

Ma'aden Reduction Potline Partial Failure Incident and Recovery

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Abstract

The Saudi Arabian Mining Company (Ma'aden) and Alcoa (USA) joint venture is the largest fully integrated aluminium complex in Ras Al-Khair, Kingdom of Saudi Arabia, and consists of an alumina refinery, an aluminium smelter and a rolling mill. The Aluminium smelter commenced operation on 12 December 2012 with 720 AP 37 technology reduction pots in two potlines at 370 kA. The potlines were upgraded with Alcoa Center of Excellence (ACE) 410 kA package from 2019 to increase amperage to 410 kA producing 805 kt/a of aluminium.

In November 2022, Ma'aden experienced a significant operational challenge when 304 pots were cut out due to a series of anode collapses and anode fall-offs in addition to other operational challenges. Remarkably, there was no power shutdown of the potline due to various preventative actions, taken to save the potlines. During five months of continuous pot cleaning, inspections and relining, all affected pots were back into operation safely at zero lost time incident, and production targets were back to normal. This paper explores the various factors that led to the sudden pot stoppages in pot operations, which significantly impacted metal production, and it gives details of the successful recovery. The incident provided a unique opportunity to perform extensive multiple pot autopsies, which in turn facilitated enhancements in cathode design, the assessment of diverse preheating techniques, and the examination of lining materials performance in addition to anode quality improvement.

Keywords: Potline crisis, Potline recovery, Amperage increase, Anode failures, Pot relining.

1. Introduction: Event of Operation Upset

Both Ma'aden potlines experienced an upset condition in November 2022 with exceptionally high anode incidents after receiving under-baked batches of anodes from carbon plant which led to an increase in potline instability and a deviation in potline indicators. A stepwise amperage reduction from 410 kA to 370 kA, and stopping 304 pots followed for both potlines to minimize the severity of the incident.

- Many pots with multiple anodic incidents, spikes and fallen blocks (Figures 1-2), put the potlines at risk of having open circuit if not removed on time.
- High number of pending unscheduled anodes, spikes and fallen blocks increased workload in equipment and manpower.
- Late work in potlines increased due to high number of anodic incidents removed.
- Number of critical pots with high silicon increased sharply in potlines with many pots with red shells and also a few pots tapped out from side shell due to high instability.

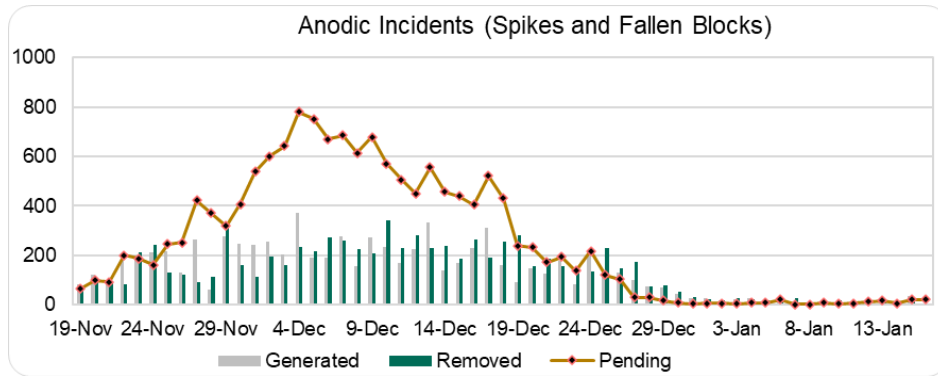


Figure 1: Trend of anodic incidents and fallen blocks.



Figure 2. Type of anodic incidents and fallen blocks.

2. Instability and Metal Purity

Pot instability increased from 45 nΩ to above 100 nΩ in mid-crisis, at the end December 2022 (Figure 3). When improvements in the potlines were made, and good anodes were supplied, the instability started to improve in January 2023.

Iron content in metal was affected by high number of anodic incidents specially fallen blocks; the level of iron jumped from 1100 ppm to more than 2500 ppm during the peak of anodic incidents and decreased in January 2023 (Figure 3).

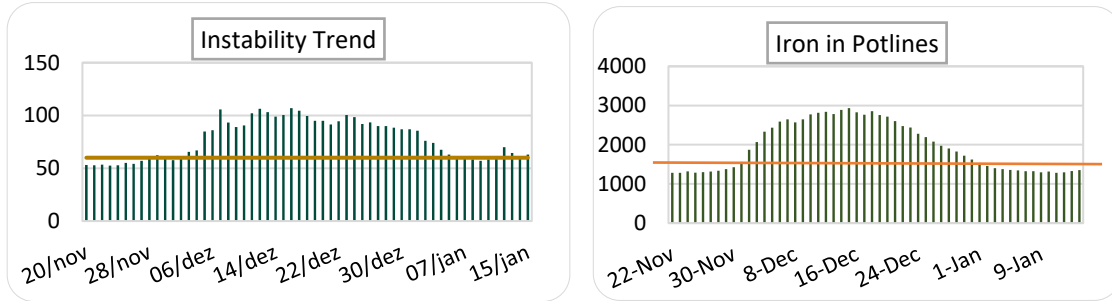


Figure 3. Instability (nΩ) and iron content (ppm).

3. Red Shells and Tap-Outs

Due to upset condition during December 2022, the red shell events started to increase, and at the same time 12 pot tap-outs occurred (Figure 4). The team started to be proactive, which helped to identify and treat red shell before tap-out.

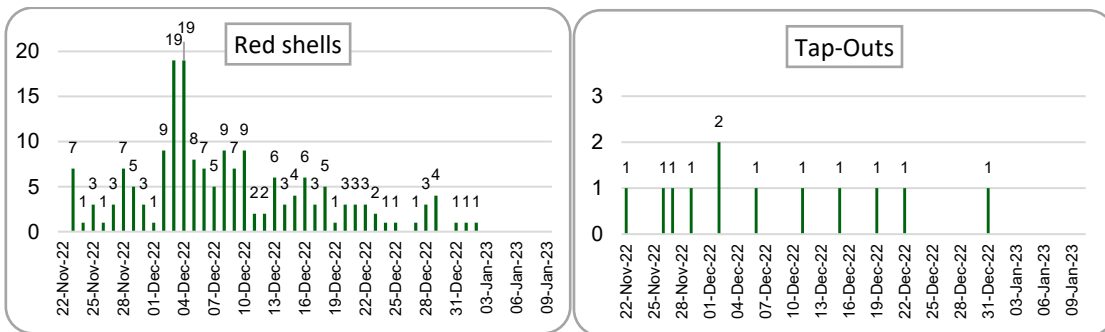


Figure 4. Number of red shells and pot tap outs.

4. Bath Height

Pending anodic incidents increased in potlines, bath levels dropped drastically, and many actions were taken to improve the level of bath to improve line stability and to avoid any risk of bath shortage during December 2022 (Figure 5).

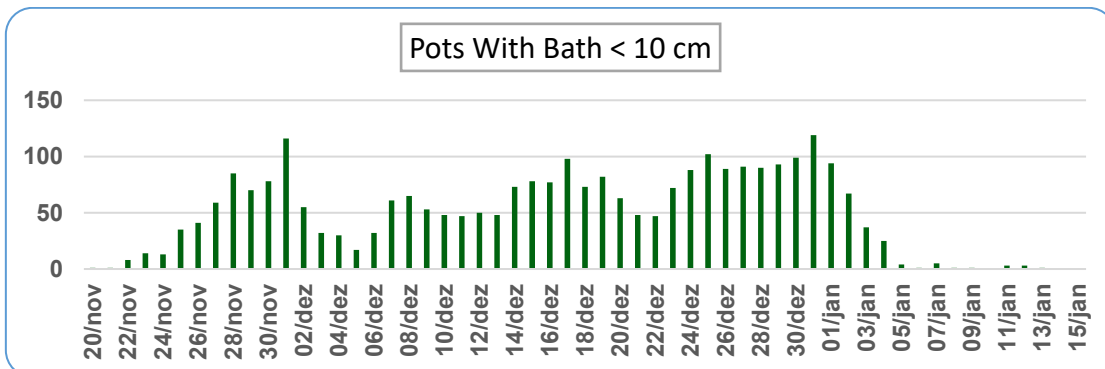


Figure 5. Number of pots less than 10 cm bath height.

5. Actions Taken

The following actions were taken by potline team to stabilize the potlines:

- Potline amperage was reduced from 410 kA to 370 kA in steps to minimize the instability and red shell pots.
- Potline instability action room was established around the clock with all functions to safely and effectively manage the situation and ensure plant was returning to normal operating condition.
- Stop the supply from the anode baking furnace (ABF) for sections with lower baking temperature by re-baking anodes to ensure that all anodes reached the desired temperature. Anode re-baking started for underbaked anodes to support built inventory and meet reduction demand (Figure 6).

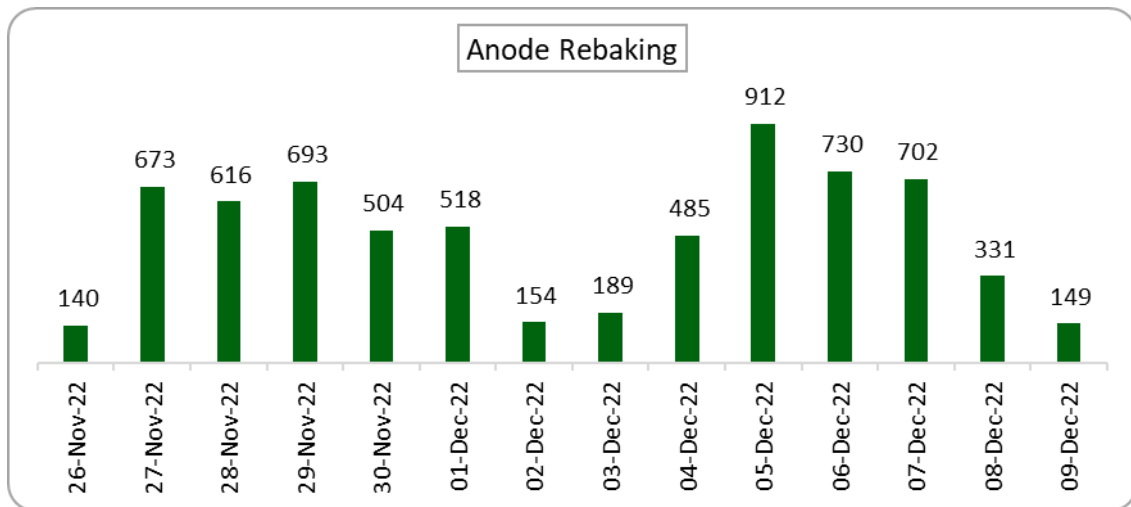


Figure 6. Number of anodes re-baked.

- Utilize the rejected baked inventory to segregate and use only anodes having healthy ABF temperatures. This action resulted in a baked reject recovery of around 7 000 anodes from the available stock of 19 750. This activity took place from 24 November to 9 December (Figure 7).

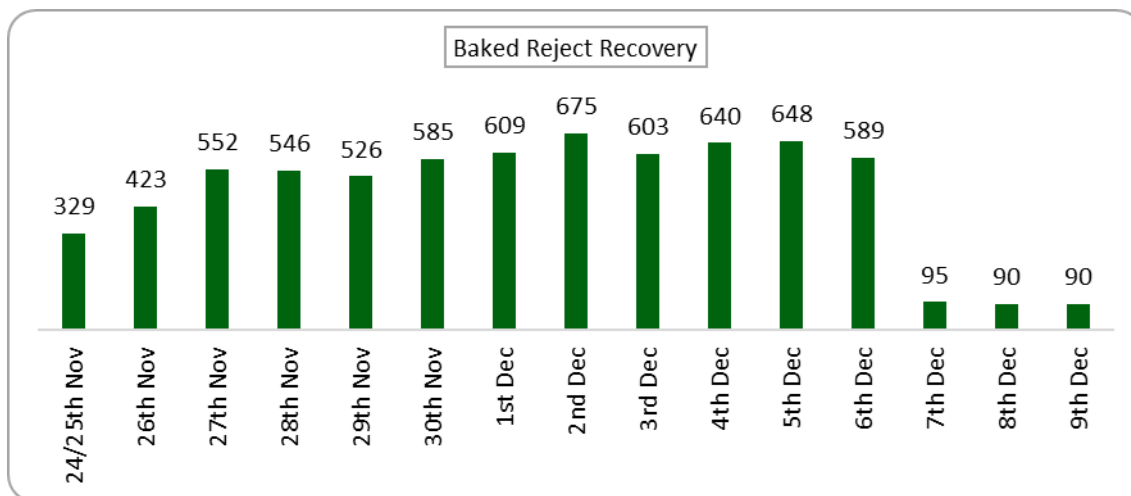


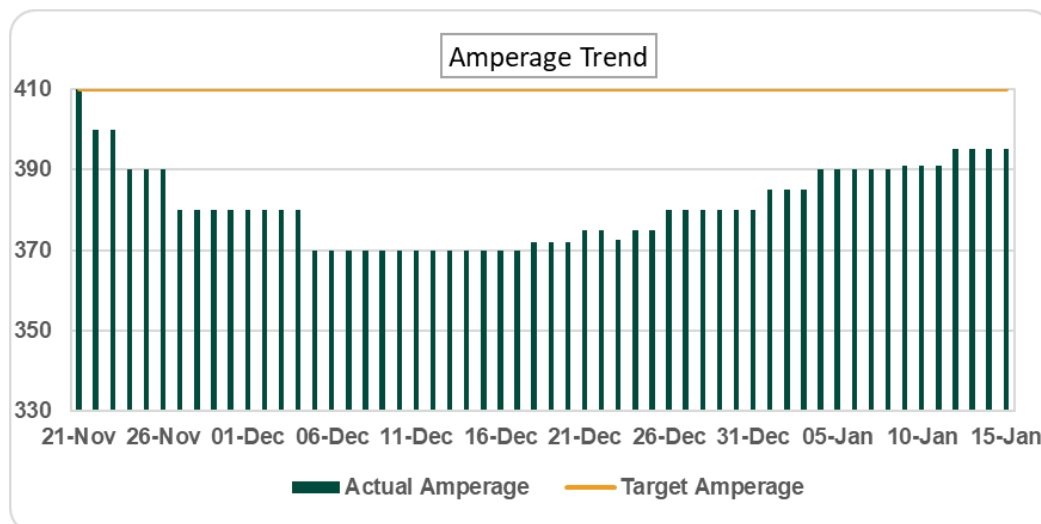
Figure 7. Number of baked-reject recoveries.

- Anode change cycle was changed from 25.5 days to 27 days to reduce workload in anode change and build inventory in carbon plant.
- List of critical pots with multiple anodic incidents and high instability was made and pots stopped to avoid tap-out and open circuit. A total of 304 pots were stopped safely during the crisis period.
- All potline process set points were changed and adjusted based on amperage change.
- Extra manpower was injected in every shift by changing from 4 teams to 3 teams to help and support the crisis.
- Full on-site coverage from leaders from all areas round the clock to follow up and support.
- Actions implemented to improve bath generation in potline which helped to remove the anodic incidents and improve the situation quickly.
 - Pure bath blending,
 - Bath donor pots addition,
 - Emergency line feeding in GTC with pure bath,
 - Liquid bath from stopped pots used in low bath pots,
 - Metal height set point reduced.

6. Potline Amperage Reduction and Current Efficiency Loss

- To reduce potlines demand from carbon plant, the anode set cycle was changed in parallel with amperage change.
- The first amperage reduction was on 22nd November. Later, and with daily evaluation of lines condition and KPIs, the amperage was reduced to 370 kA (Figure 8a and 8b).
- Potline indicators were closely monitored every shift to decide on amperage steps. The first amperage increase was on 18th December after evaluating the potlines and carbon plant situation and inventory improvements.
- In spite of amperage decrease, the carbon crisis had a large impact on current efficiency, with the low of monthly average of 79.3 % at the top of the crisis in December 2022 (Figure 8c).

This shows how serious the consequences of a carbon crisis can be even for the best pot technology.



(a)

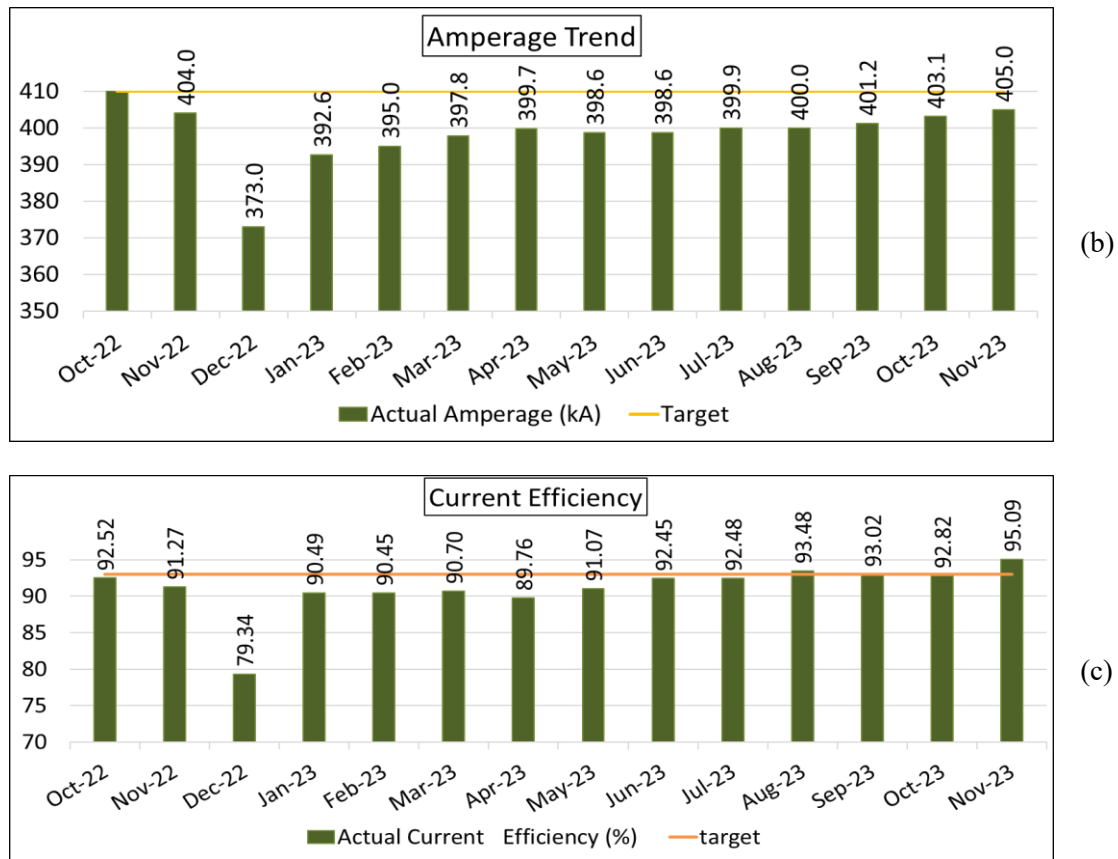


Figure 8. Potline amperage (kA) – daily average (a) and monthly average (b). Potline current efficiency (%) (c).

7. Pots Stopped

One of the actions to control the situation in the potlines was stopping any critical pot to avoid the risk of tap-out or open circuit. The team was preparing a daily list of critical pots in shift basis to treat and deal with these pots. A total of 304 pots were stopped during the crisis period (Figure 9).

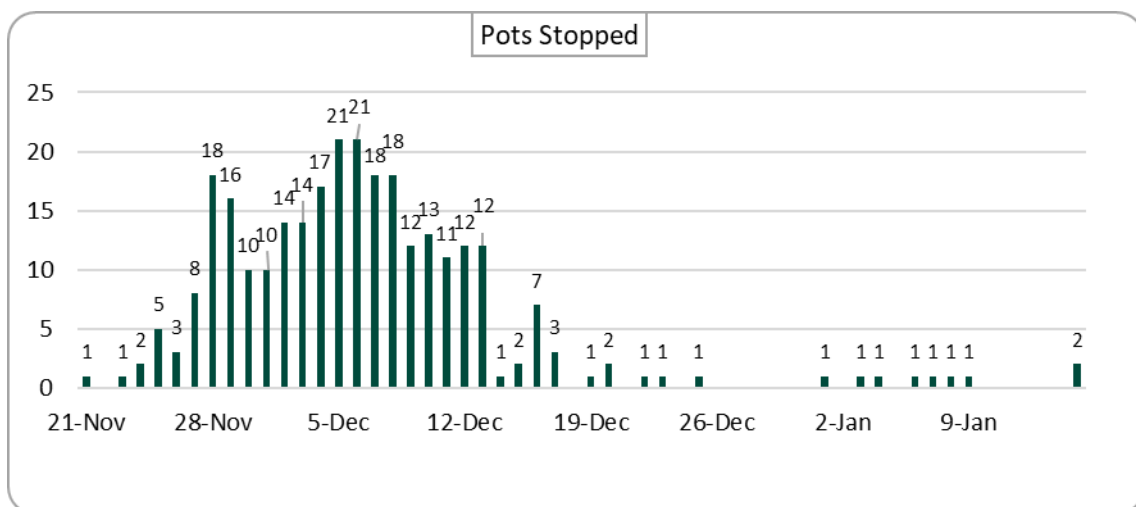


Figure 9. Number of pots stopped.

7.1 Stopped Pots Classification Based on Pot Age (Table 1)

Table 1. Stopped pots classification based on pot age.

Pot Age (Days)	< 800	800-1200	> 1200	Total
L1 – Room A	22	14	26	62
L1 – Room B	38	24	37	99
L2 –Room C	10	35	25	70
L2 – Room D	14	22	37	73
Total Pots	84	95	125	304

7.2 Individual Pot Performance Evaluation and Stoppage Criteria

Establishing a pot stoppage criterion during crisis is of utmost importance to prevent risk of pot tap-outs and or open circuit. It also protects personal safety, prevent catastrophic events, and preserve equipment and assets in potlines. Ma'aden teams were following below criteria to stop a pot during crisis period.

- Pots with red shell history,
- Pots with multiple anode incidents (≥ 4),
- Pots with 7 days Si content, average > 700 ppm,
- Pots with pot age > 1700 days.

8. Pot Cleaning, Repair, Pot Cutout and Start-up Sequence

It is important to adhere the correct sequence to avoid disruptions between operational activities. By following the correct sequence, we not only ensure the smooth flow of tasks but also prioritize safety. As you know that, our work environment can be hazardous, and it is essential that we take all necessary precautions to prevent incidents. The sequence of our tasks was as follows (Figure 10).

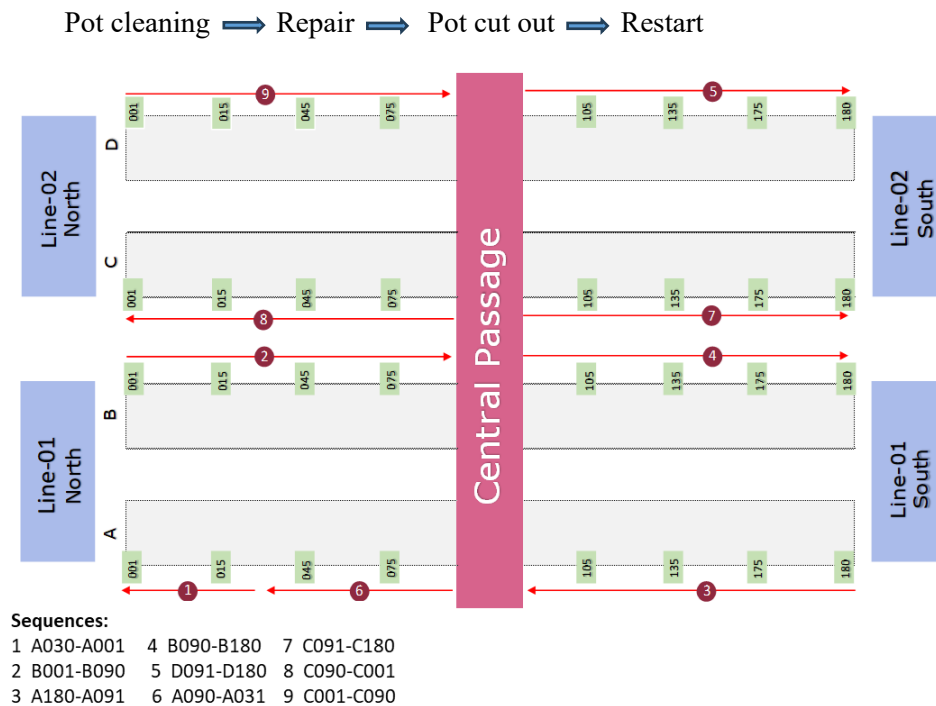


Figure 10. Pot cleaning and pot cutout sequence.

8.1 Pot In-Situ Cleaning

Pot in-situ cleaning was completed earlier than the plan. In total, 161 pots were cleaned and re-started (Figure 11). Cathode condition was physically checked and verified by experienced team dedicated for this activity. All re-started pots were being closely monitored during energization to avoid any incidents related to non-uniform current distribution.

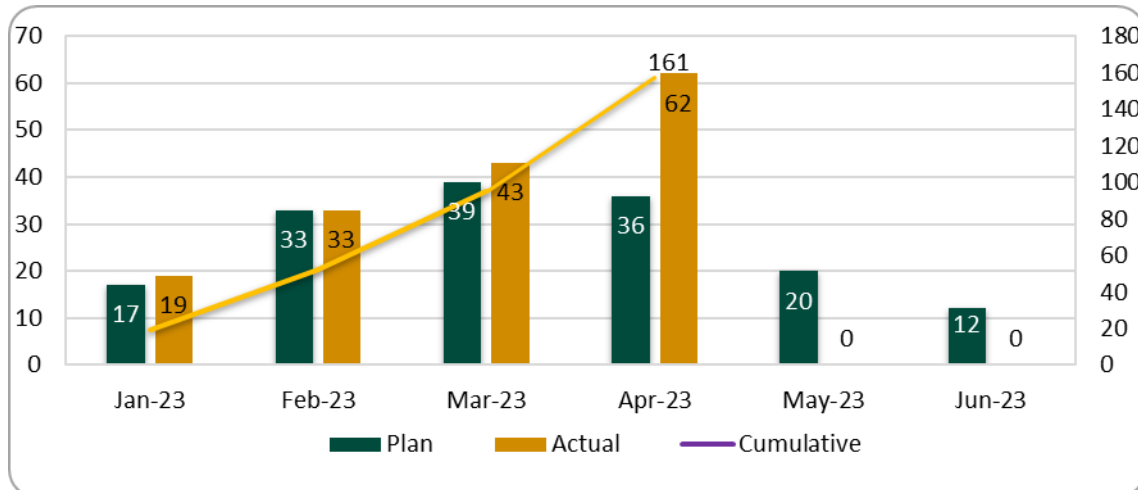


Figure 11. Pot in-situ cleaning.

8.2 Pot Start-Up (Repaired + Relined)

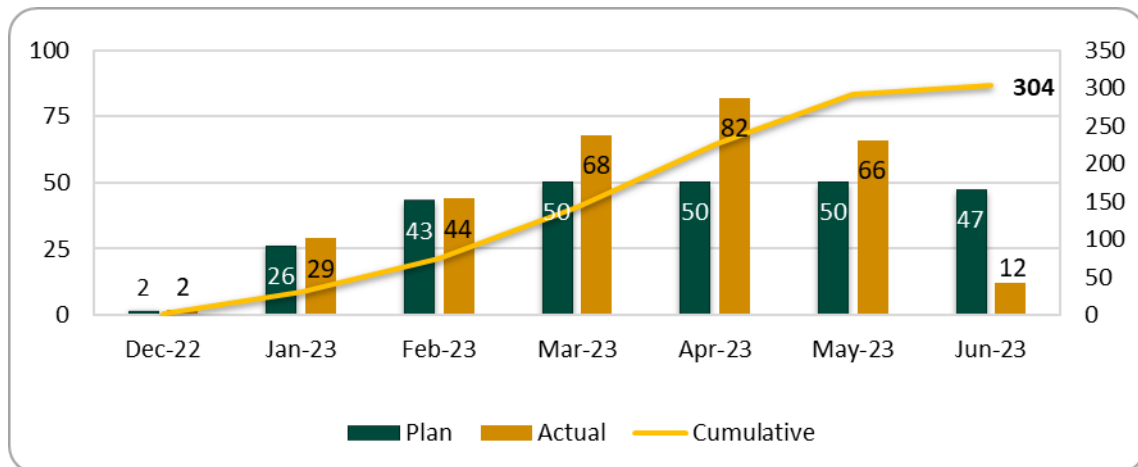


Figure 12. Pot start-up (repaired and relined).

9. Potlines Recovery Steps

9.1 Step 1: Pots in Various Locations Identified

When it comes to repairing pots, the age of the pots is a significant factor to consider. Older pots lining tends to have more deterioration over time. Therefore, a thorough assessment of the pot's condition is crucial before starting any repair work. The technical department examined and evaluated pots in different locations based on their age and performance history to determine which ones should undergo repairs or relining (Figure 13).

9.2 Step 2: Pots In-Situ Recovery Preparation

Prior to commencing the pot cleaning procedure, a formal meeting was conducted wherein all relevant departments convened to plan the day's activities, communicate the movement of cranes, define production requirements, address potential risks, and establish control measures (Figure 14). The aim of this meeting was to guarantee a secure and effective shift.



Figure 13. Pot identification.



Figure 14. Preparation meeting.

9.3 Step 3: Initial/ Manual Cleaning

A group consisting of 6 to 8 individuals initiated the process of extracting loose materials from the pot and transferring them into bags for transportation to the designated storage zone. This cleaning operation was executed by means of shovels, aimed at gathering any loose materials present. The bags were then relocated utilizing the overhead crane and carefully positioned onto wooden pallets in preparation for transport to the assigned lay down area, utilizing a forklift.

9.4 Step 4: Initial Inspection

After removal of loose material, an initial examination was performed to determine whether a superstructure should be removed or not (Figure 16). The following criteria were adhered to during this inspection:

- The quantity and size of anodes,
- The size and thickness of metal pad,
- The volume of the bath mixed with the metal,
- The feasibility of safe removal without any harm to individuals, equipment, or property.



Figure 15. Manual cleaning.



Figure 16. Initial inspection.

9.5 Step 5: Anode Superstructure Removal and Lancing Metal Pad

9.5.1 Removal of the Anode Superstructure

A specialized team was assigned to detach the anode superstructure from the ducting, electrical connections, and risers before preparing it to be removed (Figure 17). Subsequently, a street crane equipped with custom-built lifting frames was utilized for the transportation of the superstructure to a designated temporary location.

9.5.2 Detach Anodes and Metal Pad with Use of Bobcat

When required on denser metal surfaces, the bobcat, equipped with a pneumatic hammer chisel, was utilized to detach anodes from the metal (Figure 18). It also helped in the separation of the metal from the cathodes.



Figure 17. Removal of superstructure.



Figure 18. Use of bobcat to detach anode and metal.

9.5.3 Oxygen Lancing Metal Pads

The process entails using oxygen lances to divide large metal pads into smaller, easier-to-handle sections (Figure 19). This undertaking necessitates a team of at least three individuals, comprising a proficient lancer operator, a fire watch, and a standby stationed near the cylinder cage.

9.6 Step 6: Removal of Anodes and Metal from the Pot with Superstructure

A crane with a capacity of 28 tonnes was employed, along with a chain sling, to extract metal from the pot effectively, guaranteeing adherence to safety protocols (Figure 20). The metal was carefully arranged on wooden pallets, facilitating its smooth and secure transportation to the designated storage area using a forklift.



Figure 19. Lancing metal pad.



Figure 20. Removal of anodes and metal.

9.7 Step 7: Second Stage Cleaning

The process of manual cleaning persisted in eliminating any remaining loose material and carefully removing any material present on the cathode surface to adequately prepare it for technical inspection (Figure 21).

9.8 Step 8: Re-Install Anode Superstructure

The anode superstructure underwent reinstallation (Figure 22), which involved various tasks such as:

- Reconnecting the ducting,
- Reestablishing alumina feed connection,
- Reconnecting the plant air union,
- Establishing electrical connection,
- Performing raiser welding,
- Applying J hook torque,
- Inspecting the sealing jaw,
- Buffing the contact surface on the anode beam.



Figure 21. Second-stage cleaning.



Figure 22. Re-install anode superstructure.

9.9 Step 9: Technical Inspection

After thorough cleaning of both cathode surface and sidewalls, the technical department of Ma'aden proceeded to examine and accurately determine the condition of the cathodes and sidewalls (Figure 23). If the sidewall or ramming of the pot required necessary repairs, the repair team was provided with a detailed scope of work by the technical team.

9.10 Step 10: Sidewall Repair

Upon receiving instructions from the technical team, the repair crew proceeded to break the sidewall as indicated by the team (Figure 24). It is important to note that in the process of breaking the sidewall, there exists a possibility of harming the upper brickwork, which must then be fixed before the sidewall can be installed. It is worth mentioning that these repairs are extensive and require a substantial amount of time to complete. Additionally, other repairs may involve the removal of metal penetrations in the rammed fillet.

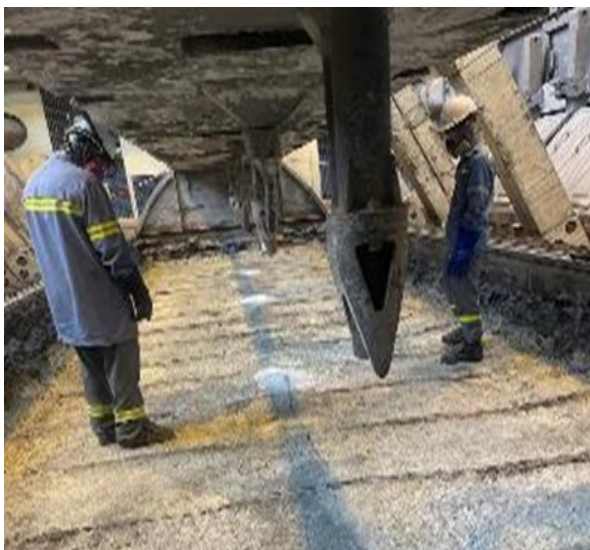


Figure 23. Cathode inspection.



Figure 24. Side wall repair.

9.11 Step 11: Shot Blasting of Cathode Surface

Cathode surface shot blasting is a crucial step that shouldn't be overlooked after pot repair. This process entails directing a high-velocity stream of abrasive particles onto the cathode surface to remove unwanted material. Once the cathode has undergone the process of shot blasting, it is essential to safeguard the cathode surface against oxidation by covering with a plastic sheet. This precaution is necessary to sustain the integrity of the cathode and ensure its readiness for subsequent pot preparations.

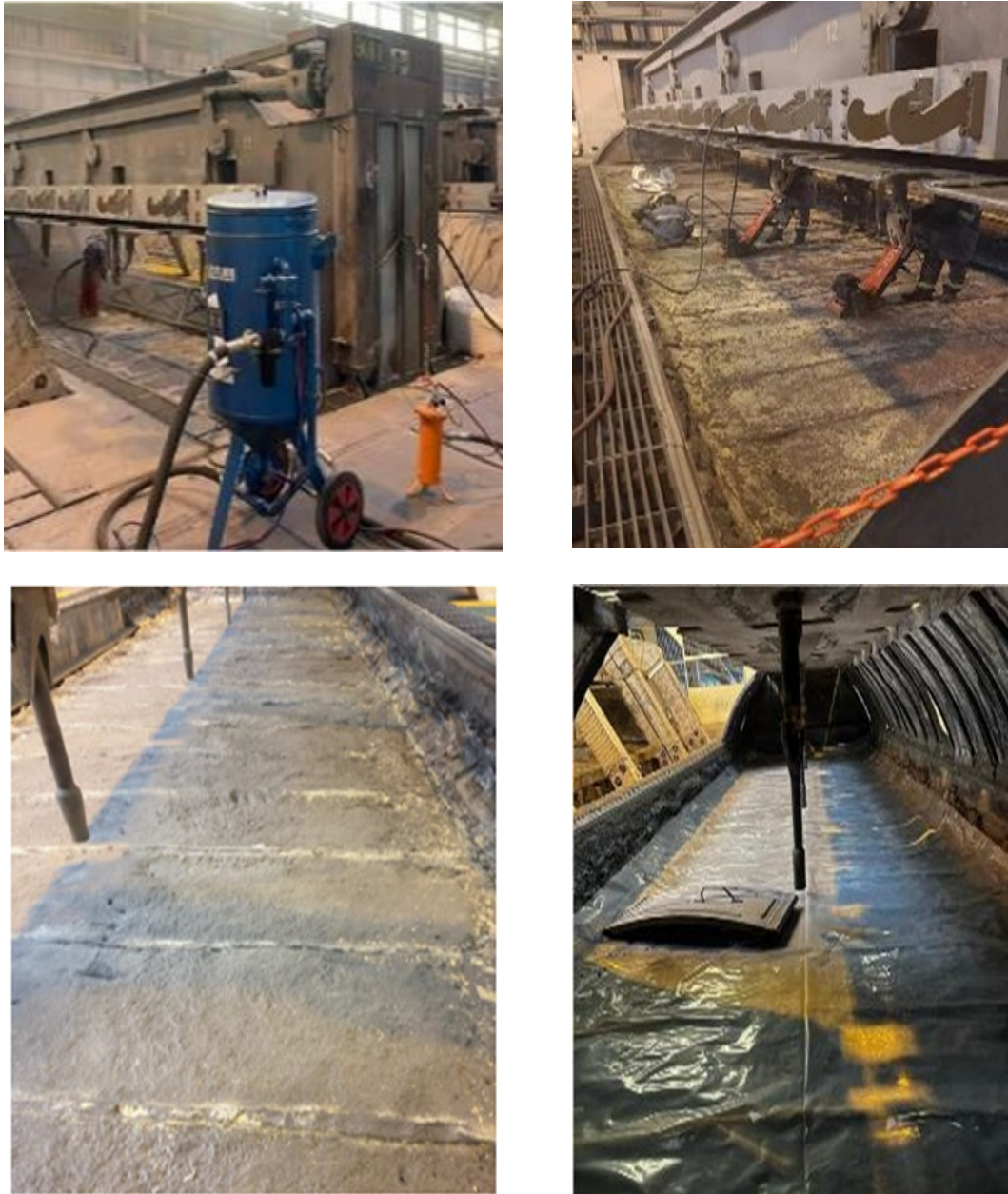


Figure 25. Shot blasting of the cathode surface.

9.12 Step 12: Sidewall/Fillet Ramming

Sidewall ramming plays a vital role in ensuring the optimal performance and longevity of aluminum reduction pots. By effectively ramming the sidewalls, the pot can maintain its structural integrity, prevent sidewall erosion and enhance pot life. Sidewall ramming commenced 24 hours prior to pot preparation. Following the completion of this concluding phase, the pot was transferred to the start-up team.



Figure 26. Sidewall and fillet ramming.

10. Lessons Learnt During Potline Recovery

- **Identify lay down areas for storage and/or repair of the following:**
 - Connectors, hoods, slabs, temporary and permanent, solid bath and metal, anodes.
- **Determine the requirements for each pot that has been stopped:**
 - Pots < 800 days age to be cleaned. In-situ cleaning is faster and requires less lining repair.
 - Pots 800–1200 days old to be cleaned. In-situ cleaning may take longer with extensive lining repair (especially side wall) is expected.
 - Pots > 1200 days are designated for full relining. This number may be increased based on lining condition.

- Pots tapped out with busbar damage. Planning of these depends on whether the potline has partially or totally failed.

The above information, displayed on a map of the potline assisted in determining the schedule for all recovery activities and for developing a drumbeat.

- **When developing the schedule and timeline consider logistical constraints in each room:**
 - Develop standards and procedures for in-situ cleaning.
 - Ma'aden Strategy: Pot cutout → In-situ cleaning → Start-up. On completion of all pots, we returned to repair those requiring busbar repair.
 - Work from end passages to central passage if cleaning is following pot cutout.
 - Preferably, pot cutout should be complete in the potroom where cleaning is in progress.
 - Congestion means delays.
- **Equipment availability:**
 - Do not assume each crane has the same ability.
 - Verify the capability of each crane, pot tending assembly (PTA), tapping metal assembly (TMA), construction crane.
 - Bobcat and mini excavators can be used in the pots for cleaning. Older models have less electronics and work better in the magnetic field.

11. Conclusions

In November 2022, a major crisis occurred in the potlines after receiving batches of underbaked anodes. These were produced due to the lack of maintenance of the burner ramp in the anode baking furnace, where the fuel injector was not supplying enough fuel for baking.

Remarkably, there was no power shutdown of the potline due to various preventative actions, taken to save the potlines, but 304 pots were cut out due to a series of anode collapses and anode fall-offs in addition to other operational challenges. During five months of continuous pot cleaning, inspections and relining, all affected pots were back into operation safely at zero lost time incident, and production targets were back to nearly normal.

During the crisis, the potline amperage was reduced from 410 kA to 370 kA and current efficiency dropped to monthly average of 79.3 % at the top of the crisis in December 2022. A large number of underbaked anodes were sent back for re-baking. Stopped pots younger than 1200 days were restarted after cathode cavity cleaning and repairs. The restoration of normal operation was successful, but the loss of metal production was significant, 3.5 % in 2022 and 12.4 % in 2023 of annual production of 805 kt.