

The Roadmap of AP-ALBA to 400 kA

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Abstract

Aluminium Bahrain (ALBA), the world's largest single-site aluminum smelter outside China with aluminium production of more than 1.548 Mtpa (2020 production) is known for its technological strength and innovative strategies. Reduction Line 5 in ALBA was built in 2005 using AP30 technology at 330 kA with a capacity of 308 ktpa being the longest reduction line at that time with 336 AP30 pots. Line 5 was started in a world record time of 77 days. The operating performance of Line 5 has been one of the best among all AP30 potlines. With a commitment to improve further, many actions and strategies were put in place, taking advantage of the technology robustness and in-house innovations. Presently, Line 5 is operating at 400 kA which is 20 % higher than the original capacity. As per technology supplier and peer potlines, installation of Forced Convection Network (FCN) is crucial for Line 5 design to operate at 400 kA safely. ALBA has taken the challenge and the risk to increase to 400 kA and defer the large CAPEX of FCN installation to a later stage. Special focus was given to optimizing process parameters, improving practices, upgrading of lining design, increasing anode size and training/developing the technical competency of the teams. This paper details the experience of amperage increase journey without large investment on FCN and the performance of ALBA Line 5.

Keywords: ALBA AP30 Potline 5, Amperage increase, Anode-cathode distance (ACD), Forced cooling network.

1. Introduction:

Aluminium Bahrain (ALBA) started its metal production with commissioning of two reduction lines 1&2 in 1971-1972 with capacity of 120 kt/y. ALBA has been progressively expanding until it reached production of 500 kt/y in 1993. Reduction Line 5 was started using AP30 technology in 2005, being the longest reduction line at that time with a total of 336 pots. In 2018 Reduction Line 6 was built using DX+ Ultra technology with a total of 424 pots at line amperage of 460 kA and is now operating at 476 kA. Upon completion of Potline 6, ALBA has become the world's largest single-site aluminum smelter outside China with aluminium production of more than 1.5 Mtpa.

Reduction Line 5 pots started up in a strategic way in the shortest duration of reduction line start-ups ever. It took only 77 days to bath up all the 336 AP30 pots. On 5 April 2017, Reduction Line 5 suffered from long power outage which led to shutdown of 274 pots out of the 336 pots operating. Speed, Agility and Simplicity (SAS) concept made the recovery of reduction Line-5 at ALBA a benchmark in the aluminium industry. Line 5 was recovered in less than four months with start-up speed of 3.20 pots/day in a safest and fastest manner in the world. After recovery

from the long power outage the amperage increase journey resumed and now Line 5 is operating at 400 kA with outstanding operating performance as compared to other AP30 smelters.

2. Historical Performance

2.1 Current Increase Milestones

Since the start-up in 2005 current increase projects have always been part of the operation of Line 5. Line current in start-up design was at 330 kA and in the first year a current increase of 7 kA was achieved in 2006. Followed by ongoing current increase projects at a rate of 4 kA per year, Line 5 is currently operating at 400 kA with a total current increase of 70 kA above the design current. The fastest increase rate per year was achieved in 2018 (15 kA) from 378 kA to 393 kA (Figure 2) with the implementation of copper insert lining design. The current creep journey has achieved total growth in production of 60 ktpa, approximately 20 % above the start-up design capacity as it is shown in Figure 1.

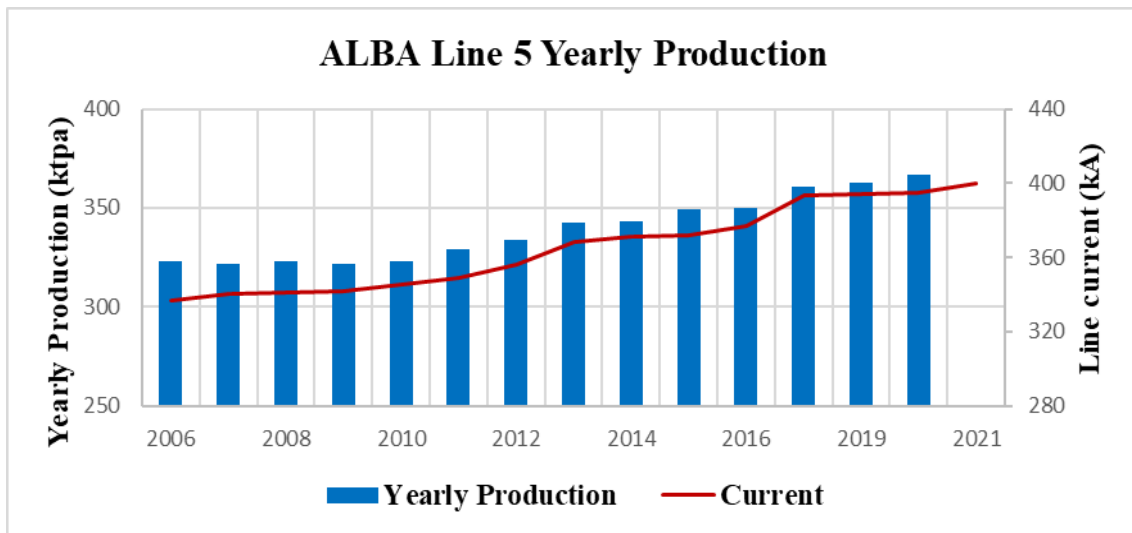


Figure 1. Line 5 current increase with annual production until the end of 2020.

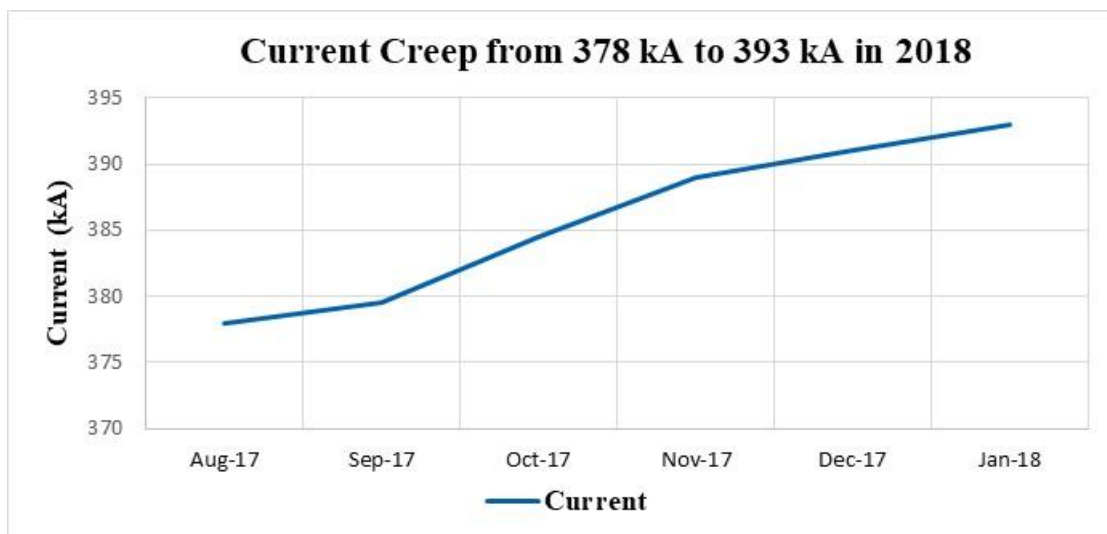


Figure 2. Line 5 highest current increase rate in 2018.

2.2 Current Increase Strategy

ALBA used different current increase strategies along the years. With the adoption of new lining designs, parameter optimizations, process modeling, and cell elements modifications, ALBA had successfully achieved the target of 400 kA and beyond.

In general, the following strategies are being used in any potline for amperage increase [1]:

1. Constant anode-cathode distance (ACD); this implies higher cell voltage and higher heat generation.
2. Constant voltage; this implies lower ACD and higher heat generation.
3. Constant internal heat; this implies lower voltage and lower ACD.

ALBA has been mixing between the above three strategies through the years depending on the pot condition. The approach adopted was based on the ability to squeeze ACD, while maintaining thermal balance and the ability to dissipate the additional internal heat and the scope to modify anode dimensions. Table 1 lists the current increase projects that involved major modifications.

Table 1. Current creep projects that included major modifications.

Year	Line Current (kA)	Major Modifications
2005	330	Line Start-up
2011	349	Increase Anode length by 10 mm & anode height by 5 mm
2012	356	Increase Anode length by 60 mm
2013	368	Increase anode length by 15 mm
2014	370	New lining design with copper insert
2016	377	Increase anode length by 30 mm & anode height by 10 mm
2017	378	Increase anode height by 10 mm
2018	393	Full implementation of copper insert lining design
2021	400	End of July 2021

3. Major Modifications

The following major modifications and improvements in cell design and other auxiliary units were undertaken for amperage increase. The design changes were all based on in-house technical studies and state of the art innovation implementation.

3.1 Pot Lining Modification

The major drive for current creep in ALBA Line 5 was the adoption of new lining design. Line 5 started with AP30 design pots with steel collector bar in 2005 and in 2014 the first trial for developed lining design was commissioned to allow for current increase. The new lining design was featured with a bigger graphitized cathode and a copper insert collector bar allowing for higher pot age at higher current with lower voltage drop. Furthermore, the new lining design was optimized to maintain good heat balance and dissipate additional heat.

3.2 Anode Size Modification

Due to increase in current and production, and to maintain constant anode current density, anode size modifications were necessary at a certain point and the main manipulated variable was anode length. The initial anode length was 1515 mm at start-up and it has been increased gradually with different current increase projects. In 2011 anode length was slightly increased by 10 mm

followed by a major increase in 2012 equal to 60 mm and then in 2013 another 10 mm were added to the anode length. The last anode length modification was in 2016 and since then the anode length is 1630 mm as shown in Figure 3. Correspondingly, the anode length modification transformed the anode to asymmetric shape to allow for spacing in central channel.

Anode height was also increased to maintain target butt thickness under stub at 65 mm. The initial anode height was 645 mm in 2005 and currently it is 670 mm as shown in Figure 3. In addition, when anode length increased, the bath volume was reduced. In order to address this challenge, the anode slot height was increased. The increase in slot height reduced the bubble voltage drop and anode noise. Moreover, the stub hole depth was increased from 130 mm to 140 mm to reduce anode voltage drop and to increase contact strength for the bigger anode.

Accordingly, anode cycle was changed from 80 to 76 8-hour shifts to maintain target butt thickness under stub.

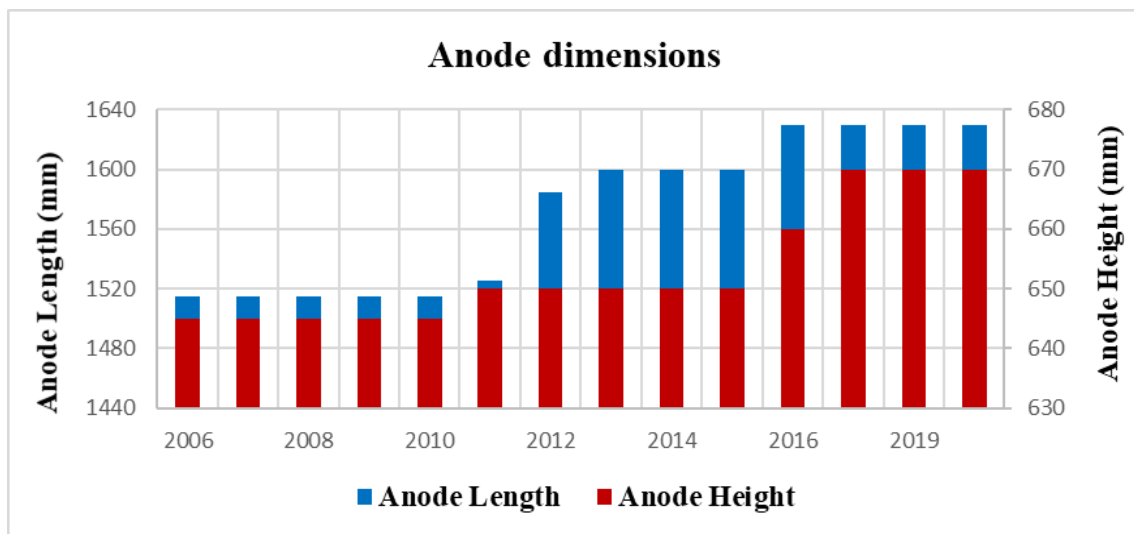


Figure 3. Anode size modifications since start-up of Line 5.

3.3 Liquid Levels

With the implementation of new lining design, metal level targets were increased gradually from 2017 until now. Metal level optimization was necessary for the purpose of heat balance and for maintaining pot stability. The pot shell cavity was taken into account at each metal level modification in Line 5. Since 2017, metal level targets have been increased by 33 %. Metal level target has been increased gradually from 18 cm in 2017 to 19.5 cm in 2018 to 22 cm in 2019 to 22.5 cm in 2020 and 24 cm in 2021 as shown in Figure 4. The bath level target was maintained at 16 cm in order to maintain high purity of aluminium.

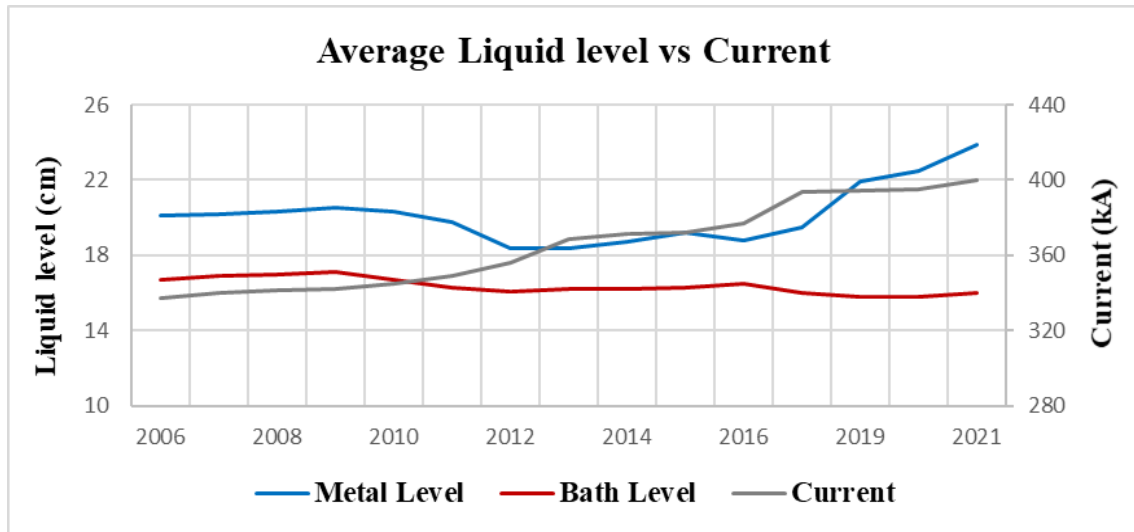


Figure 4. Liquid level trend of Line 5.

3.4 Anode Cover Thickness

Anode cover thickness was gradually modified to compensate for the extra heat generation, allowing for more heat dissipation from the top of anode side. Currently the average anode cover thickness is approximately 80 mm, reduced from the thickness of 100 mm. The main concern in this subject was to maintain low net carbon consumption. So far, the NCC is excellent as shown in Figure 5.

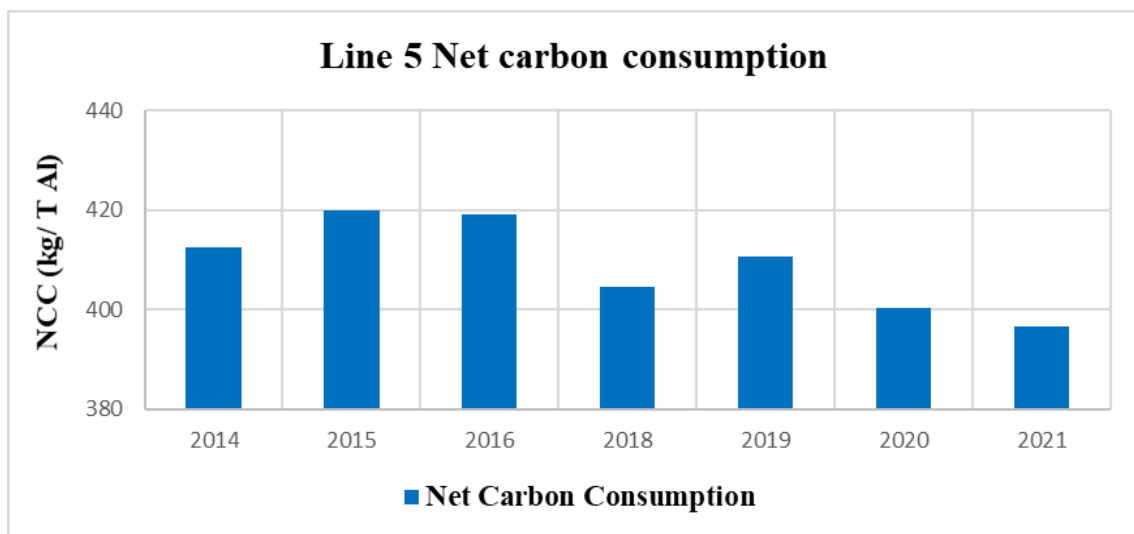


Figure 5. Line 5 net carbon consumption.

3.5 Excess AlF₃

Excess AlF₃ set points were gradually reduced along with current increase. Excess AlF₃ is the main variable to control superheat and plays a vital role in electrical conductivity of the electrolyte and side ledge. Since the beginning of current increase, average excess AlF₃ has been reduced from 11.5 % at 330 kA to approximately 9.5 % at 400 kA as shown in Figure 6. Nevertheless, CaF₂ in Line-5 has been averaging approximately 7.0 % which is higher than in other smelters and this increases total fluoride in the pots. Hence, our currency efficiency was not affected.

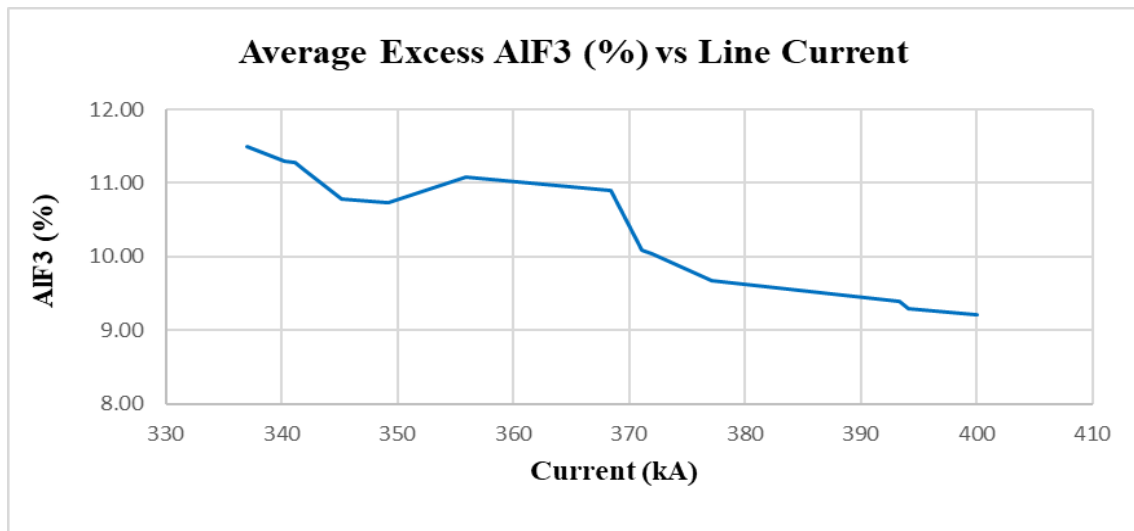


Figure 6. Line 5 excess AIF3 (%) vs current.

3.6 Implementation of Magnetic Compensation Loop (MCL)

In 2018, ALBA took the decision to implement magnetic compensation loop (MCL). The purpose of a compensating loop is the creation of a magnetic field which compensates the vertical magnetic field created by the adjacent potrooms. In 2018, ALBA built Line 6 which is running currently at 476 kA which emphasized the importance of implementing MCL.

MCL has increased pot stability in Line 5 and it is predicted that it will contribute to pot stability also at current increase up to 415-420 kA. The main benefits of MCL are as follows:

- Symmetrical eddies in the metal pad circulation,
- Lower bath and metal velocity
- Flatter interface,
- Improved pot stability.

4. Major KPI Trends

Note: All the KPI trends show a disturbance in 2017 due to long power outage. The data of 2017 were excluded from most of KPI trends for illustration of current increase project.

4.1 Current Efficiency

Current efficiency (CE) is outstanding in Line 5 as it has been sustained near the target of 94 %, although it has decreased slightly due to ACD squeeze during the current creep [2]. Nevertheless, the production increased by approximately 20 % while CE was marginally reduced. Figure 7 shows Line 5 current efficiency trend from start up until the end of 2020.

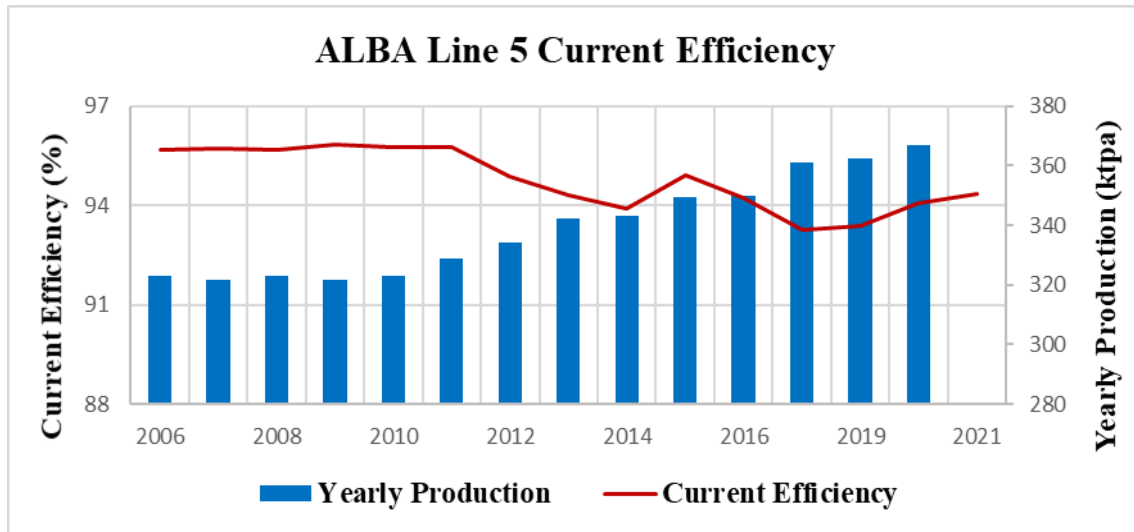


Figure 7. Line 5 current efficiency trend from start up until July 2021.

4.2 Energy Consumption

The specific energy consumption for Line 5 is comparable to industry’s best. It was kept on target. The average for the line since the start-up is 13.1 kWh/kg Al. Average net voltage was also on the target of 4.10 V. The highest pot voltage was 4.13 V in 2016 at 377 kA to compensate for the heat loss in the new copper insert lining design. Further optimization, implemented on pot parameters and anode dimensions, led to net voltage decrease to 4.11 V in 2017 and to 4.07 V in 2018 when line current was increased to lining design specifications. Figure 8 shows Line 5 specific energy consumption and net voltage trends from the start until the end of 2020.

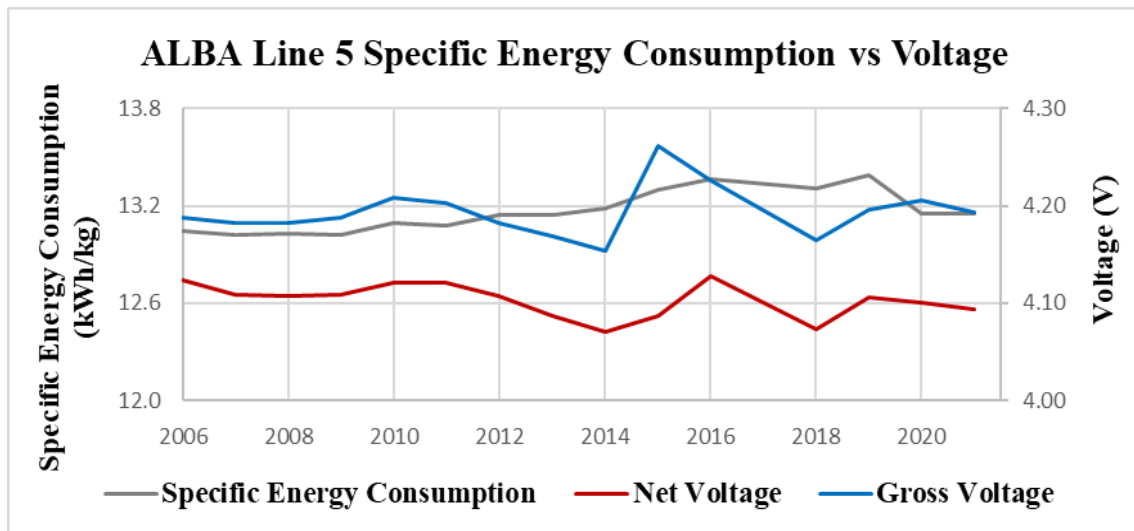


Figure 8. Line 5 specific energy consumption and voltage from start up until July 2021.

4.3 Pot Internal Heat

The main challenge of the current increase in Line 5 was maintaining the heat balance of the new lining design using copper insert collector bars with reduced cathode voltage drop and increased heat loss. The new lining was designed to achieve optimum heat balance at 385 kA, 4.10 V net voltage, 18 cm metal level, and 10 cm anode top cover thickness. The challenge at that time was to balance the internal heat of these pots as the potline current was 370 kA at that point. The

optimum heat balance was achieved in these pots at lower line current by increasing the net voltage by 100 mV at 370 kA to give sufficient heat input to the cell. The extra net voltage later was gradually reduced to zero as the potline current was increased to 385 kA and operated at 4.10 V. Figure 9 shows the change in internal heat in copper insert collector bar pots with current increase in Line 5.

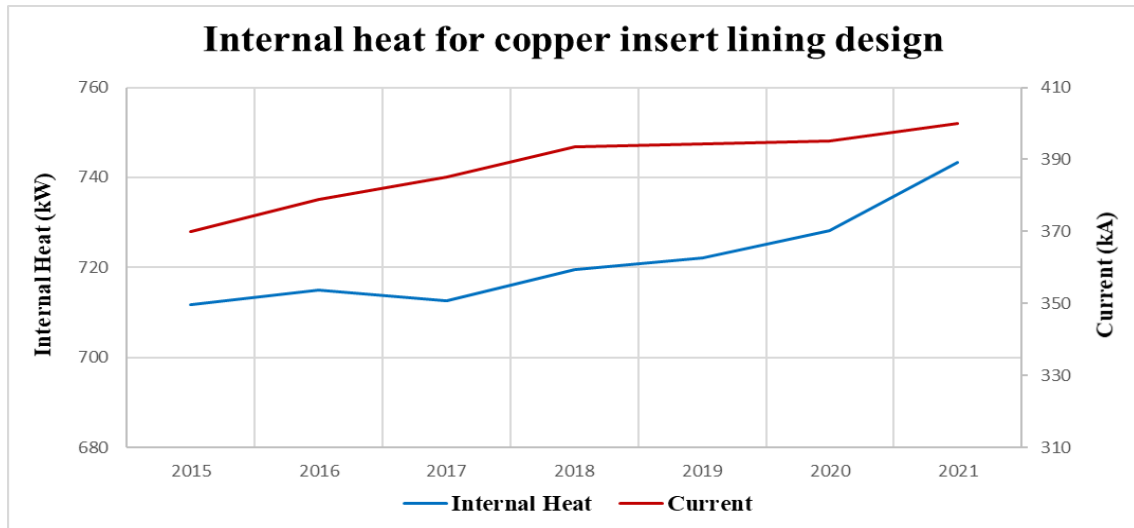


Figure 9. Internal heat of new lining design pots with copper insert collector bars in Line 5.

With the introduction of MCL, upgraded pot control logic with alumina auto adaptive feeding robustness, and improving noise control with separation of low frequency and high frequency noise, significant improvement in pot stability was observed. It became apparent that there is a good scope to increase the line current further up to 400 kA by maintaining constant voltage and reducing the ACD. The increased internal heat was compensated by increased metal level and reduced anode top cover. As it was mentioned earlier in this paper, metal level targets were increased gradually from 18 cm in 2017 to 24 cm in 2021. Furthermore, the reduction of the anode cover thickness allowed for extra heat dissipation from top of the anode.

A total increase of internal energy of approximately 34 kW, driven by the current increase from 385 to 400 kA was compensated with the above modifications. Thus, ALBA has successfully reached the target of increasing the current to 400 kA without the implementation of FCN.

4.4 Metal Purity

As shown in Figure 10, iron and silicon content in metal were not significantly affected along with current creep. Some fluctuation and deviation of metal purity have occurred, especially in 2010 due to dealing with high population of aged pots since the line start-up. However, ALBA has always had the reputation of supplying high purity metal for its end customer consistently maintaining metal purity above 99.88 % and in the last 8 years, metal purity has been maintained and is improving.

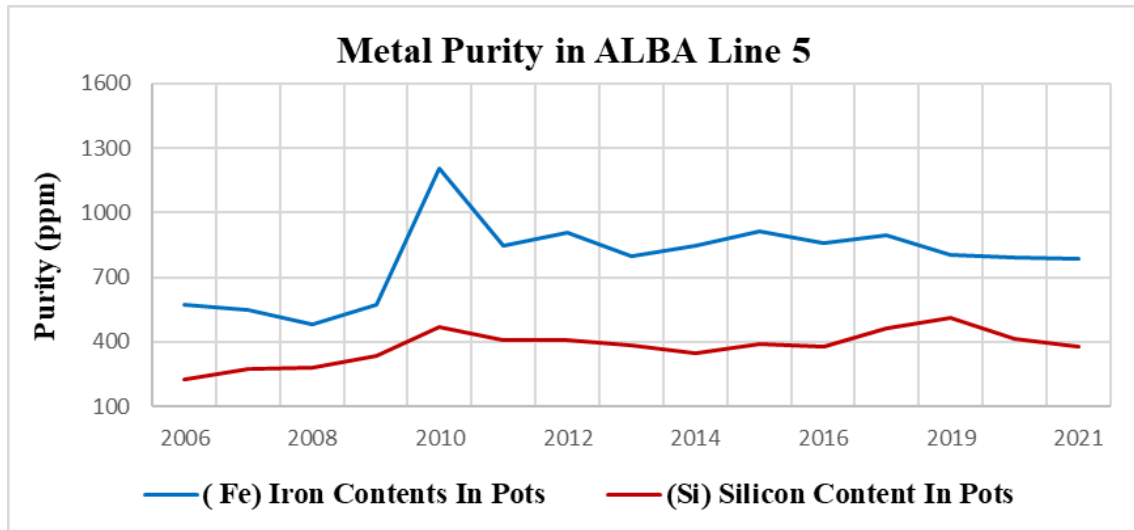


Figure 10. Metal purity trend in Line 5.

5. Challenges During the Amperage Increase

5.1 Increase in Anodic Incidents

Anodic incidents were the main challenge especially with spiked anodes as shown in Figure 11. These were mitigated with increased carbon dust skimming frequency during anode setting and through tap hole. Weekly carbon dust inspections were carried out and pots with high carbon dust were highlighted for extra skimming. Other spike detection activities were carried out regularly to prevent cell operational problems. Baked anode quality played a vital role in the appearance of this incidents. In order to reduce anodes spikes, crystal length (L_c) has been maintained above 34 Å and the pots are operated above critical Anode Cathode Distance (ACD).

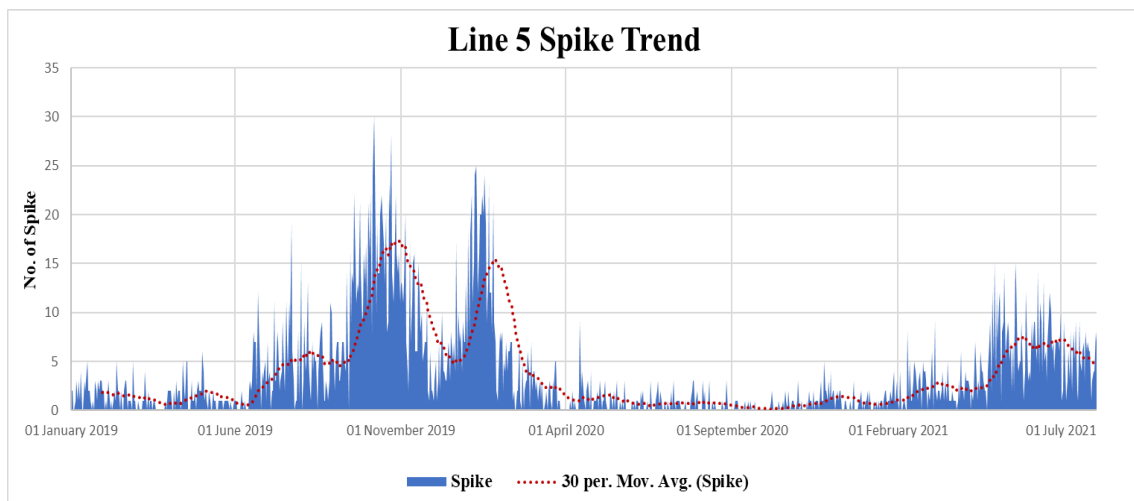


Figure 11. Line 5 Anode Spike trend 2019-2021.

5.2 Long Power Outage in 2017

On 5 April 2017, there was a long power outage in all ALBA potlines due to a power blackout. After this outage, another three hours of power shutdown in Line 5 was required to weld emergency busbars after an open circuit incident in one of the pots caused by anode clad failure. These unforeseen events resulted in a power outage of almost six hours in Line 5 causing the

potline to freeze and 274 pots had to be stopped out of the 336 pots in operation [3]. ALBA demonstrated extreme resilience and in-depth technical know-how in recovering these pots in one of the fastest and safest recoveries in the aluminum smelting industry. The potline was recovered in less than four months with start-up speed of 3.20 pots/day. Nevertheless, the consequences of this outage is still a challenge to Line 5 operation and current increase projects.

One of the main present challenges in Line 5 are bad contacts of anode (positive) riser connections. Most of these bad contacts occurred due to thermal shock after the power outage. Other damages occurred due to bus bar movement and displacement or due to handling during the fast recovery of the potline. These bad contacts are increasing pot instability and reducing productivity. Extra measures have been taken to resolve these issues by taking frequent riser voltage drop measurements and developing new methods to fix and prevent riser damages. One of the methods that has been used was to cut out the pot for a short period of time and fix the riser damage. This method was implemented in Line 5 and has succeeded to recover the pot stability.

The other main challenge was dealing with a large population of restarted pots especially pots with only side wall repaired after potline freeze. Most of these restarted pots had defects due to long power shutdown such as erosion of the cathode or cooling cracks which had been repaired. Operating such pots required delicate operation procedures and special care by operation team and had set limitations to parameter optimization.

5.3 Red Shells

Red shell incidents have been one of the main challenges faced in Line 5. This is mainly encountered on restarted pots with high age (more than 1900 days). Red shell incidents were significantly increasing during the summer season as shown in Figure 12 due to high ambient temperature. Extra measures have been taken to control this issue. Visual inspection of red shells have been carried out frequently. Superheat, side ledge profile, and shell temperature have been measured in pots with high internal heat. The number of pots with red shells were contained in a controlled manner.

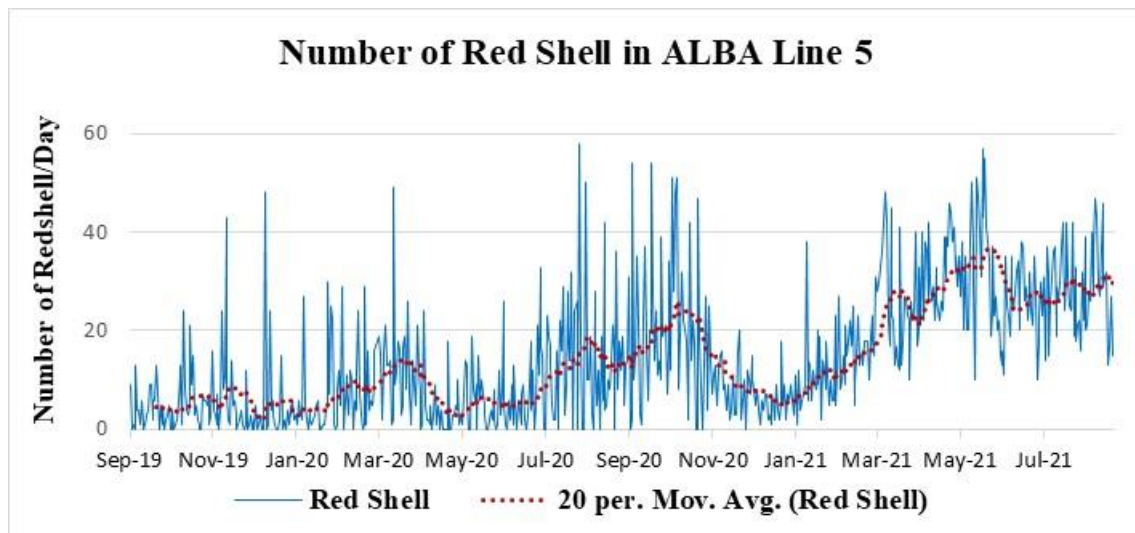


Figure 12. Number of red shell incidents in Line 5 (Sep. 2019 to Aug. 2021).

6. Improvement in Work Practices

- To improve the quality of operation and workmanship, it was decided to initiate process excellence team to monitor and control key performance indicators. At the beginning the assigned team had the responsibility to do physical inspection of different operations and compare the performance score of different teams in different shifts. Moreover, the team had the responsibility to improve the procedures of the different activities, such as anode change and covering, metal & bath level compliance, tapping compliance, etc.
- Later on, more development was done by the team which included monitoring the technical aspects of potline operation such as the number of pots kept in manual control, number of raised anodes, pots with abnormalities such as high instability and high temperature, etc.

The results achieved by each team are being discussed by the employees themselves and corrective actions are put in place. All the mentioned activities have contributed to engage all the employees and increase awareness about the importance of quality, procedures, and safety.

7. Measurements during Amperage Increase

Necessary measurements have been taken during amperage increase in reference pots and at defined frequency before and after amperage increase. The necessity of measurements was mainly to determine the heat balance and cross voltage around different cell components and based on the results of measurements necessary actions and optimizations were done. Examples of monitoring activities is shown below:

- Side shell temperature
- Side ledge profile
- Red shell inspection
- Basement cleaning: Busbars temperature and overall conditions.

8. Conclusion:

ALBA has safely increased amperage from designed 330 kA to 400 kA keeping the potline operating performance as benchmark as compared to other AP technology smelters. The challenge to reach 400 kA without installing FCN has been achieved by implementing major modifications, introducing cutting edge technology and engaging all stakeholders. Further current increase journey has been launched to reach 415-420 kA by 2023.

9. References

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