underfeeding or null feeding (tracking) raises it. Periodic fluctuations in bath temperature are typical and do not indicate that the stability of the bath temperature has been compromised. The stability of bath temperature can only be determined by looking at the longer-term trend of such changes across multiple cycles.

After implementing the ideal solutions in the Phase-1 group of cells, bath chemistry indicators of excess AlF_3 and CaF_2 variation improved when compared to the prior comparison campaign. Multiple comparative campaigns were conducted during the Phase-1 trial period, and their outcomes were compared to the control groups. The positive aspect is that this difference is fairly steady and is now mostly a matter of calibration (accuracy) and following standard practices.

8. Phase-1 Cell Performance Review

After Phase-1 testing period was over, the control group that used the STARprobe^{TM} to control the bath ratio and temperature was found to be highly accurate in measuring temperature and ratio and was able to replace traditional bath sampling and XRD laboratory analysis. Response and subsequent reaction on chemical (AlF_3) additions have also been reported to be significantly quicker. The ability to promptly reject inaccurate readings and request a retest measurement has led to greater confidence in the findings.

A decrease in the amount of aluminium fluoride (AlF_3) added and a narrower range of temperatures indicate promising results from the experimental groups. In addition, ever since the STARprobe^{TM} measurements started, the superheat levels of the test groups have been improving while the cell instability has been decreasing. There are fewer opportunities for error with the STARprobe^{TM} measurement because the probes are pre-calibrated and require no maintenance.

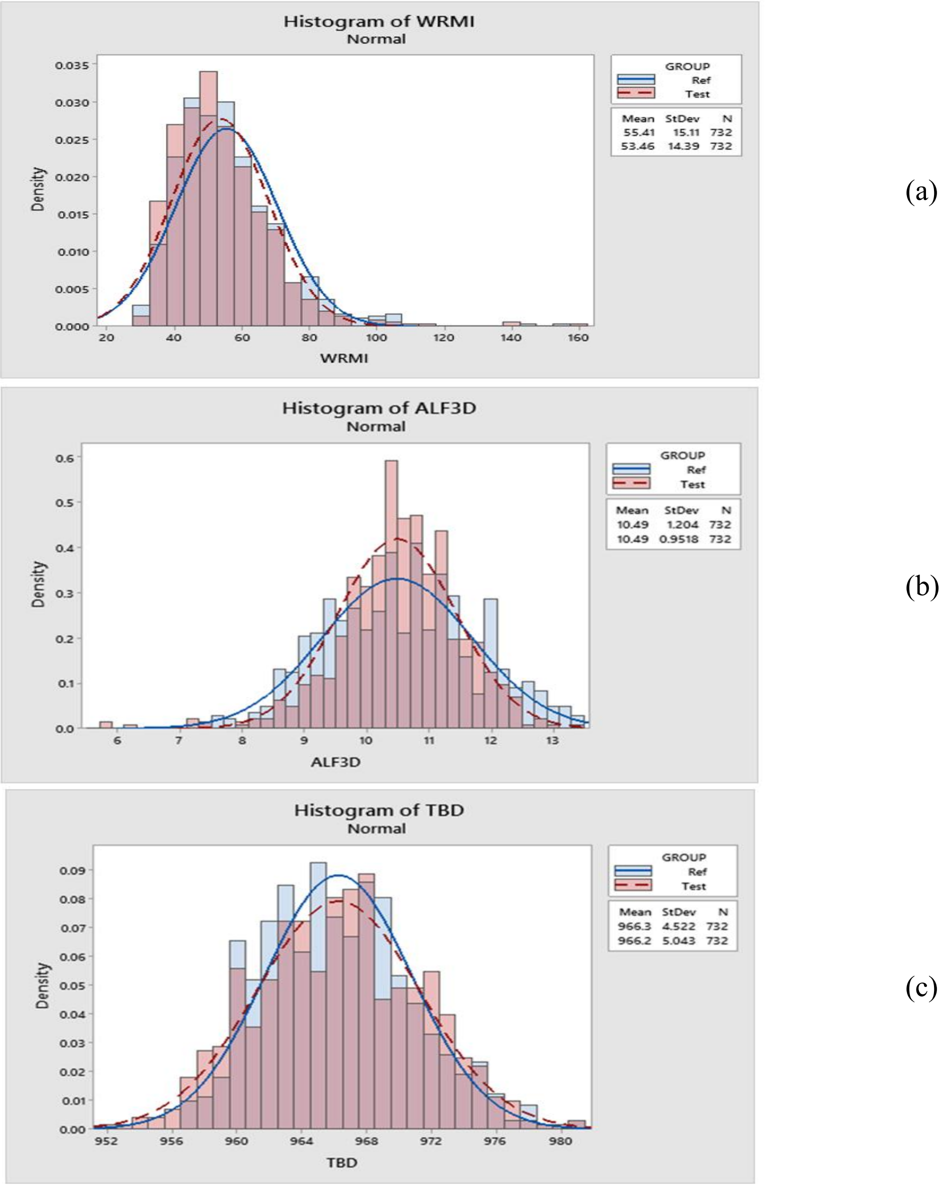


Figure 6. Instability (WRMI) (a), excess AlF_3 (ALF3D) (b) and temperature (TBD) (c) for test and reference group.

It is still possible for errors to occur during the control of the process; for instance, the precision of measured data can significantly alter the outcomes of the process. Sometimes, incorrect measurements are caused by extreme cells (sick, unstable, or new), since the cooling curve algorithm is influenced by the concentration of free alumina in the bath. Therefore, accurate measurement is essential to guarantee the control effect using this method. For accurate results, it is also important monitor factors such as tip use, damage, immersion depth in the bath, errors while doing the measurement etc., which are all closely tied to operator skill and work compliance. Especially since the program automatically detects many potential accidental errors by operators and gives them an opportunity to make corrections before continuing.

9. Potential of Process Control Improvement by STARprobe™

By simultaneously monitoring bath temperature and the excess AlF_3, the STARprobe™ eliminates the temporal lag that can occur in the thermal regulation system. Assuming a constant cell superheat, standard cell control logic considers both, bath temperature and the bath ratio to regulate bath ratio by altering the amount of AlF_3 delivered to the cell.

Since the STARprobe™ can also measure bath superheat, it is possible to separate bath ratio control from bath temperature control, controlling the bath superheat. Adjusting AlF_3 concentration changes bath ratio, while independently changing the pseudo-resistance of the target cells affects the bath superheat.

The new STARprobe™ device offers Sohar Aluminium a substantial opportunity to boost process efficiency, but additional improvements to the cell control logic are required to fully realize this opportunity. Using the STARprobe™, Sohar Aluminium was able to reduce the thermal regulation horizon from 96 hours to 32 hours, giving them greater thermal control. There is less over- or under-correction of AlF_3 now that regulation times are shorter, as this has led to quicker and more prompt control decisions on the cell for smaller deviations in AlF_3 or temperature. Better thermal and superheat control will protect cell side walls, extending its life.

In the event of a superheat deviation, corrective action can be taken quickly in the form of a confirmation check, a feed modification based on free alumina, or a temporary resistance change. Superheat control is essential for optimizing seasonal fluctuations in the potline, and the STARprobe™ has helped to achieve this. However, better temperature management of the cells does support productivity improvements and has helped Sohar Aluminium maintain its current efficiency at a good level, so there is certainly room for improvement at any particular smelter, regardless of its current level of process efficiency.

10. Main Challenges Faced and Lesson Learnt

Adopting a new measurement methodology is one of the most difficult tasks, as it can directly affect the potline ability to produce metal and cause the biggest disruption to the cell current performance and long-term cell-life.

Therefore, a decisive and courageous leadership is necessary to embrace the change. Before commissioning and implementing new equipment, training, practice, physical feasibility to function in the local context, and many more functionality tests are required. Additionally, the team needs a reliable piloting technique to help them make the most of their time and energy during the changeover. To ensure the success of the project, it is important to encourage and empower your team. The new operational control on the STARprobe™ presents a significant challenge, as does its rapid implementation and adaptation.

We also ran into challenges with operational practice for properly employing the probe, as the excessive dipping of the probe tip resulted in many damaged probes during the early stage of the installation. We were able to consistently obtain roughly 80 dips per tip by monitoring shifts and providing rigorous refresher training sessions for the operators to make them more familiar with standard practice and monitor their work for compliance.

In order to effectively accommodate the work schedule in the measurement group, it was also one of the most important requirements that each group measurement be finished in under 2.5 hours. This will give you enough time to adjust the cell parameters for optimal cell performance, allowing you to optimize the cell before the following period.

11. Conclusion

Sohar Aluminium Smelter's adoption of the STARprobe^{TM} was a technical and productivity success story. The potline performance has been boosted to its present benchmark level with the aid of the STARprobe^{TM} assistance in enhancing the thermal regulation system as an enabler, and this improvement in thermal management can be further refined.

Measurement precision and reliability can only be achieved by strictly adhering to the STARprobe^{TM} outlined principles and procedures. Paying close attention to these rules and principles will increase the likelihood that the promised advantages will be attainable. The interface of the STARprobe^{TM} with thermal regulation was formed, and these new insights improve thermal regulation potential to be successful, resulting in a stable thermal balance of the cells. Reduction in the variation of the deviations of the operating parameters from the target values resulted in thermal stability, a decent side ledge thickness, and more stable AlF_3 feed shots.

Measuring superheat and alumina content in bath helps process engineers to determine preventive action, such as regulating the resistance target, optimizing the AlF_3 shots, or adjusting the bath in the cell. STARprobe^{TM} delivers reliable bath chemistry and superheat for preventative process control of the cells, thus improving regulation of the cells and productivity.

Further improvements were forecast prior to implementation and validated through pilot tests. These improvements were accomplished through increased cell performance, less use of AlF_3, and decreased exposure of humans to the process.

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