Design and Trial of Electrical Collector Plate in Cathode Assemblies

Guorong Cao and Hao Zhang

Abstract

Aluminium smelting is a very energy-intensive process; therefore, reducing power consumption has been a continuous focus of the aluminium smelting industry for many decades. A unique concept of electrical collector plate (ECP) has been developed and tested in industrial reduction cells to validate the thermal electrical performances and financial benefits of the ECP design. The development process including thermo-electrical and thermo- mechanical modelling of various ECP designs will be discussed. The ECP cathode assemblies were installed and tested in industrial reduction cells. Significant energy savings were realised and validated through stable operation of trial cells. It is also found that ECP cathode assemblies can provide versatile applications such as leveling out the cathode surface current density and reducing horizontal current flow in the metal pad.

Keywords

Aluminum smelting • Cathode voltage drop • ECP • Low energy cell

Introduction

Over the last few decades, reducing energy consumption of the Hall-Héroult aluminium smelting process has been a key focus for industry research and development work. Rio Tinto Aluminium has been working on low-energy aluminium reduction cell technologies since the mid-1980s. The early work was focused on the drained cathode cells using proprietary wettable cathode technologies [1, 2]. Since 1994, significant efforts have also been made in Australia to develop other conventional methods of reducing energy consumption. One of the approaches that was investigated is the reduction of the voltage drop over the cathode assembly and applying the concept of electrical compensation to achieve uniform cathode current distribution, lower cathode erosion (through elimination of high current density areas) and improved metal pad stability (through alleviation of horizontal currents). These efforts resulted in a two-pronged R&D cluster of projects, namely, electrical collector plate/plugs (ECPs) and copper cored collector bar (CCCB) cells. This paper will focus on the development and testing of ECP designs.

The Electrical Collector Plate with Plugs (ECP 1)

The early work on ECP started on the concept of using flat plates underneath the cathode and welded electrical contact plugs as a means of achieving a more uniform cathode current distribution, lower cathode erosion (through elimination of high current density areas) and improved metal pad stability (through alleviation of horizontal currents). Figure 1 illustrates the potential benefits of developing the ECP with Plugs concept (ECP1) in comparison to the conventional cathode collector bar technology. Two cells of the ECP1 concept were installed in the Bell Bay Aluminium smelter in 1996 and operated for up to 3 years to test the concept. Figure 2 shows one of the ECP1 designs used in the test cells. Thermal electro-mechanical modelling as well as MHD modelling was conducted to ensure the placements of the plugs reduced the horizontal current flow through the metal pad.

The performance of the first ECP1 test cell was impacted by the robustness of the plug installation method and process changes that led to unstable operations of the cell. Operational performance of the second test cell validated some of

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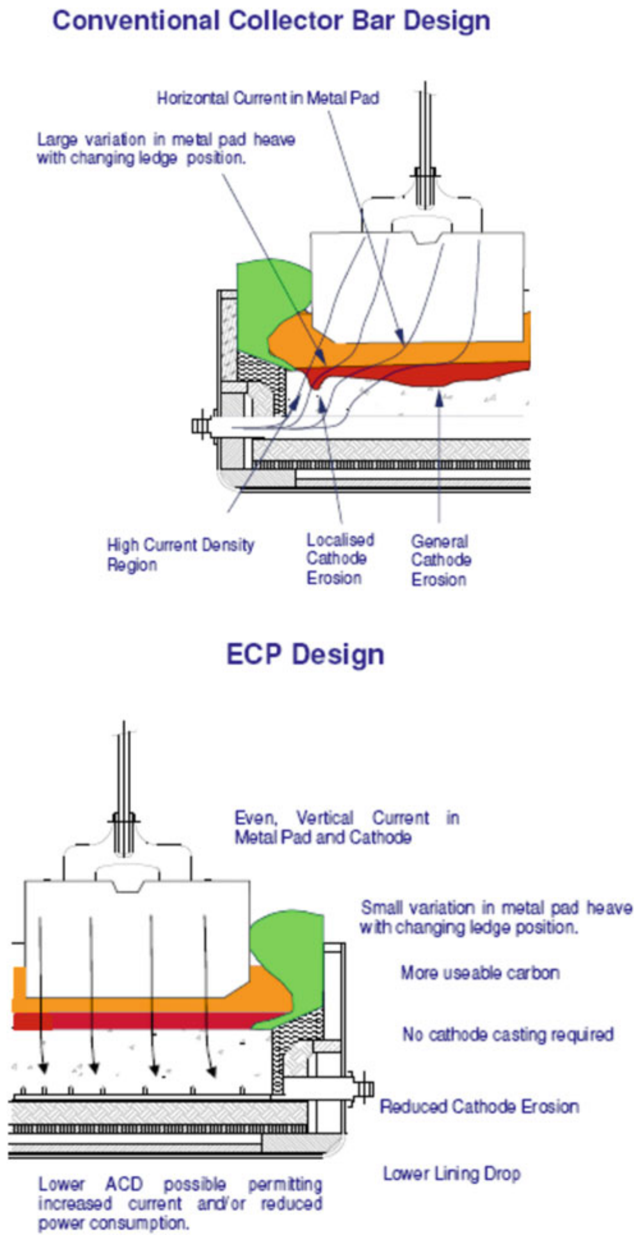

Fig. 1 Potential benefit of the electrical compensation by using the electrical collector plugs

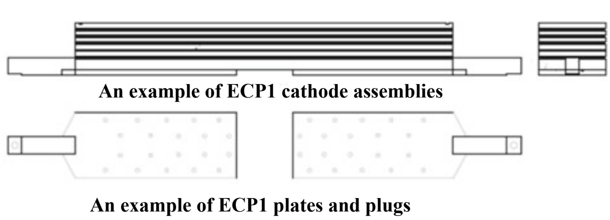

Fig. 2 An electrical collector plate with plug design and configuration of the cathode assembly

the key benefits of the ECP1 designs. On average, ECP1 operated with a 0.25 DC kWh/kg improvement in specific energy consumption compared to the rest of the line. However, a higher than expected lining voltage drop was recorded for most of its operating time, most likely due to deterioration of the ECP contact with the cathodes. Furthermore, the electrical plug concept was developed to redistribute the electrical current evenly along the cathode surface. As shown in Fig. 3, there was a voltage penalty if the current was diverted towards the center of the cathode by placing more plugs under the middle of the cathode. An autopsy of the ECP1 cells revealed that differential thermal expansion of the cathode and steel ECP plate and plugs led to cathode cracking in weak areas and earlier than normal failure of the cells. This key finding led to the development of the ECP concept with fins.

The Electrical Collector Plate with Fins (ECP2)

The ECP design with fins (ECP2) was developed to overcome the problem of differential thermal expansion between the ECP with plugs and cathodes and to improve power efficiency of the new cells by targeting lower electrical resistance collectors. One of the ECP2 designs used in the trial is shown in Fig. 4. As can be seen from Fig. 4, the ECP2 design intent is to use a vastly more conductive collector plate combined with low profile electrical collector fins to reduce electrical resistance while maintaining or even improving the useable cathode carbon. The fin design (three parallel fins over the length of the plate) eliminated the cathode stress generated by the differential thermal expansion between the plugs and cathode in the ECP1 design and also significantly increased the contact area between the plates and the cathodes. The steel plate has the same width as the cathode so the net effect is a much more conductive cathode assembly that attracts more even current distribution across the width of cathodes. The dimensions of the ECP plates and fins were optimized using 3D thermal electrical and thermo-mechanical models.

Optimisation of the ECP2 Design

Thermal electrical and thermo-mechanical models were used to study the impact of various ECP2 designs on the reduction cell thermal electrical performance and the mechanical integrity of the cathode assembly. Figure 5 shows a half cathode slice model of a reduction cell design with the application of ECP2 cathode assemblies.

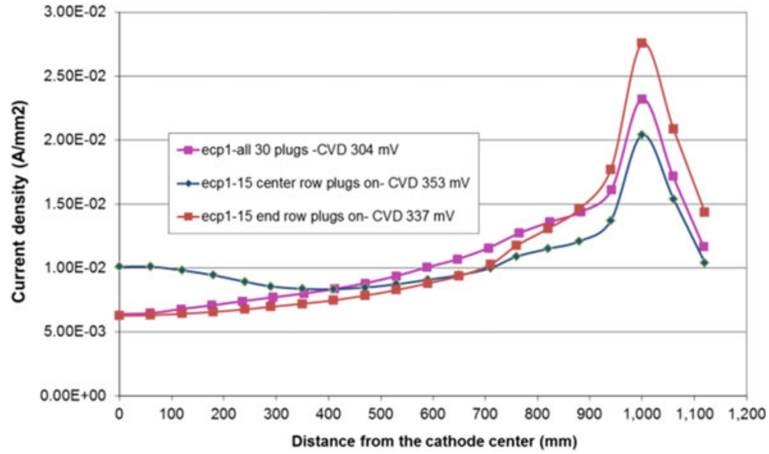

Fig. 3 Impact of ECP1 plug positions and numbers on the ECP1 cathode assembly voltage drops and cathode surface current density distributions

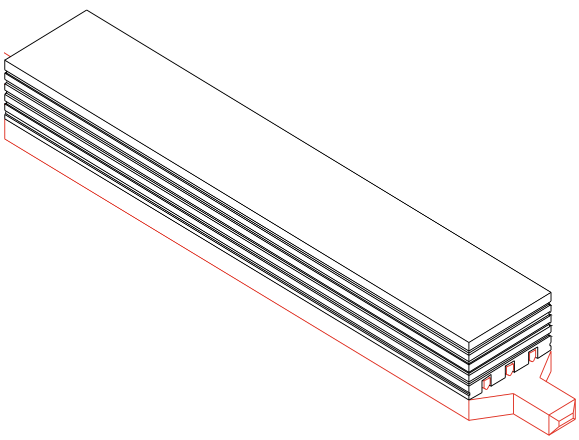

Fig. 4 An example of the ECP2 design used for trial at Bell Bay Aluminium

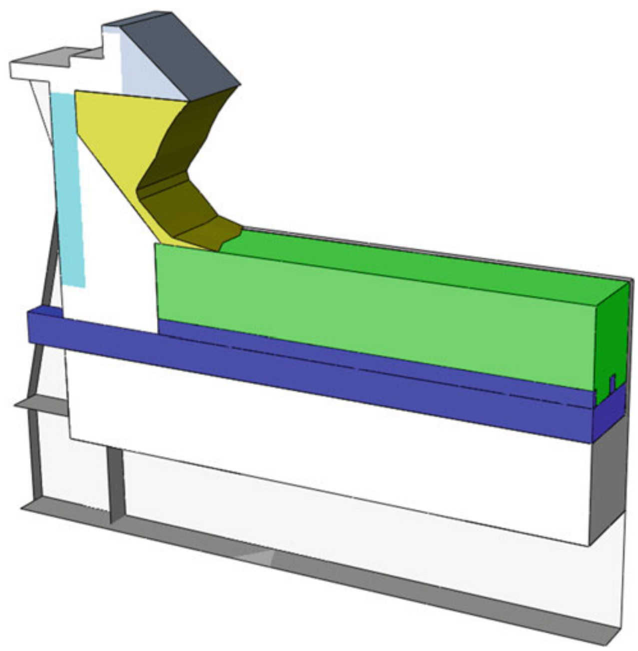

Fig. 5 3D slice model used for design optimisation of the ECP2 cells

The electrical collector fin design was also compared with the plug concept by simulating the plug design as shown in Fig. 6. Figure 7 shows the temperature distributions in an ECP2 cell while the electrical potential distributions inside the same cell are shown in Fig. 8. As a comparison, the electrical potential distributions inside an ECP1 cell are shown in Fig. 9. Electrical current flow inside the ECP cathode assembly is a key aspect of the design and can be analysed in detail using the model. Figure 10 shows the electrical current flow vectors inside the ECP2 cathode assembly. The current density on the cathode surface can be examined in detail for different ECP designs.

The main goal of the design optimisation was to seek a balance between lower cathode assembly voltage drop and cell heat balance as well as between a lower cathode assembly voltage drop and more uniform cathode surface current density. The optimisation on the mechanical integrity of the ECP cathode assembly focused on reducing the risk of cathode cracking while maintaining good electrical contacts between the ECPs and cathodes. Maintaining a good cell heat balance while achieving the voltage savings from the ECP cathode assemblies, is a key design target. The cell lining design also needs to take into account the operating capability of the test site and operating conditions of the particular reduction line.

The impact of loss of electrical contact between the ECP and cathode was also studied using the model. The voltage drop from the cathode surface to the end of the collector plate for a full electrical contact between the ECPs and cathode was compared with the voltage drop for a partial electrical contact. The partial contact was modelled assuming there is no contact for the first 100 mm from the end of the cathodes as shown in Fig. 11.

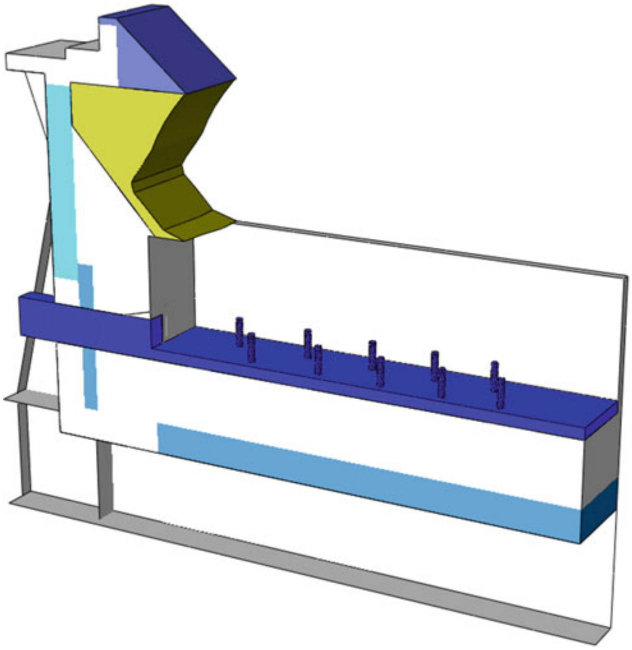

Fig. 6 3D slice model used for comparing the performances of ECP1 cells using electrical plugs and fins. The cathode was not shown to reveal the ECP details

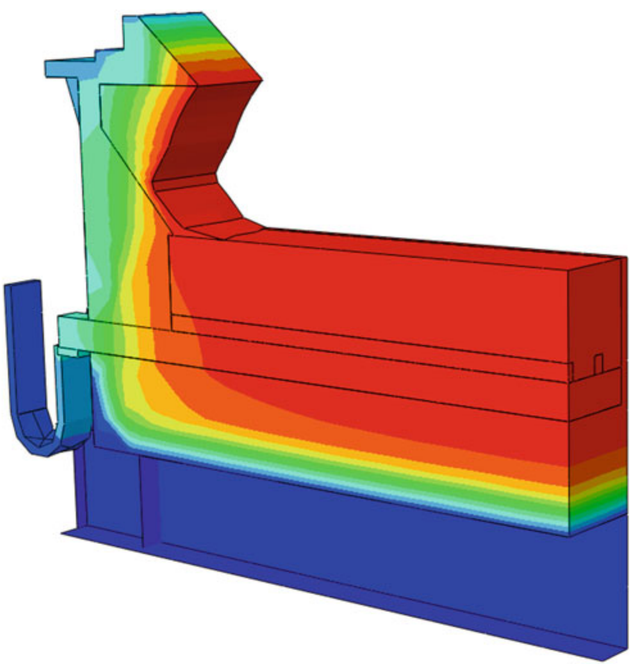

Fig. 7 Temperature distributions predicted for one of the ECP2 cell design

Based on model analyses, there are two effective and feasible pathways to even out the current distribution on cathode surface and reduce cathode assembly voltage drop:

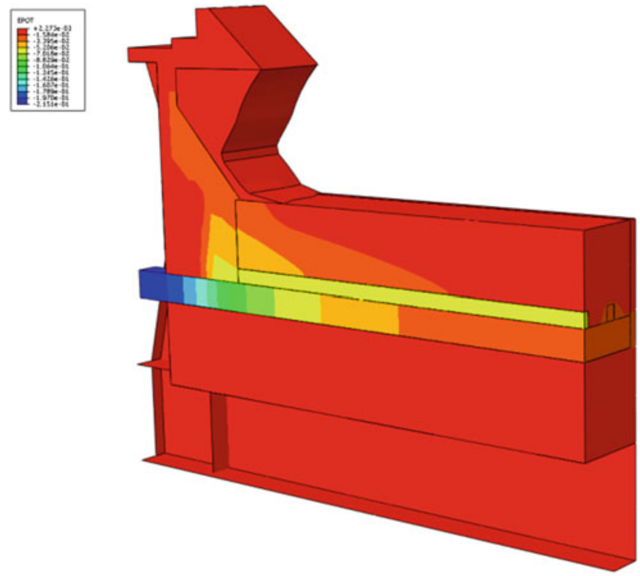

Fig. 8 Electrical potential distributions predicted for one of the ECP2 cell designs

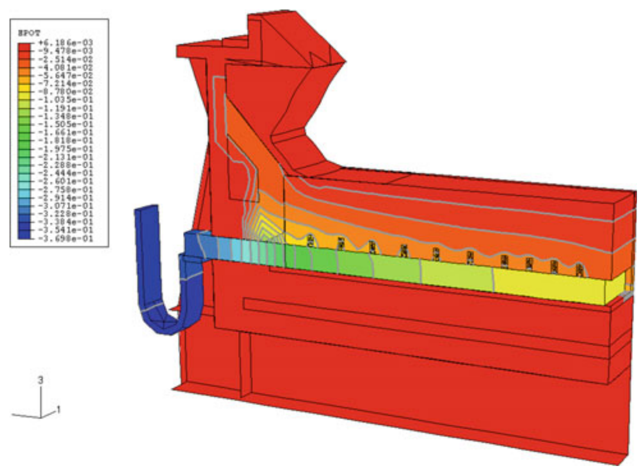

Fig. 9 Electrical potential distributions predicted for one of the ECP1 cell designs

1. Decrease the ECP electrical resistivity; and
2. Increase the cross-sectional areas of the ECPs to not only reduce the electrical resistance but also to increase the contact area between the ECPs and the cathode and, thus, reduce electrical contact resistances.

Basic physics dictates that the electrical current always flows via the least resistive path and there is a penalty on cathode assembly voltage drop if the current is redistributed to get a more uniform cathode surface current distribution. An optimized design is therefore a fine balance between the lining drop and current distribution.

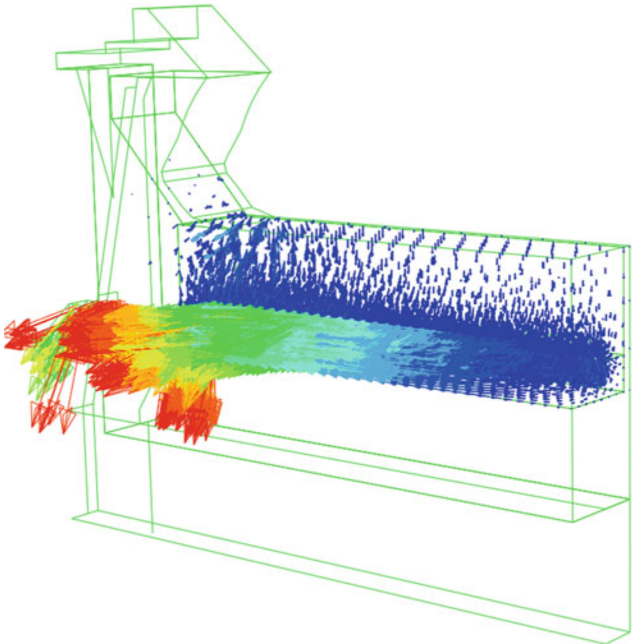

Fig. 10 Electrical current flow predicted for one of the ECP2 cell designs

Industrial Trials of ECP2 Cells at Bell Bay Aluminium

The ECPs and cathodes were glued together instead of the conventional method of cathode sealing with molten cast iron. The cathode was prepared in advance with an even application of glue onto the contact surface. To test the mechanical integrity and contact conditions between the ECP2 and the cathode, an ECP2 cathode assembly was loaded into the anode baking furnace and heated up to 1000 °C and cooled to room temperature as shown in Fig. 12. No cathode cracking or ECP plate separation from the cathode was detected in the trial. The ECP2 cells were gas baked for start-up since the ECPs were glued to the cathode so the full electrical contact between the ECPs and cathodes can only be established at elevated temperature. Figure 13 shows the start-up protections of the linings for an ECP2 cell. Two ECP2 cells were successfully constructed and started in 2004 at Bell Bay Aluminium and one of the cells was tested for more than 1200 days before it was cut out in early 2008 due to operating issues. The ECP2 concept was successfully used for a series of other low energy test

Fig. 11 Impact of electrical contact between the ECP and the cathode on cathode voltage drop was estimated by the cell model. The CVD in the good contact case (left) is 10 mV less than the partially insulated case

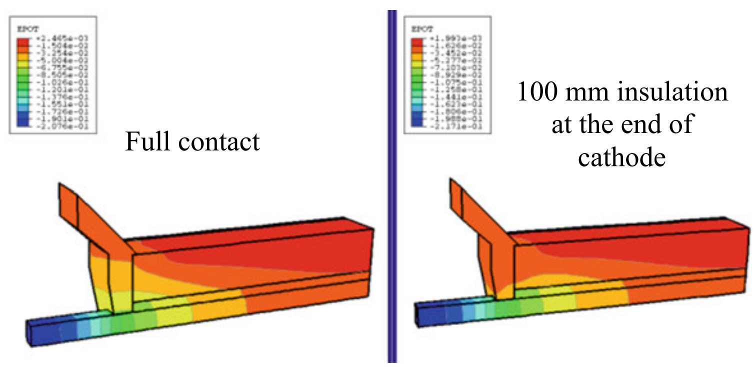

Fig. 12 Heating and cooling an ECP2 cathode assembly in the carbon baking furnace

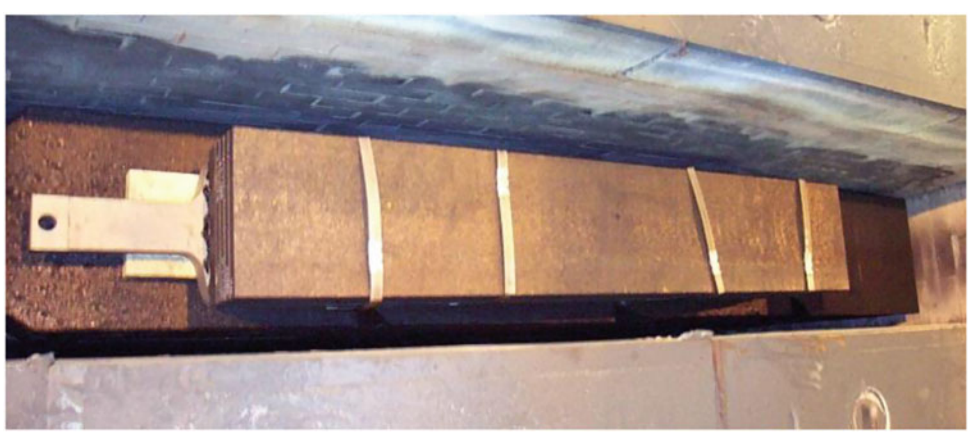

Fig. 13 Start-up protections of ECP2 cells showing insulation over the ram fillets and rammed slots

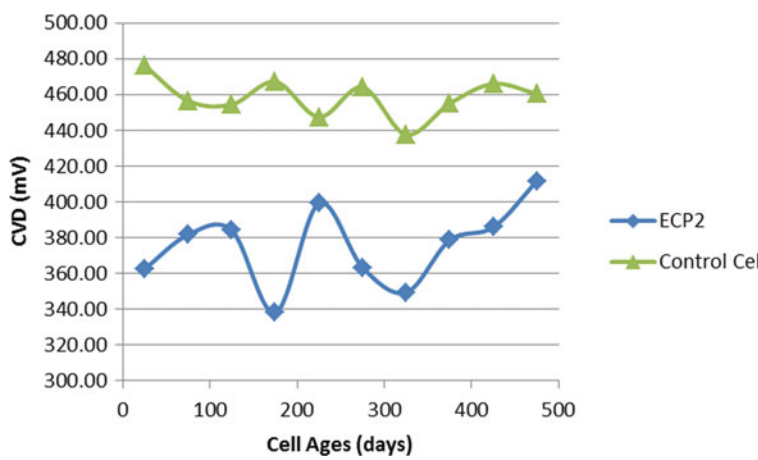

Fig. 14 Cathode voltage drop (CVD) measured during the trial confirmed significant voltage savings with the ECP2 design

cells that were incorporated with other proprietary technologies and tested in Bell Bay Aluminium smelter between 2004 and 2009. The ECP2 test cell achieved the expected 20% reduction in cathode voltage drop as shown in Fig. 14 and 0.25 DC kWh/kg improvement in specific energy consumption compared to the control cell. No mechanical failures of the ECP2 were detected during the operation.

Conclusions

This paper summarises past work carried out by Rio Tinto Aluminium on the development and testing of the ECP in a reduction cell. The concept of using ECP with fins in particular (ECP2) in a cathode assembly was developed and applied to low-energy cell designs and tested extensively at Bell Bay Aluminium between 2004 and 2009. The ECP2 technology was validated as an effective method to reduce cathode voltage drop. The technology has potential to increase useable cathode carbon, leading to longer cell life. The ECP2 cathode assembly was mechanically robust and proved to be able to sustain the harsh mechanical loading conditions during industry cell operations and maintain good electrical performance.

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