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RIO TINTO AP44 CELL TECHNOLOGY DEVELOPMENT AT ALMA SMELTER

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Abstract

The AP30 platform reached an important milestone at the Alma Smelter. This latter is the first to operate above 400 kA. Following this success, Rio Tinto Aluminium group launched the AP44 cell development to offer a technology capable of operating above 440 kA. This represents fifty percent more than the original AP30 cell. The technology is expected to deliver world-class performance such as metal production of 3274 kg/day/cell and an energy consumption of approximately 13.23 kWh/kg.

Advanced modeling tools and process control system were developed and used to cope with the challenge in designing and operating high amperage cells. Consequently, the AP44 cells integrate the most recent AP technology developments.

The industrial piloting is underway at the Alma Smelter on eight dedicated cells to demonstrate the technology at both 405 kA and 440 kA to validate the transition parameters. At the end of September 2016, the new AP44 technology would be available for implementation in existing or new aluminium smelters.

AP4X Technology Evolution

The AP30 technology has already demonstrated robustness and spectacular capacity to increase metal production. In 1986, the first AP30 platform at 280 kA was installed in one of our plants, in France, and continuously improved in current density and productivity. Rio Tinto has gradually and successfully developed the AP30 platform towards higher amperage technologies. Over the years, advanced pot lining materials and control logics combined with low anode-cathode distance (ACD) operation have largely contributed to maximizing AP30 platform performance. In 2015, Alma Works was the first smelter to operate above 400 kA by using the available technological breakthrough.

Considering the relatively recent construction of the last four smelters equipped with the AP4X technology, there is now more than 25 AP4X based potlines aiming at increasing the overall performance. Accordingly, the cell development considers market needs by working on both energy consumption and high productivity package.

To exceed 400 kA with the AP30 platform

In recent years, Rio Tinto has actively launched several technology development initiatives in an effort to continue improving the AP4X technology, and to achieve operating amperage above 440 kA. Tests conducted at various plant sites, dedicated booster circuits (Alma, Dunkirk, Alouette, Grande-Baie) and research centres have contributed to develop and industrialise technological bricks for specific AP30 applications, while ensuring compatibility with existing series and lower capital expense.

The technological bricks are also developed to be combined in various ways to optimise performance and address different energy and market requirements associated with retrofit or greenfield applications.

At present, many technological bricks have been industrialised and fully integrated into the AP4X technology:

- Alma – 432 cells at 405 kA
- Sohar – 360 cells at 388 kA
- Alouette – 594 cells at 380 kA
- Kitimat – starting at 405 kA

The AP4X development program, in collaboration with various plants (e.g., Alma, Dunkirk, St-Jean, and Alouette), includes among others the following newly developed technological bricks:

- low-ACD operation for minimal power consumption or increased amperage;
- low-electrical-resistance anode assemblies and slot design;
- low-cost lining components to lower cell production costs;
- optimized shell design;
- advanced ALPSYS control logic.

The combined advantages of these technological bricks justified the development of a new AP4X platform. In order to maximise the overall project value, two strategies were proposed and studied:

- high production with the AP44 technology targeting operation above 440 kA,
- low energy cell with the AP42 technology targeting low specific energy consumption at 12.300 kWh/kg and at an amperage up to 420 kA.

AP4X Platform Trials

The new AP4X platform operates with longer anodes to support high amperage increase. Engineering studies were launched to identify the maximum anode size according to various constraints. The anode design needed to take into account a sufficient central channel space to dissolve alumina from the feeders, and a sufficient lateral channel space to create a sidewall ledge protection.

The new platform was first tested at Aluminium Dunkirk Works, in 2012. The objective of the trial was to evaluate the potential of the new AP4X platform for low energy cell development (12.5 - 12.7 kWh/kg at 380 – 390 kA). The cell performance targets focussed on low energy consumption, robustness and low capital investment (CAPEX) including retrofitting for existing AP30 plants. One cell was built and operated in a plant environment to evaluate, understand and mitigate possible risks related to a new platform.

During cell operation, the thermo-mechanical behaviour of the new shell design was measured. Aluminium Dunkirk is equipped with a forced convection cooling network (FCN) aiming at cooling the shell wall. Upon blowing air along the side of the shell, the FCN increases the heat extraction to better support high amperage technologies and cools the sidewall of the shell. This technology allowed the development team to modulate the shell temperature and measure the resulting shell deformation. The shell deformation increases or decreases according to the change in temperature. The magnitude of the measured deflection was similar to that of the thermo-mechanical model predictions.

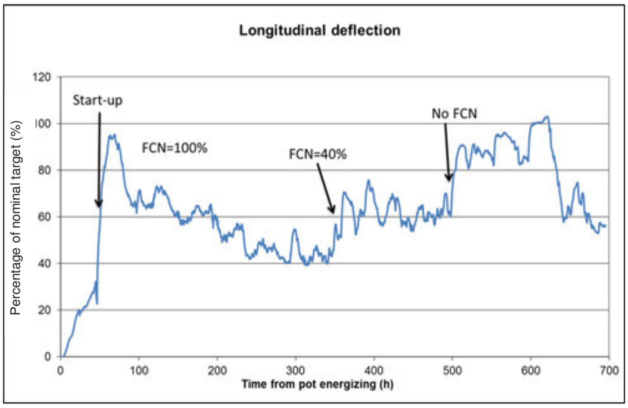

Figure 1: Shell deflection obtained at different FCN levels

Testing also allowed confirming the various issues or technological risk associated with long anode assemblies. The first risk associated with very long anode operation is the alumina feeding. In fact, the smaller liquid surface available could affect the alumina shot dissolution.

The second risk, especially for brownfield plant (retrofit), is associated with the asymmetric anodes assemblies that are required to compensate for the fixed anode beam position. Theoretical non-uniform current density could also lead to a non-horizontal butt surface wear. Another consequence is the importance of the angle between the stem and the vertical axis during anode change. This point could particularly introduce difficulties on anode change when removing and positioning the anode near the positive risers.

Figure 2: Long anode that is evenly consumed

Consequently, the Aluminium Dunkirk trials were used to demonstrate and validate various operational concerns with bigger anodes such as; i) anode change, ii) tapping, iii) anode plan movement , iv) process control, and, v) superstructure behaviour. In addition, specific measurements were taken to assess the shell structure behaviour and process related environmental aspects including; i) cover state, ii) pot hooding, and iii) general operating condition. The Dunkirk trial was also used to validate and implement retrofitting solutions to enable upgrade from the AP30 series to the AP4X platform.

The successful demonstration of the AP4X at Dunkirk provided valuable information to begin and accelerate a new cell development program to reach 440 kA. The AP44 cell potential should improve the current Rio Tinto production with more than 200 kt/yr, and the capital investment for implementation is estimated at lower than 2000 US/mt.

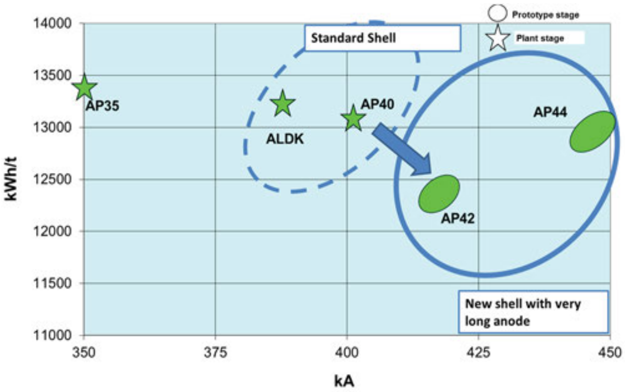

Figure 3: AP4X development roadmap

The operating windows shown in Figure 4 represent the set of operating points for which the thermal performance of the cell meets defined criteria within a given ACD range. The upper boundary is the high thermal limit while the lower boundary is the low thermal limit. Advanced modeling is used to set these thermal limits. Depending on the cell design, the operating window moves towards higher amperage or low energy consumption. Figure 4 shows how combining different technological bricks can improve AP4X cell performance for the same range of anode-cathode distance. The brick combinations are customised to client's constraints. Further R&D is still required to achieve much higher amperages while reducing the negative effects on the magnetic stability of the cells.

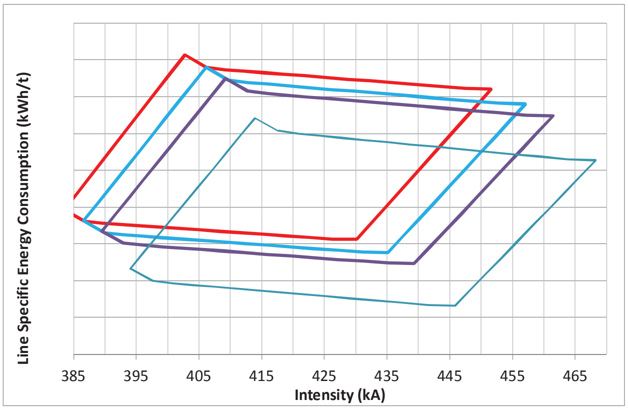

Figure 4: Impact of various technological bricks on performance operating window

AP44 target performance at Alma Works

In 2015, Alma Works achieved record amperages above 400 kA for the AP30 platform upgraded with AP40 technology. Consequently, the Alma plant was selected for the industrial piloting of the AP44 technology including the following reasons:

- two dedicated boosters capable of increasing the amperage by 50 kA, for high-amperage cell development;
- ALPSYS control system and potential R&D improvements;
- short distance from the Arvida R&D Centre and access to expert resources;
- opportunity from the pot relining campaign in 2016 to accelerate development.

Based on this opportunity, the plant's specific arrangements and existing technologies were considered during the early design stage. Indeed, Alma's existing conductors and standard anode assemblies were incorporated into the cell design. The expected performance during the industrial piloting is shown in Table 1.

Moreover, during the conversion, the two technologies will need to coexist at the highest possible amperage in the former technology. When converting from AP40 to AP4X, the latter must be able to operate at 400 kA and, preferably, with the same smaller anodes. This requires various technological component combinations and settings. The industrial pilot includes a design to operate at low amperage with the existing smaller anodes, and another design to operate at the targeted amperage of 440 kA with longer anodes.

Performance Indicator	**Target**	
Current intensity [kA]	405	440
Metal production [kg/cell/d]	2989	3274
Energy consumption [kWh/kg]	13.37	13.23
Anode effect frequency [EA/cell/d]	<0.1	<0.1

Table 1: AP44 performance targets for the Alma industrial pilot

Figure 5 shows the expected operating window for the AP44 technology designed for industrial piloting.

The low-amperage and high-amperage configurations will confirm the conversion strategy from the existing 400 kA cell line to the new AP44 platform.

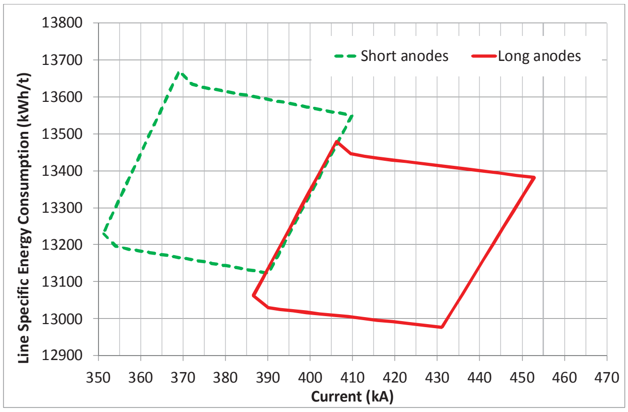

Figure 5: Operating windows of the industrial pilot cells

Dedicated Booster Circuit

To test the new high-amperage platform, a dedicated booster circuit had to be designed and implemented. It is known that higher amperages will amplify adverse MHD effects. Moreover, the presence of a booster circuit, in a cell line, can negatively affect cell stability. To lessen MHD disturbances and ensure the magnetic stability of the test cells, Rio Tinto MHD experts modelled and designed a busbar setup with a magnetic field suitable for both 440 kA pilot cells and 405 kA line cells. In line with the modelling, the Alma Works booster circuit was entirely reconfigured to allow starting and operating five cells at 440 kA. This was done in the spring 2015 to be ready for the 440 kA cell start-ups in July 2015. Figure 6 shows the five-cell booster arrangement.

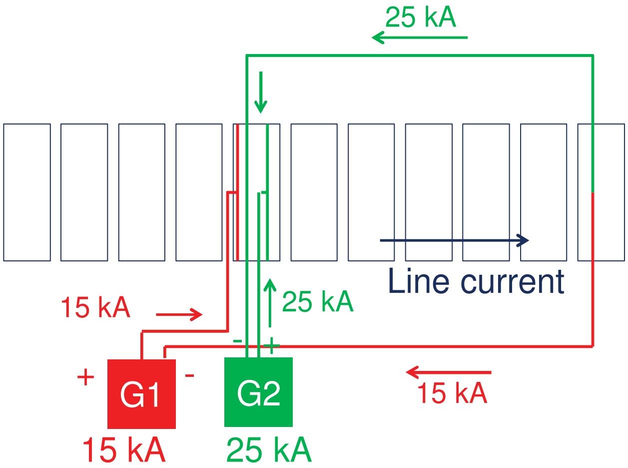

Figure 6: Diagram of the booster circuit arrangement

Experimental results

The industrial pilot includes a total of eight cells. Five cells were started at 440 kA, in the booster circuit, and three other cells were started at 405 kA line amperage. This setup was designed to confirm that the new AP4X platform could be started and operated in different current conditions. It was intended also to confirm that the technology could withstand the transition from the existing platform to 440 kA.

A total of eight test cells were successfully started in July 2015, at Alma Works. A new start-up method, helping to keep the cell voltage constant during the preheating stages, was also used. The size of the preheating bed was adjusted according to amperage levels. The heating rate of the cathode blocks was within acceptable limits and below the maximum rate of 40°C/h.

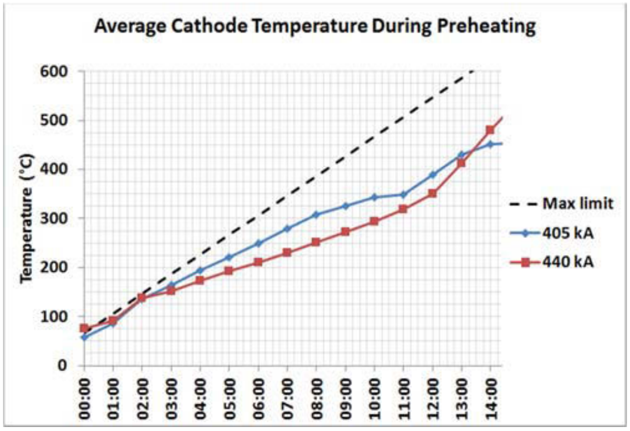

Figure 7: Average cathode temperature during preheating

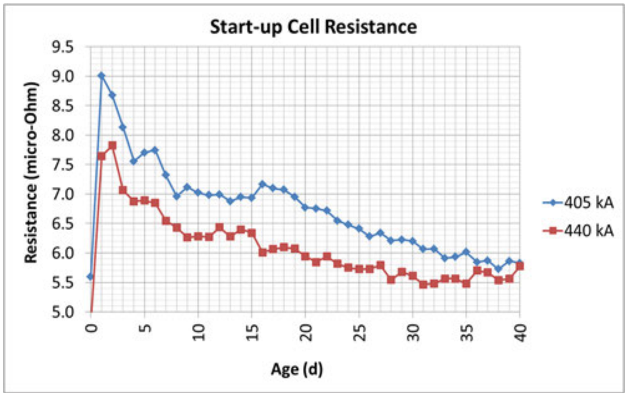

Figure 8: Cell resistance at start-up

Thermocouples were installed in the cell linings to compare readings with thermo-electric model predictions and also to assess start-up robustness by looking for signs of liquid infiltration in the linings. Initial measurements showed that the isotherms were properly positioned, in line with the prediction.

No sign of infiltration was detected during start-up.

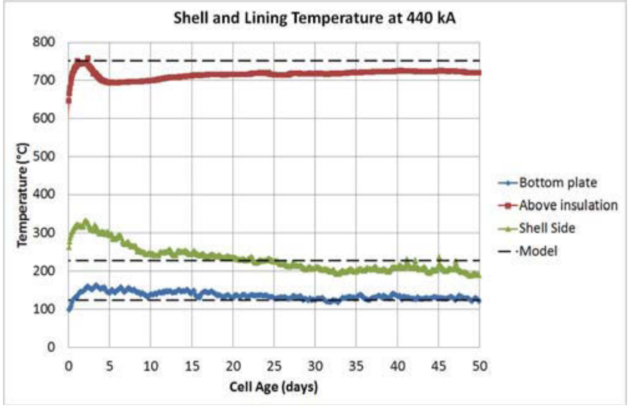

Figure 9: Lining temperature

Conductors

Apart from validating the cell technology, other technical aspects had to be checked experimentally to confirm their capacity to withstand the new current levels.

The higher amperage generates extra power in the cell-to-cell electrical conductors under the walkways and crossovers. First-generation conductors, initially designed for 300 kA, are the most limited in terms of thermal expansion and were modelled. The most aggressive condition for conductors is the electrical bypassing of more than three consecutive cells. Temperatures up to 260 °C, in some areas, can unavoidably generate extensive thermal expansion. To start up the cells at 440 kA, five consecutive cells had to be shut down and bypassed, meaning that heat expansion occurred and the thermo-mechanical behaviour of the conductors was assessed to confirm that the conductor network was able to withstand 440 kA.

The conductors deformation was observed, and temperature measurements were taken at various stages of the tests. Reference marks were made to assess conductor displacements according to line amperage and the number of bypassed cells.

Prior to starting up the cells, wedging zones were prepared to limit the electrical resistance between the wedges and busbars. Voltage drop and temperature measurements of the bypass wedges were taken at 440 kA with satisfactory performance. Figure 10 shows that voltage drop in the bypass wedges, was below 44 mV, and temperatures were below 150 °C with maximum tolerance being 200 °C. With properly prepared wedging zones, the AP30 wedges can withstand 440 kA.

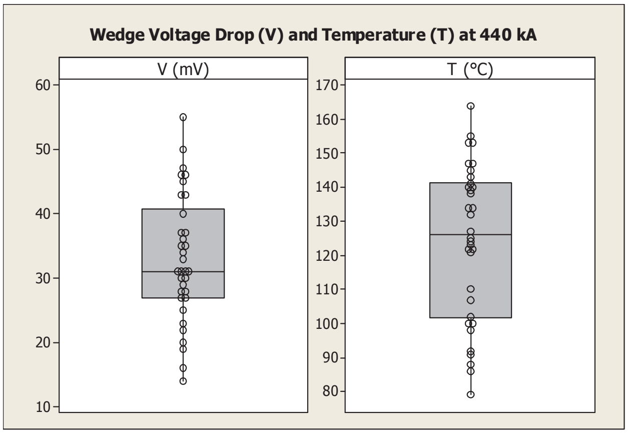

Figure 10: Voltage drop and temperature of short-circuiting wedge

Only the switching fuse was resized to allow for sufficient explosion delays at 440 kA, to efficiently protect the wedging zones.

Environment

For industrialisation purposes, the impacts of significant amperage increase on workplace conditions and occupational hygiene must be determined. The airflow inside the buildings and shop-floor temperatures were modelled. A temperature increase in the 3 °C to 7 °C range was expected, compared with AP40 technology operating at 400 kA. These results will be physically measured during testing.

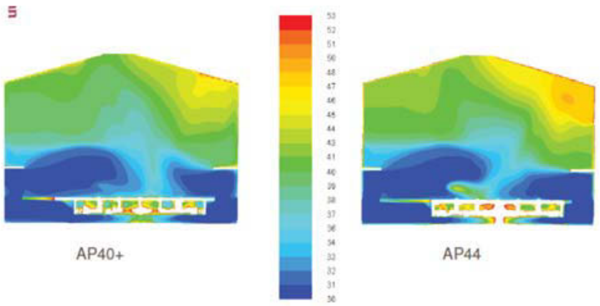

Figure 11: Temperature prediction in the building

Timeframe and next steps

The performance of the AP44 technology will be validated in the spring of 2016.

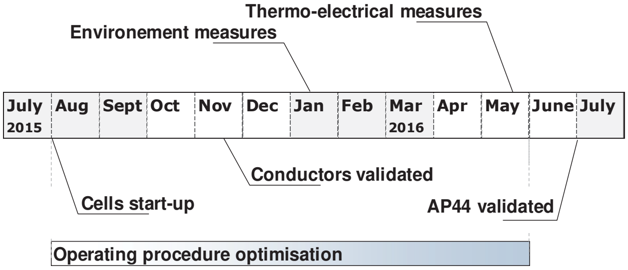

Figure 12: AP44 validation timeline

Test cell operation is currently ongoing and kept stable to ensure thermal balance. The upcoming milestones are:

- performance validation of various cell components;
- exhaustive thermo-electrical measurement campaigns and performance analysis to confirm AP44 performance at targeted and transition amperages;
- completion of the financial analyses for the purposes of industrialisation at Alma Works.

Conclusions

Since its first industrialization, the AP30 technology had been continuously developed following the economical worldwide context evolution.

The technological brick development approach allowed fast evolution of the different variants of Rio Tinto's AP4X technology.

The Aluminium Dunkirk trial has allowed validation of the use of bigger anodes and optimized shell design. Consequently, this pot technology is considered as the best pot upgrade to be implemented in AP30 based smelters given its easy implementation concept with changes mostly at low technological risks.

AP44 is currently being developed at Alma Works. Testing will allow validating the technology at two separate amperage levels and confirming the conversion strategy for an existing potline.

The withstanding capacity of various components at current levels in the 440 kA range, as well as long anode loads, will be confirmed.

The technology will be validated in the spring of 2016, in line with growth plans for Alma Works. The AP44 technology will be made available for industrialisation purposes.

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