

## Alba Reduction Line 1 Outage and Recovery

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### Abstract

Aluminium Bahrain B. S. C. (Alba) is one of the world's largest single-site aluminium smelters outside of China, operating with six reduction potlines, Alba achieved a record production of above 1.62 million metric t per annum (Mtpa) in the year 2024. Alba experienced a catastrophic power outage on 13 November 2024 that affected Reduction Line 1, Alba's oldest potline. A fire in a critical rectifier (R16) caused a full line current interruption for approximately 8 h, leading to solidification ("freezing") of electrolytic bath and metal in about 60 % of the line's reduction cells. Conventional industry wisdom suggests that potline recovery becomes extremely difficult after 4 hours without power, and that a full potline shutdown is usually inevitable beyond 8 hours of outage. Defying these odds, Alba successfully restored roughly 40 % of the pots on Line 1 even after this prolonged outage and achieved full line restart in an unprecedented 44 days – a timeframe believed to be the fastest ever for such an event. This paper details the incident and Alba's recovery strategy, including immediate response measures, pot "triage" (sorting) and cleaning innovations, and novel restart methodologies such as the "Crash-Start" process. Through disciplined planning, technical innovation, and extraordinary team effort, Alba not only minimized the production loss but also preserved pot integrity and safety. The outcome offers valuable lessons on emergency preparedness and showcases Alba's resilience and ingenuity in crisis management. Insights from this case are discussed in context of global smelter outage incidents, highlighting how extreme ownership, innovation, and strategic execution can turn a potential disaster into a success story.

**Keywords:** Aluminium Bahrain Alba, Potline recovery after power outage, Crash-start of Montecatini technology cells, Cell preheating with resistor, Crisis management.

### 1. Introduction

Aluminium Bahrain B. S. C. (Alba) is known as one of the world's largest single-site aluminium smelters, operating six reduction lines with a total production capacity exceeding 1.62 million tonnes per annum (Mtpa) as of the 2024 fiscal year. All six lines utilize Hall-Héroult prebake cell technology, operating at varying amperages depending on design. Lines 1 and 2, originally commissioned in the early 1970s with Montecatini technology, began operation at approximately 100 kA and have since been progressively upgraded to around 143–144 kA. Each of these legacy lines comprises of 114 electrolytic reduction cells (pots) connected in series. In contrast, Alba's newer Lines 4 to 6 operate at much higher amperages (ranging from 415 to over 478 kA) and feature modernized cell configurations. Despite their age, Lines 1 and 2 have proven exceptionally robust and reliable, remaining critical to Alba's production strategy.

On 13 November 2024, the resilience of Alba's operations faced an unprecedented challenge. A critical equipment failure and fire at Rectifier R16—responsible for converting and supplying direct current to Line 1—led to a complete and abrupt power outage at approximately 04:12 a.m. The entire line was de-energized, and despite swift emergency response efforts, power could not be restored for nearly 8 hours. In aluminium electrolysis, such a prolonged loss of current poses a severe risk: without continuous electrical heating, the cryolite-based electrolyte and molten aluminium in the pots begin to solidify. By the time power was partially restored, approximately 60 % of Line 1 pots had frozen, rendering them inoperable and effectively shutting down a majority of the line.

Faced with a potentially catastrophic scenario, Alba's leadership was at a crossroads. Conventional industry guidance suggests that after 6–8 hours of total outage, a full shutdown and potline rebuild is inevitable. However, driven by an unwavering commitment to operational continuity and supported by deep technical expertise, Alba embarked on an aggressive recovery effort. Rather than abandoning the line, the company pursued an ambitious plan to restart all pots in a shortest period. Within just 44 days, a timeline considered extraordinary by global standards, Line 1 was fully restored to normal operations. This paper presents a comprehensive overview of the incident and the strategic measures that enabled this successful recovery.

## 2. Impact of Power Outage in Aluminium Smelting

Unplanned power outages are among the most perilous events for aluminium smelters. The Hall-Héroult reduction process depends on a continuous supply of high-amperage current to maintain molten aluminium and cryolite-based electrolyte at around 960 °C. When power is interrupted, pots begin cooling rapidly. As the temperature drops, the risk of solidification increases potentially freezing the cell and leading to permanent damage. Industry experience suggests that outages shorter than 2 hours are usually manageable, with sufficient residual heat to restart normal operations. However, beyond 4–6 h, the likelihood of cell freeze rises sharply.

The vulnerability of a smelter during a power outage depends significantly on its cell technology and design. Most modern electrolytic cells are engineered for thermal efficiency with thinner linings and enhanced heat transfer, but this means they also lose heat faster and are at greater risk during prolonged power cuts.

Against this backdrop, Alba's Line 1 outage was particularly critical. The power loss lasted approximately 8 hours at the upper threshold of cell survivability. The successful recovery of dozens of cells under these extreme conditions is a rare and remarkable achievement in the aluminium industry.

## 3. The Incident

On the 13th of November 2024 at 04:12 a.m., Line-1 which is almost 55-year-old, experienced a complete power trip due to the failure of rectifier R16 which is responsible of feeding Line-1 and therefore the current has dropped from 144 to 0 kA. This marked the beginning of a prolonged power outage that lasted nearly 8 h, during which the line remained inactive.

Current restoration efforts began at 12:12 p.m., with an initial ramp-up to 50 kA. The line current was then gradually increased in a controlled, stepwise manner to avoid thermal shock and to protect the integrity of the pots. By 1:29 p.m., the current reached approximately 70 kA, followed by progressive increments throughout the afternoon. At 2:30 p.m., it reached 90 kA, and by 3:10 p.m., 100 kA. Continued ramp-up brought the current to 120 kA by 3:40PM and 130 kA by 4:15 p.m.. Full restoration to 140 kA was achieved by 4:41 p.m., successfully completing the recovery process of the line electrical current within 12.5 hours of the initial trip (Figure 1).

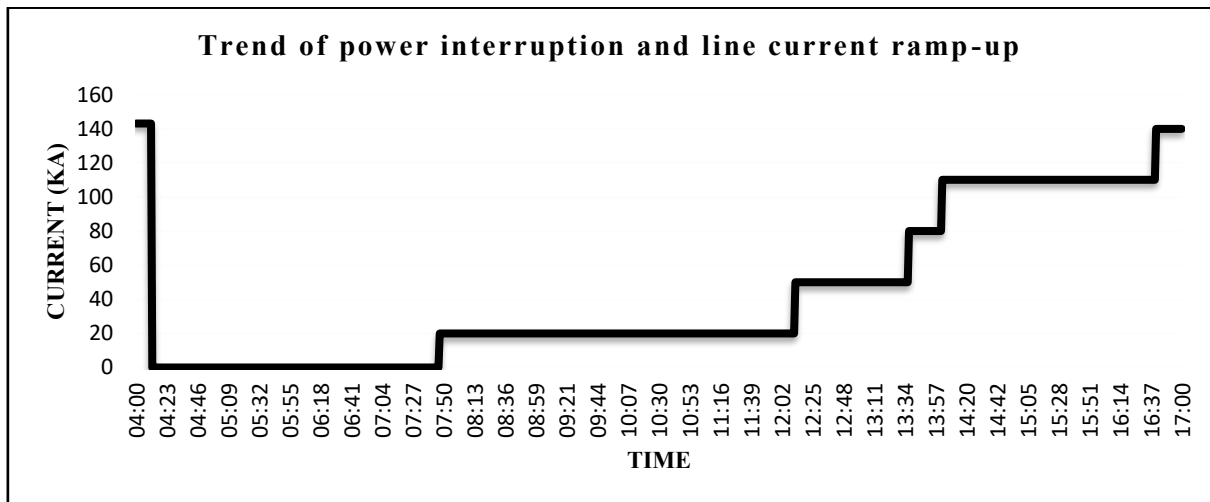


Figure 1. Trend of power interruption and line current ramp-up.

Figure 1. Line current profile for alba line 1 on 13 November 2024, showing the sudden outage (zero current) and the subsequent controlled ramp-up of current once power was restored. the potline remained without power for ~8 hours (04:12–12:12), after which current was gradually increased from 50 to ~134 kA over a 4-h span.

Field inspections confirmed that around 60 % of the pots in Line 1 as shown Figure 2 mapping of potline 1 had frozen due to the prolonged 8-h outage and allowed the remaining 40 % of pots to continue operational.



Figure 2. Mapping of pot line 1 (green are live and red stopped pots).

#### 4. Post-Restoration: Assessing and Organizing Recovery

After restoration of current on 13 November, Alba launched a large-scale recovery operation to address the extensive pot freeze on Line 1. With nearly 60 % of pots solidified, a structured, multi-disciplinary response was initiated.

##### 4.1 Pot Assessment and Classification

Each pot was quickly evaluated for the extent of freeze, structural damage, and restart potential. Based on age, shell condition, and freeze severity, pots were categorized for restart, partial repair, or full relining. This triage guided the allocation of resources and priorities.

##### 4.2 Rapid Resource Deployment

- **Manpower:** Crisis teams were formed, working round-the-clock. Staff from other lines were redeployed to support Line 1 recovery, ensuring cross-functional coordination.
- **Equipment:** Mechanized tools (e. g., JCBs vehicles with custom attachments) were used to accelerate bath and metal removal. Gas burner systems were installed for pot preheating, supported by temporary gas manifolds.
- **Materials:** Critical supplies were secured, including spare anodes, crushed bath, alumina, and soda ash.
- **Logistics:** Dedicated fleets of trailers and containers were used to remove solidified debris. The carbon plant handled thousands of recovered anode butts for recycling or disposal.

##### 4.3 Central Coordination

A dedicated command centre was established to oversee progress, supported by daily milestones and executive oversight. Real-time updates and structured planning ensured clear communication across all teams.

##### 4.4 Key Challenges and Response

- **Scale:** Restarting ~80–90 pots in parallel was unprecedented at Alba. Efficient crew and equipment deployment were critical.
- **Technical Uncertainty:** Each frozen pot presented unique risks. Smart triage and flexible tactics such as early use of the Crash-Start method were crucial.
- **Safety Under Pressure:** Despite tight timelines, strict safety protocols were followed. No major incidents were reported, reflecting disciplined execution.
- **Human Factors:** High physical and mental demands were managed through shift rotation, rest areas, and strong leadership presence. A culture of “extreme ownership” helped sustain motivation and accountability.

#### 5. Strategy to Recover Line 1

Immediately following the power outage, a management team was created under the leadership of the CEO. It was developed to handle the recovery programme and to provide all the required resources. Preparations for the pot restart and pot relining were determined based on the age of the pot. To ensure a faster recovery process, pots were classified into three categories in which pots < 1000 days were to be patched up and started by crash start method. Pots between 1000–1500 days went for dry scaling of bath and metal removal and only affected areas of the pot were repaired. Moreover, all pots over 1500 days were immediately decided to go for reline (Table 1).

To avoid delay and overlapping of activities, the potline was divided into zones to maintain high safety standards, the activities were scheduled in such a way that pots cleaning followed by pot preparation and then followed by start-up, and finally normalization activity. The pot room was divided in such a way that if cleaning was scheduled on one side of the pot line, the pot preparation or start-up activities were scheduled on the opposite side to mitigate safety concerns and ensure efficient operation. A daily meeting was held with all parties concerned conducting different activities to ensure achieving the required at the end of each day. The meeting also discussed any safety concerns that were observed during the past 24 hours by safety coordinator and action was taken immediately to reduce any associated risks.

The pots were classified into three categories showed in Table 1.

**Table 1. Classification of the affected pots.**

Priority	Category	Age criteria	No. of pots cut out	Action required
High	Restart	< 1000 Days	87 Pots	Anode and butt removal Bath scaling Metal Crash-Restart
Medium	Partial Lining	1000–1500 Days	20 Pots	Anode and butt removal Bath scaling Metal removal Side wall removal (condition based) Few cathodes removal (condition based) Partial lining & repair Resister bed Startup (24 h)
Low	Reline	> 1500 Days	44 Pots	Normal relining Process Resister bed Start-up (48 h)
		Total	151 Pots	

## 6. Cathode Cleaning and Preparation

Based on the established criteria, all affected pots were classified into three priority categories High, Medium, and Low, according to their age and required level of intervention. This categorization guided the pot cleaning and recovery strategy.

High-priority pots, with less than 1000 days of operation, were deemed fit for immediate restart and underwent rapid anode and butt removal, bath scaling, and metal crash-restart procedures.

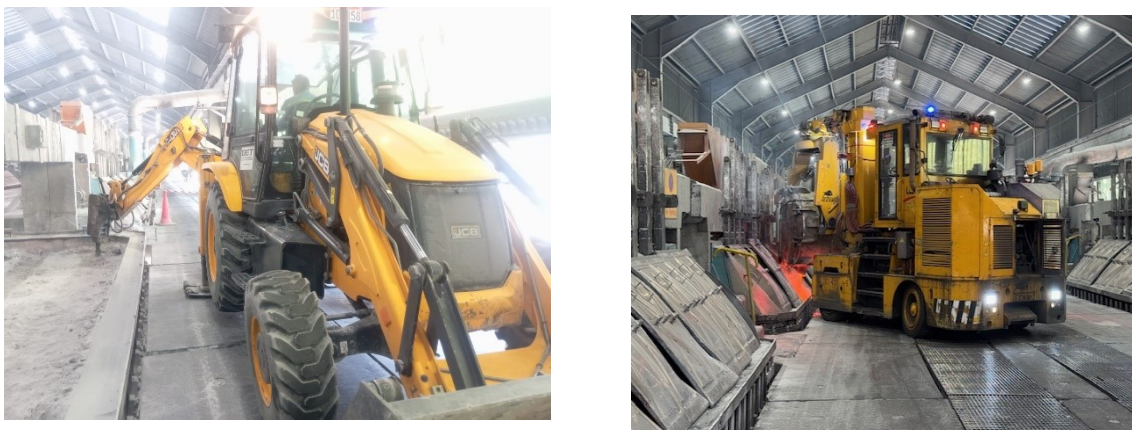
Medium-priority pots, aged between 1000–1500 days, required partial lining. These pots underwent more extensive interventions, including sidewall and selective cathode removal, metal and bath extraction, followed by lining repairs and 24-h resistor bed startup.

Low-priority pots, aged over 1500 days, were identified for full relining. These pots followed the standard relining protocol and required a 48-h resistor bed startup.

This structured approach ensured a prioritized and efficient recovery process, aligning resources and actions with pot condition and restart feasibility.

## 7. Special Equipment

As a part of the quick recovery plan special equipment had to be used for removing solid bath and the immersed anodes. JCB (Figure 3) was introduced in order to ensure a faster recovery process. Moreover, specialized contractors were deployed for cathode cleaning and relining on working simultaneously in separate areas to speed up the recovery process.



**Figure 3. Special equipment, JCB & BTV, were used to assist and contribute towards a faster recovery for dry scaling, removing anode butts.**

Anode and Butt Removal Systems: Each pot had multiple large carbon anodes (likely 18–20 per pot in Line 1 design). Once the bath and metal froze, these anodes were stuck in place, attached to what became solid aluminium “butts” at their bottoms. Removing these heavy carbon blocks is necessary to access the frozen metal underneath and to install new anodes for restart. Alba organized a systematic removal of all anodes from the cut-out pots. Utilizing crane systems and JCB for extracting the stuck carbon, they achieved a removal rate of about 9 pots’ worth of anodes per day at peak. Over the whole campaign, hundreds of anodes (on the order of 1500–2000 pieces) were extracted. The coordination with the carbon department to handle cleaning of old anodes to decide if it can be recycled or disposed was itself a challenge. Logistics came into place where dedicated crews were deployed to ensure that anode removal does not bottleneck the pot cleaning process.

Overall, these innovations and optimizations in the “prepare pot for restart” stage had a dramatic impact. They enabled Alba to reduce the turnaround time per pot significantly. Internal estimates showed the plan of ~1.3 pots per day could be exceeded with these measures, and indeed Alba finished the recovery in 44 days whereas an initial projection was around 69 days for the number of pots involved, implying a higher actual rate of restart. The specialized cleaning techniques, coupled with the new Crash Start process, were key contributors to this acceleration.

## 8. Overview of the Restart Activity

Based on the initial classification, pots were categorized into three priority levels, High, Medium, and Low, according to their operational age and required level of intervention. This framework helped streamline the cathode cleaning and recovery efforts. However, as the recovery progressed, a reevaluation was conducted to further accelerate the process. Upon reassessment of pot conditions, it was observed that some cells initially classified under relining could still be restarted through partial repair. Consequently, the relining threshold was revised from > 1400 days to > 1600 days, allowing a greater number of pots to be recovered under the restart or partial lining categories. This strategic adjustment enabled faster turnaround, optimized resource utilization, and significantly improved the overall recovery timeline without compromising operational

integrity. Furthermore, metal level was assessed on all pots that were to go for restart and based on the metal level height, the pot was decided to either go for crash start or if the metal height is high to an extent that the anodes cannot be placed efficiently then the metal was removed and the pot would go for 24-h resistor preheat.

Alba demonstrated remarkable operational innovation and resilience during the Line 1 recovery by employing two preheating strategies: gas burner preheating (including the proprietary “Crash Start” technique) and resistor-based electrical preheating, selecting the method based on each pot’s condition.

### **8.1 Gas Burner Preheating with “Crash-Start”**

To enhance and contribute towards a speedy recovery, crash start method was reintroduced. This method comes with inherited challenges and risks. However, the team was able to overcome these challenges efficiently by developing risk assessment along with an SOP to ensure safety while maintaining the pace.

Prior to bath-up, the pot lining is gradually preheated over approximately 48 hours to a temperature of  $910 \pm 30$  °C using gas baking. Due to the risk of bath freezing immediately after bath pouring, it is critical to maintain the pot voltage between 7–10 V (10–12 V if the bath temperature drops below 970 °C within 2–4 h) to keep the bath in a molten state and elevate its temperature to around 985 °C. Insufficient preheating, inadequate bath quantity, or improper distribution can cause the pot voltage to spike to 25–30 V, often indicated by bright cathode or anode effects. Therefore, achieving consistent and thorough pot lining preheating, along with the addition of approximately 6 t of bath (equivalent to 2 crucibles), is essential for stable bath-up and start-up conditions. Following bath pouring, the pot voltage typically reduces automatically within 3 hours as the pot continues to heat and the frozen bath begins to melt. After covering the anodes and crust area with pure crushed bath, and then a 50:50 mixture of crushed bath and alumina, the pot voltage should be maintained at  $\geq 6.5$  V, ensuring that the bath temperature does not exceed 995 °C. Over the next two operational shifts, voltage should be gradually reduced to the range of 5.5–6.0 V, while maintaining the bath temperature within the optimal range of  $985 \pm 10$  °C. Careful voltage adjustment during this period is crucial to stabilize bath temperature within the 970–985 °C target range and to minimize thermal shock to the lining, as per pot normalization procedures. This method enhanced the recovery during this critical situation which has led to an increase in the number of pots back into operation per day.

### **8.2 Resistor-Based Electrical Preheating**

The resistor preheating method is a standardized process used to thermally condition the cathode lining of a reduction cell before startup, ensuring uniform heat-up and minimizing thermal shock. The system uses silicon carbide resistors mounted across steel structures positioned inside the pot, connected to a transformer supplying a controlled current. Temporary refractory materials such as insulation blankets and backfill are applied to retain heat and ensure gradual temperature rise. Thermocouples installed at multiple locations monitor temperature at the cathode surface, sidewalls, and under the cast iron layer, allowing close tracking of the heating profile. The process spans approximately 120–144 h, gradually raising the cathode temperature to the target range of 950–1000 °C. This method improves lining integrity, enhances pot life, and reduces startup failures. Compared to traditional gas burner methods, resistor preheating offers improved energy efficiency, better process control, and eliminates combustion-related emissions, making it a safer and more environmentally sound approach but to enhance the recovery process, the crash start method was used.

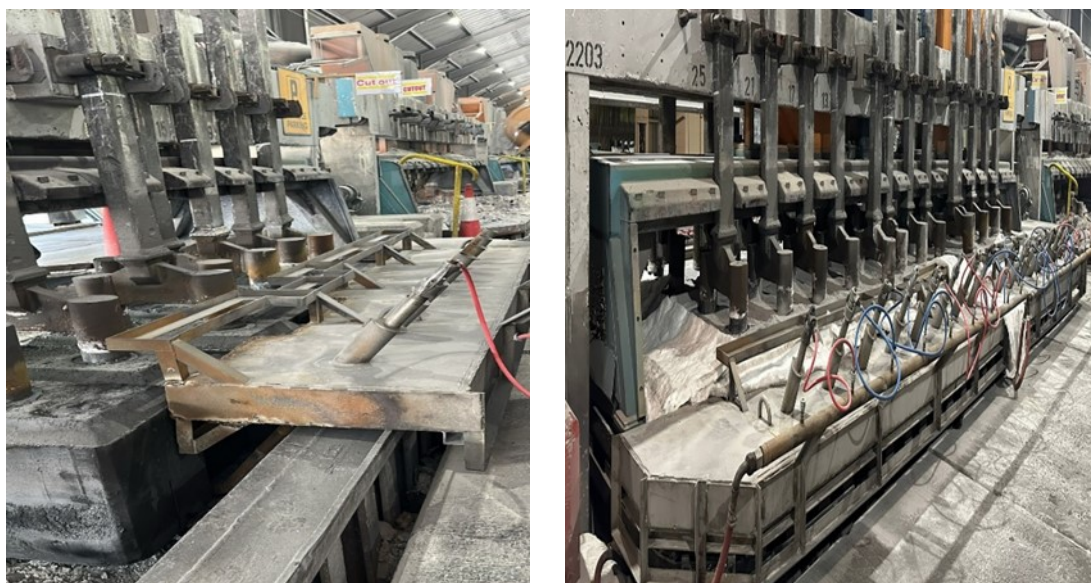


Figure 4. Introduction of gas burner for crash start method.

## 9. Recovery Performance

Initially, the target was to recover the full potline recovery within 120 days. However, following a strategic re-evaluation, the target was revised to 100 days. Through the implementation of enhanced start-up methodologies and process optimizations, the recovery period was further reduced to 69 days, and ultimately to 44 days – achieving full restoration of 100 % of the pots back into operation as shown in Figure 5. This remarkable performance established a new benchmark, with an average start-up rate of 3.43 pots per day, peaking at 6 pots back into operation in a single day. To ensure the stability of the restarted pots, a dedicated normalisation team was formed to focus on managing voltage stability and bath chemistry control during the critical post-start-up phase.

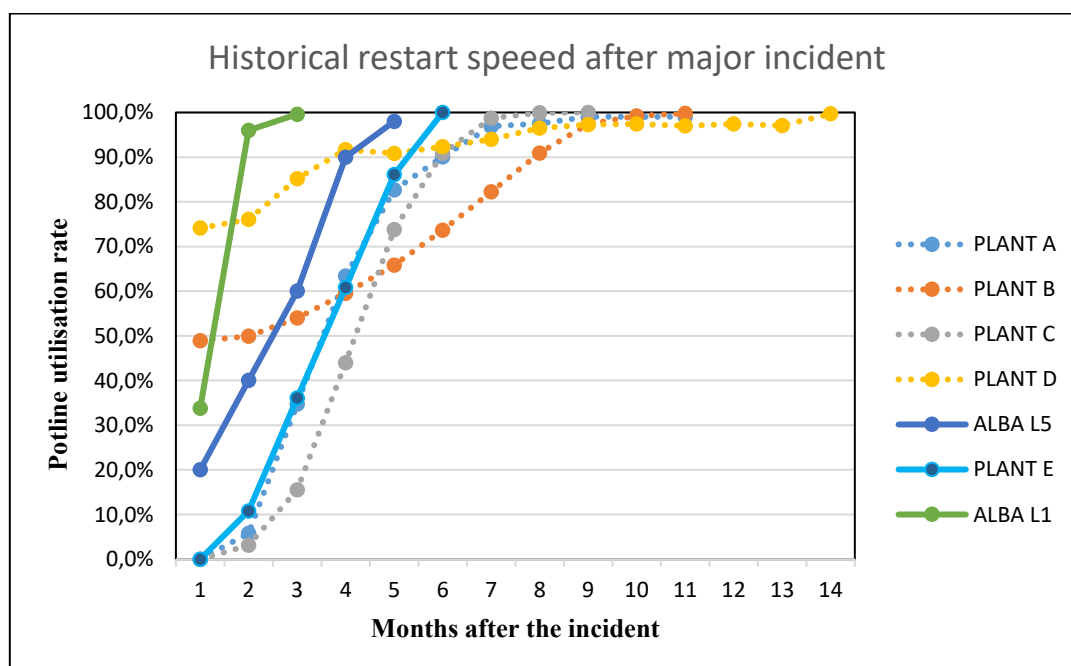


Figure 5. Pace of recovery speed in comparison to other smelters [1].

### 10. Normalization Period Challenges and KPI Performance

Following the recovery process, potline performance remained unstable during the initial phases, with several challenges impacting operation consistency. Variations in bath levels, increased anode effects and other instabilities were observed across multiple pots. These transitional disturbances were expected given the extent of the outage and the complexity of restarting frozen or partially solidified pots.

Some early failures were incurred especially coming from the crash-start method. Out of the 87 pots that were restarted under this method, 7 pots failed again after restart which is equivalent to 8 %. The exact cause of failure could not be fully determined as the cathode condition is not visible during the crash-start process. However, it is likely that some pots had pre-existing internal damage or thermal stress which could only be known during the operation of the pot. Moreover, the crash start method reinforces the overall effectiveness with a 92 % succession rate.

Voltage: Net voltage initially increased due to pot start-up, bath production pots and during normalization period, then gradually stabilized as pots normalized (Figure 6.)

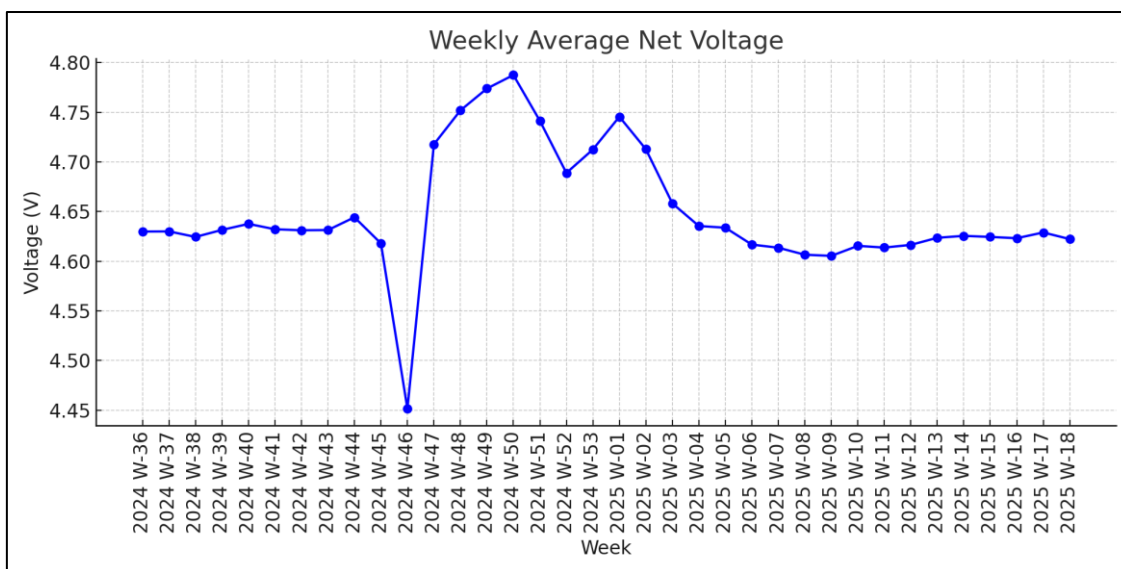


Figure 6. Weekly average net voltage.

Instability: Pot instability rose sharply during the crisis and progressively decreased as pots were restarted and normalized (Figure 7).

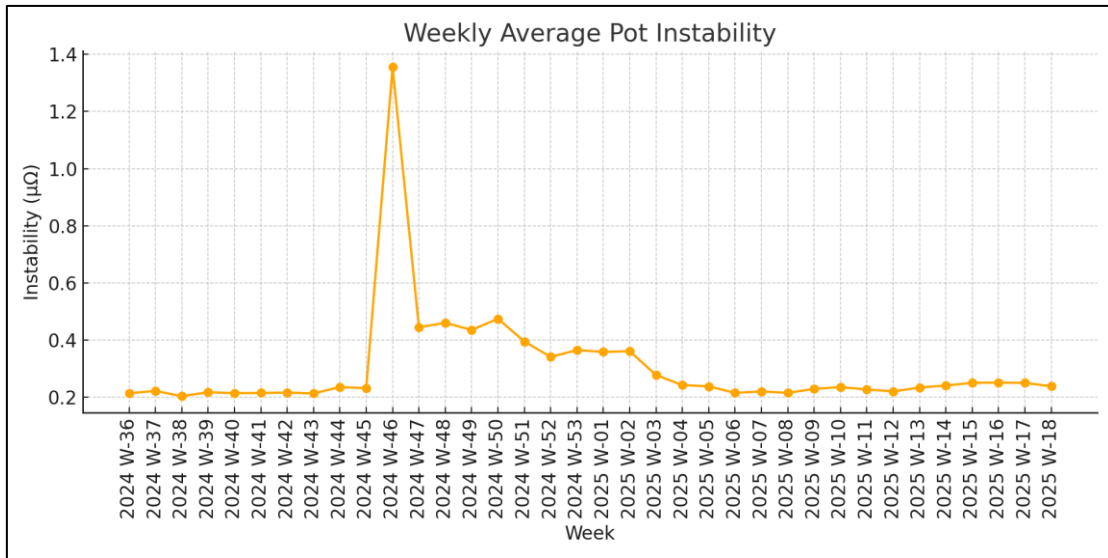


Figure 7. Weekly average pot instability.

Current efficiency: Dropped during the outage, then improved steadily during the recovery phase with stabilized operations (Figure 8).

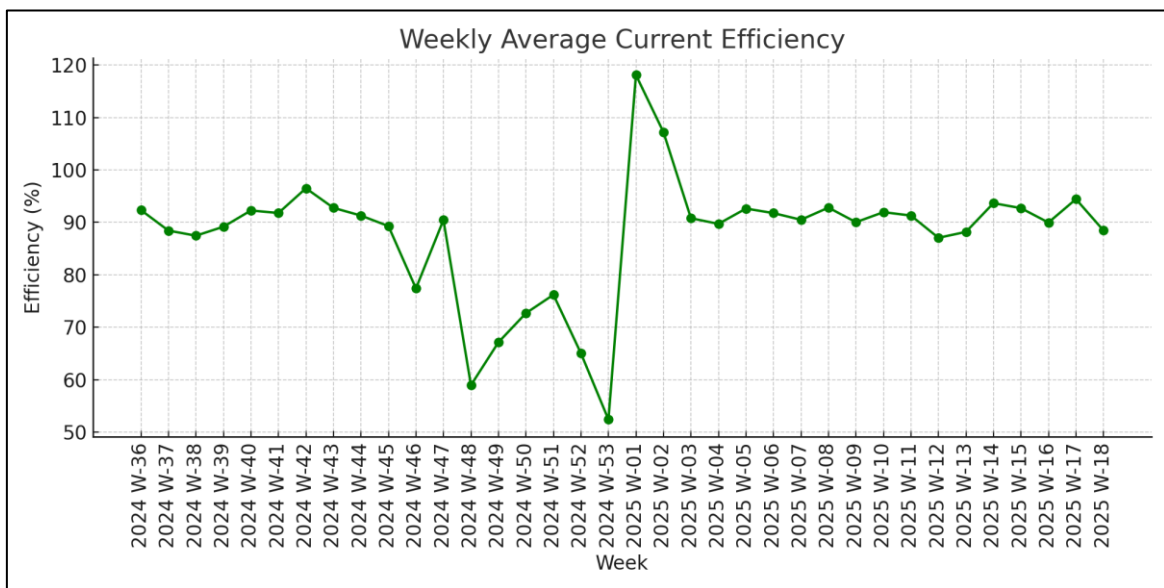


Figure 8. Weekly average current efficiency during outage.

Bath Temperature: Fluctuated during the crisis but returned to target range during recovery operations (Figure 9).

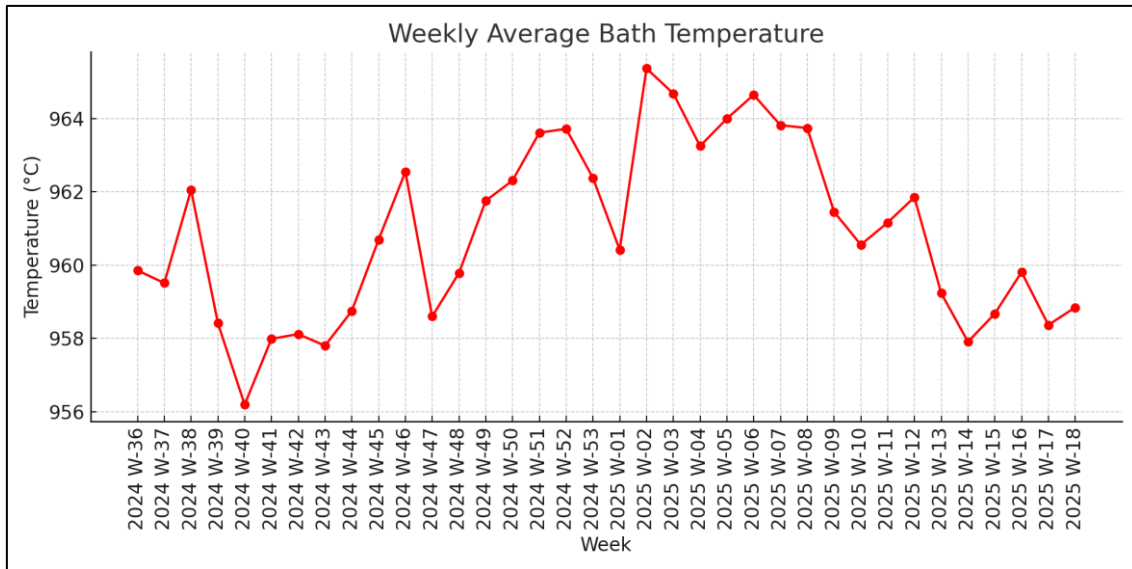


Figure 9. Weekly average bath temperature.

Anode effects: Increased sharply during unstable periods, then declined as line current and alumina feeding stabilized (Figure 10).

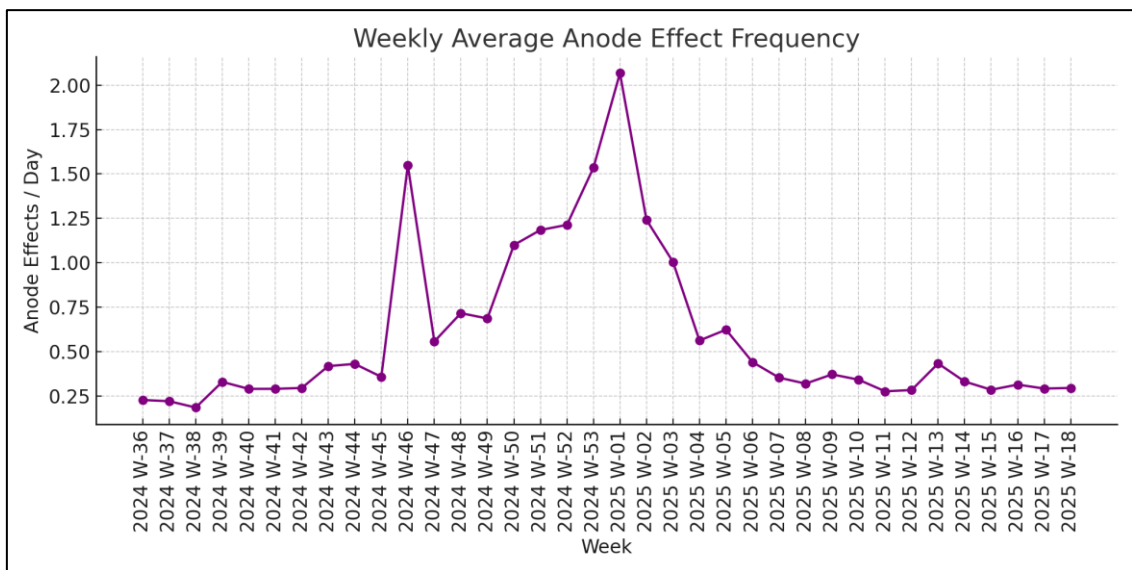


Figure 10. Weekly average anode effect.

Iron content: Showed temporary fluctuations due to bath level disturbance and anodic incidents, then normalized after stable operation resumed (Figure 11).

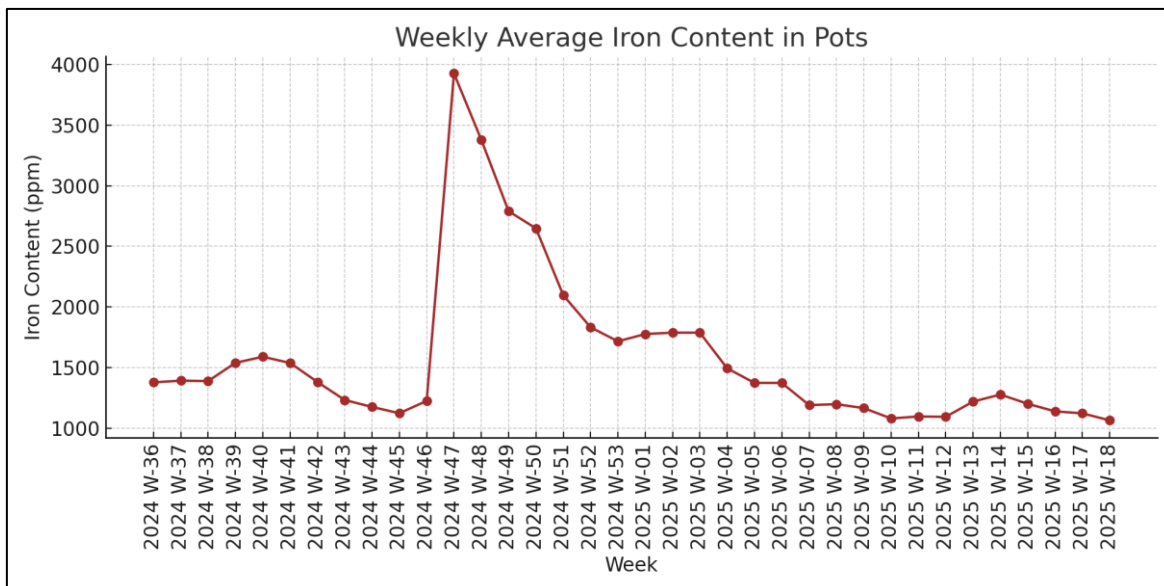


Figure 11. Weekly average iron content in pots.

Silicon: showed an increase due to pot restart and back to normal after the recovery, showing no major contamination during the recovery process (Figure 12).

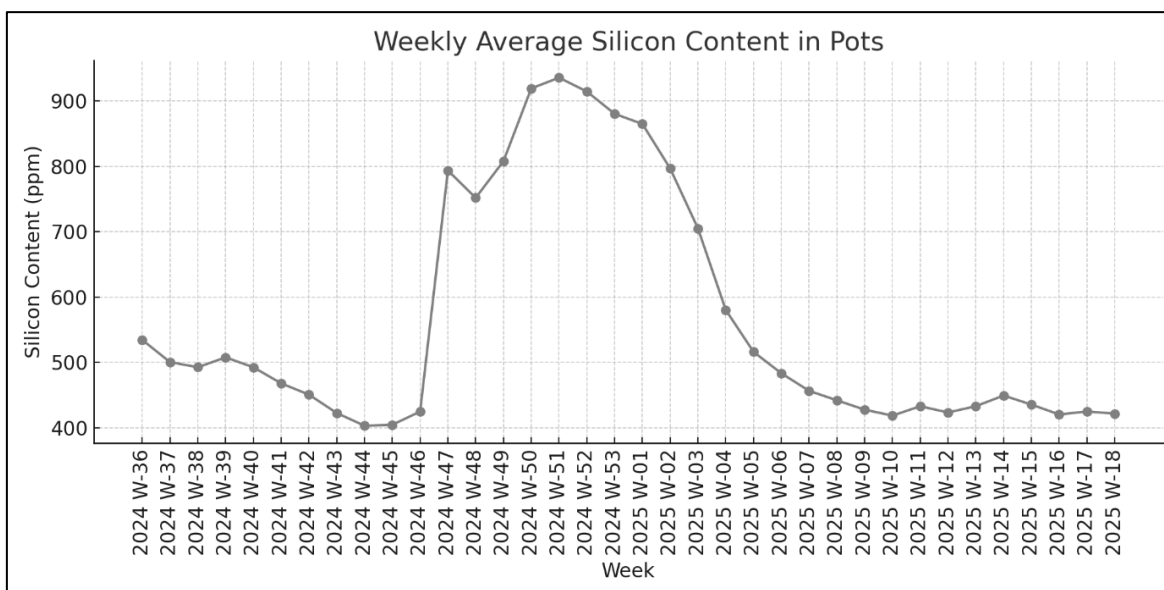


Figure 12. Weekly average silicon content in pots.

## 11. Lessons Learned and Future Recommendations

- Update Emergency Response Limits

Alba successfully restarted 40 % of Line 1 pots after an 8-h full power outage, beyond the typical industry cutoff of 4–6 hours. This challenges conventional shutdown thresholds. A recommendation is to redefine outage response criteria for each line by simulating outages of varying durations (4–8 h) to establish recovery feasibility based on cell design and thermal characteristics.

- Establish “Crash-Start” as a Contingency Plan for Other Lines

The innovative “Crash-Start” technique, where frozen metal is left in place and melted using gas burners, proved instrumental in reducing recovery time to 44 days. This procedure will be adapted for Lines 4–6 using diesel burners due to the absence of direct gas supply.

- Critical Spares Management

The incident exposed shortages in essential tools, such as pot cutout knives. A comprehensive review of critical spares across all lines will be conducted to ensure readiness during emergencies.

- Enhance Cross-Training and Workforce Flexibility

Operational staff from other lines were unfamiliar with Line 1 systems during the recovery. Cross-training programs will be strengthened to improve adaptability and preparedness during crisis situations.

- Formalize Use of Data Command Centre in Emergencies

Although the Line 1 control room was used during this event, a formal SOP for deploying the Data Command Centre during major incidents will be developed, along with mock drills for familiarization.

- Strengthening Crisis Management Protocols

A more robust crisis management framework will be initiated, including clear communication protocols, data-driven risk detection, and coordinated stakeholder engagement during emergencies.

## 12. Conclusions

In conclusion, the recovery timeline was significantly compressed from an initial target of 120 days to just 44 days, reflecting a major achievement in strategic execution and process innovation as shown in Figure 5. This success was driven by the adoption of advanced techniques, Crash-Start method, the introduction of new machineries, and the optimization of gas preheating practices. This event has reaffirmed Alba’s reputation as an industry leader in operational resilience, rapid recovery, and technical excellence

## 13. References

1. Abdulla Habib Ahmed Ali, Khalil Ebrahim M. Ebrahim and Vasantha Kumar, Speed, agility and simplicity (SAS) recovery of reduction Line-5 in Alba, *Light Metals* 2018, 491–499. [https://doi.org/10.1007/978-3-319-72284-9\\_65](https://doi.org/10.1007/978-3-319-72284-9_65) .

