# Amperage increase in DX potlines at EMAL

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## Abstract

Emirates Aluminium (EMAL) completed the greenfield start-up of Potlines 1 and 2 in January 2011, comprising 756 pots using DX Technology developed by Dubai Aluminium (DUBAL). The start-up was at 350 kA and increased to 354 kA gradually over the first year. From January 2012, amperage creep started at the rate of 0.60 kA per week in both potlines simultaneously and reached 366 kA by June 2012. After about two months of process optimisation, the second phase of accelerated ramp-up at the rate of 2.0 kA per week to 380 kA commenced in August and was completed at the end of September 2012. The third phase was delayed until September 2014 due to Potline 3 start-up and reached 388 kA by February 2015 following an amperage increase rate of 0.35 kA per week. Different control strategies were applied during the three phases of amperage increase in order to minimise the thermal disturbances in pots and optimise performance. This paper discusses the steps taken for smooth and safe amperage increase with minimum process disturbances. Performance results achieved during the process are discussed and compared with the pilot section of 40 DX pots operating at DUBAL.

**Keywords:** DX Technology; amperage creep; side shell temperature; bath voltage.

## 1. Introduction

EMAL Potlines 1 and 2 were started at 350 kA during 2009 and 2010 using DX Technology [1, 2]. The rectifier groups for each potline comprised five transformer-rectifiers, enabling an N-1 operating capacity at 350 kA. Within three months after completing the start-up, the amperage was increased to 352 kA. After confirming stable operation, the amperage was increased to 353 kA within the next three months and to 354 kA by the end of 2012. An upgrade project was on track to be completed by mid-2012, which would add a sixth rectifier to each potline and thereby increase the rectifier capacity to more than 400 kA. In January 2012, it was decided to increase the amperage slowly and steadily, even though N-1 condition would cause load reduction. By July 2012, both potlines reached 366 kA.

The sixth rectifier was commissioned in Potline 2 first and the accelerated amperage increase from 366 kA to 380 kA commenced from 7 August 2012. In the following week, the sixth rectifier was also ready in Potline 1 and the accelerated amperage increase commenced from 16 August 2012. Potline 2 reached the target amperage of 380 kA on 1 October 2012 and Potline 1 reached 380 kA on 8 October 2012. A performance test at 380 kA, carried out on a group of 30 adjacent reduction cells over a period of 28 days in February 2013, showed that DX Technology’s performance at 380 kA exceeded expectations and showed potential for further amperage increase [3].

By June 2014, DUBAL, the technology supplier to EMAL, had developed the design for the next generation DX Technology pot, capable of operating at 400 kA and beyond [4]. The DX generation two (G2) design involved a modified potshell and lining design. By mid-2014, the planned pot relining schedule based on a conservative cell age target of 1 900 days started in EMAL potlines. Accordingly, potshells that were turned around were modified to G2 design and installed with G2 lining design. As G2 design pots were designed for higher amperage, further increase in amperage was carried out, reaching 388 kA in March 2015. Figure 1 shows the different stages of amperage increase from 350 kA to 388 kA.

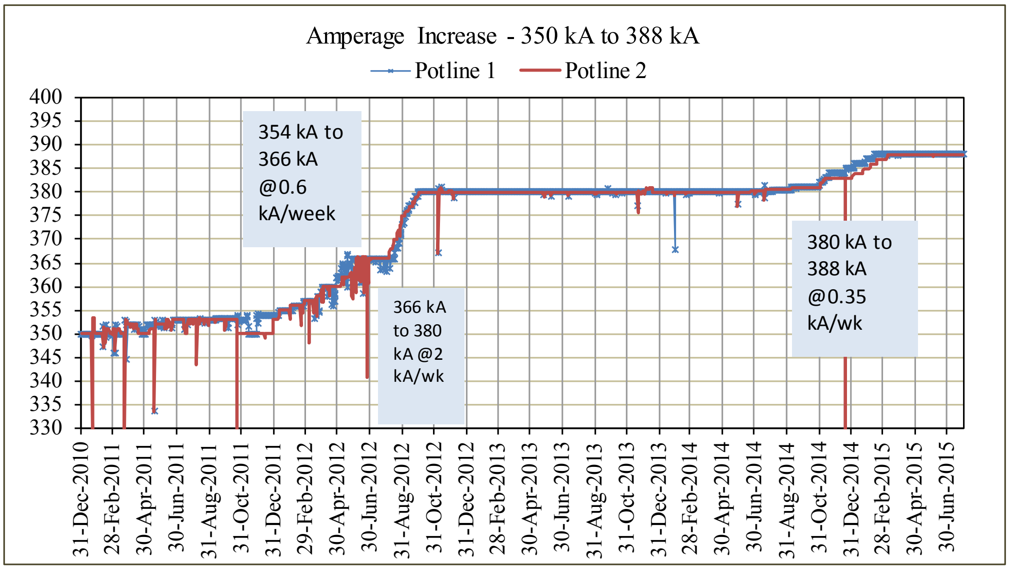


**Figure 1. Amperage increase in Potlines 1 and 2 from 350 kA to 388 kA**

## 2. Pot ages and failures

The first pot was cut out in April 2014 for autopsy at the age of 1 559 days and pot replacement started on schedule from July 2014. Potlines 1 and 2 did not experience any pot failures until December 2014. The first pot tapped out on 19 December 2014 in Potline 2, followed by only three more cases, as shown in Table 1. So few tap-outs for two large potlines show that the DX lining design is very good and the pot operation is well controlled.

**Table 1. Failed pots in EMAL DX Potlines 1 and 2.**

| Cell ID | Tap-out date | Pot age (days) |
|---|---|---|
| 2B062 | 19-Dec-14 | 1761 |
| 2B085 | 08-Apr-15 | 1859 |
| 1B142 | 24-Jun-15 | 1653 |
| 2B181 | 27-Aug-15 | 1891 |

As a part of the cell relining schedule, 38 % of the pots were replaced by the end of August 2014. About 10 % of the pots cut-out were selected because of increasing iron content in the metal (0.15 % to 0.30 %). This iron was suspected to come from collector bar attack, but only approximately half of these pots were observed during delining to have damaged collector bars. The remainder probably had smaller multiple collector bar attacks, which could not be seen during delining. The age distribution of pots cut-out until 31 August 2015 is given in Figure 2 and the statistics are given in Table 2.

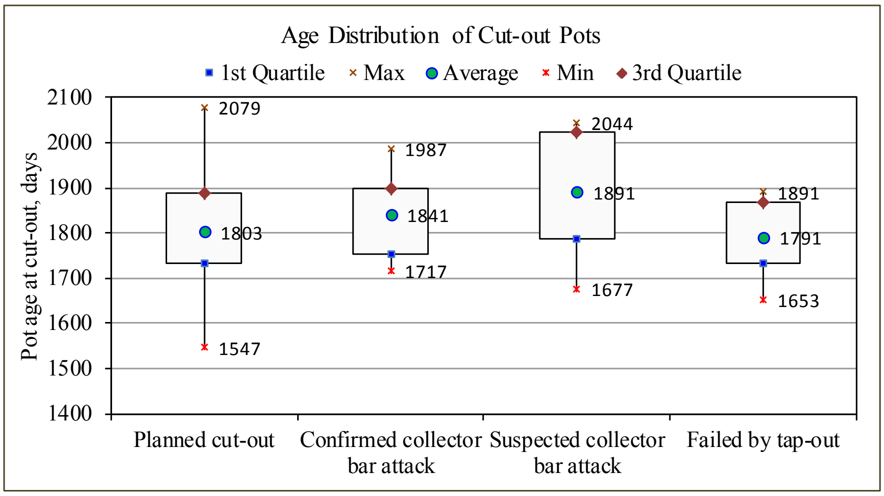


**Figure 2. Age distribution of cut-out pots in Potlines 1 and 2.**

**Table 2. Statistics of relined pots.**

| | Planned cut-out pots | Collector bar attack (confirmed) | Collector bar attack (suspected) | Failed by tap-out | Overall relined pots |
|---|---|---|---|---|---|
| Number of pots & (% of cut-out pots) | 251 (88) | 13 (4.6) | 16 (5.6) | 4 (1.4) | 284 (38 % of total 756 pots) |
| Average age, days | 1803 | 1841 | 1891 | 1791 | 1809 |
| Minimum age, days | 1547 | 1717 | 1677 | 1653 | 1547 |
| Maximum age, days | 2079 | 1987 | 2044 | 1891 | 2079 |

The age distribution of operating pots on 31 August 2015 is shown in Figure 3. The average age of operating pots from the first generation (G1) is 1 824 days. The predicted life expectancy of the first generation, based on this age distribution and on pot replacement schedule, is more than 1 900 days. This figure is expected to increase after the limitation of relining capacity will be relaxed, when more than 50 % of pots will have been replaced.

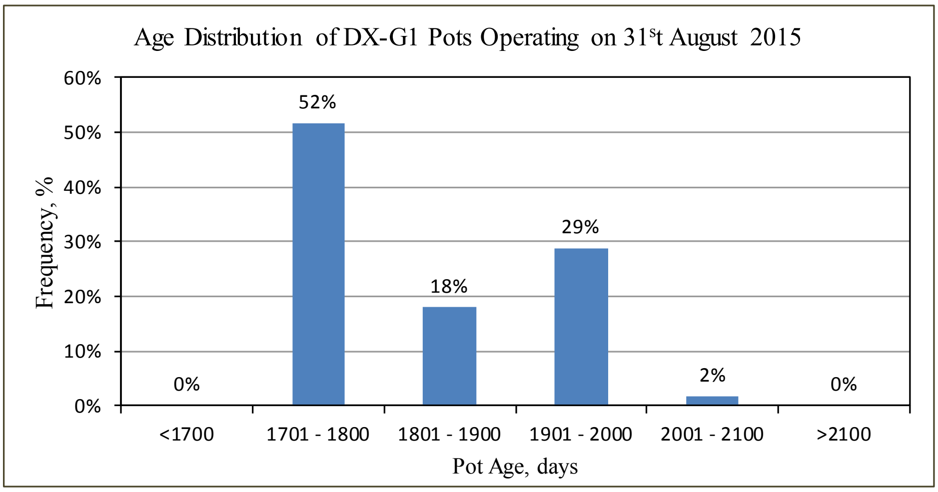


**Figure 3. Age distribution of DX generation 1 pots in operation on 31 August 2015.**

To understand the operational reasons for this performance, several operational results and strategies are reviewed.

## 3. Amperage increase from 352 kA to 380 kA

### 3.1. Amperage increase strategy

The adjustment of pot operation parameters for the amperage increase to 380 kA was based on the operation at 352 kA from March 2011 to February 2012. The change of pot operation parameters was based on model calculations, using the following compromise between three strategies – constant anode cathode distance (ACD), constant voltage and constant internal heat:

- ACD at 380 kA reduced by a maximum 7.5 % compared to 352 kA;
- Internal heat input at 380 kA increased by a maximum of 5 % compared to 352 kA.

As a consequence:

- Base Resistance Set Point (BRSP) decreased by a total of 0.42 µΩ, achieved in steps of 0.020 µΩ per kA up to 370 kA and 0.015 µΩ per kA from 371 kA to 380 kA;
- Net pot voltage at 380 kA increased by 35 mV compared to 352 kA.

Figure 4 shows the BRSP for the period in EMAL DX pots compared to DX pots in DUBAL Potline 8. The corresponding chart for net pot voltage is shown in Figure 5. At 352 kA, EMAL potlines were operating at lower bath temperature than DUBAL Potline 8 pots, therefore the planned voltage decrease in EMAL, during the transition period, was slower than in Potline 8. A step-change in the model at 370 kA is due to the assumption that the ACD would be kept constant from 370 kA to 380 kA. In practice, this was not required and the BRSP and pot voltage continued to decrease from 370 kA to 380 kA.

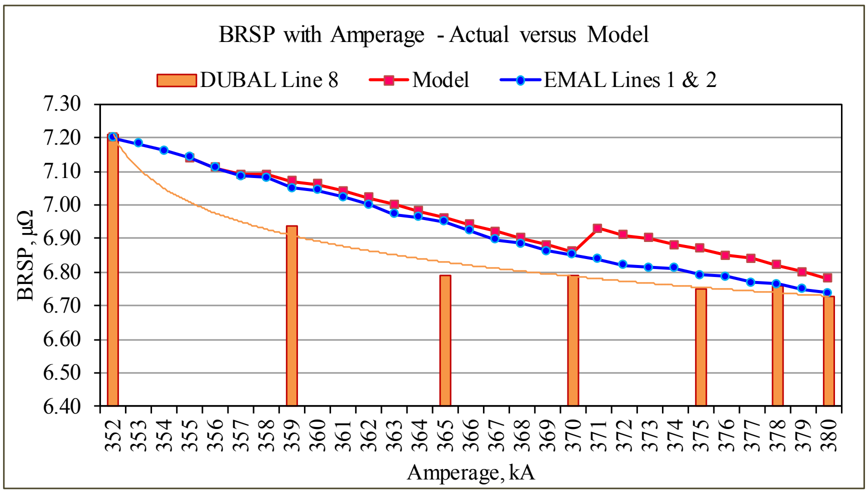


**Figure 4. BRSP with amperage increase – Model prediction versus actual in EMAL and DUBAL Potline 8.**

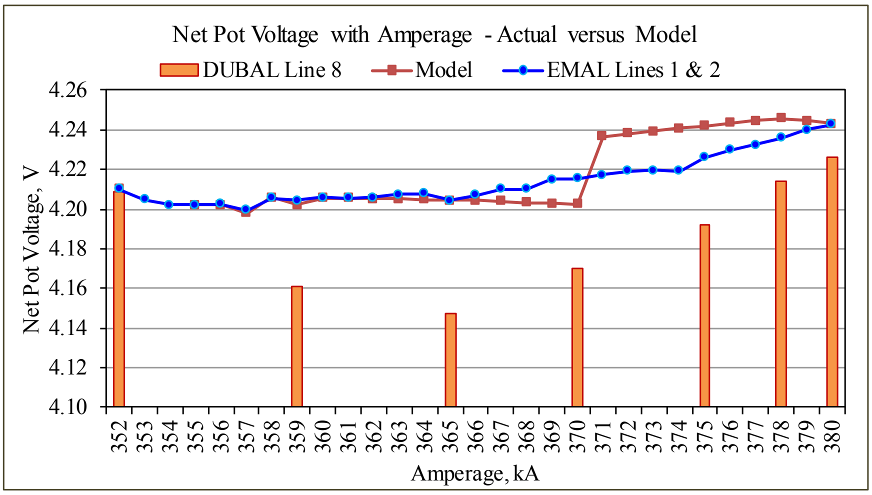


**Figure 5. Net pot voltage with amperage increase – Model prediction versus actual in EMAL and DUBAL Potline 8.**

From 366 kA to 380 kA, the amperage increase was accelerated to 2.0 kA per week and it took only two months to reach 380 kA. During this period, the thermal state of some pots was out of balance and some red potshells were observed. The situation improved after stabilisation of the amperage at 380 kA. At 380 kA, the pots were operated at the planned BRSP (varying between 6.72 μΩ and 6.76 μΩ) until August 2014, as shown in Figure 6.

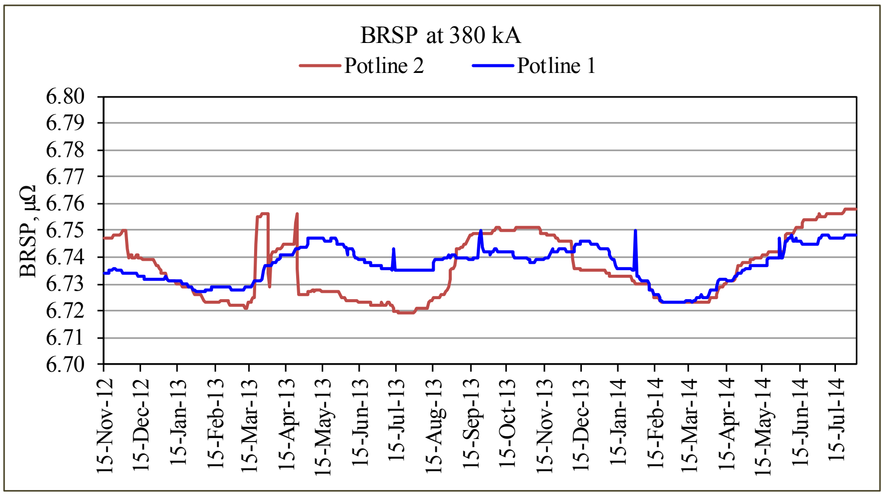


**Figure 6. BRSP in Potlines 1 and 2 at 380 kA.**

## 3.2. Monitoring and control in the potrooms

Specific monitoring of pot condition was not required during the initial phases of the amperage increase (up to 366 kA). Before commencing the accelerated ramp-up from 366 kA to 380 kA, the following monitoring and control strategy was implemented:

- No change to the metal tap table for three days after the amperage increase step;
- Daily “red shell survey” by shop floor team during the night covering the whole potline within one week and repeating the same the following week;
- Applying forced shell cooling with compressed air on red hot shells;
- Measurements of shell temperatures to monitor the freeze build-up, indicated by reduced shell temperature;
- Review of potline status every week to decide on the next step amperage increase.

## 4. Amperage increase from 380 kA to 388 kA

BRSP was reduced only marginally during the increase from 380 kA to 388 kA, which resulted in an increase in net pot voltage as shown in Figures 7 and 8, for the first generation (G1) pots. As can be seen, after reaching 388 kA, the BRSP and pot voltage were reduced and finally optimised to the same voltage as at 380 kA, which meant a net reduction in ACD.

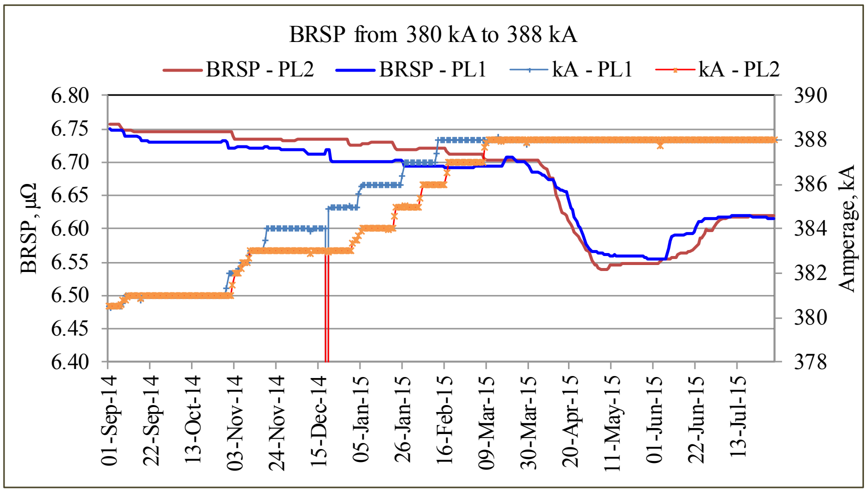


**Figure 7. BRSP reduction from 380 kA to 388 kA.**

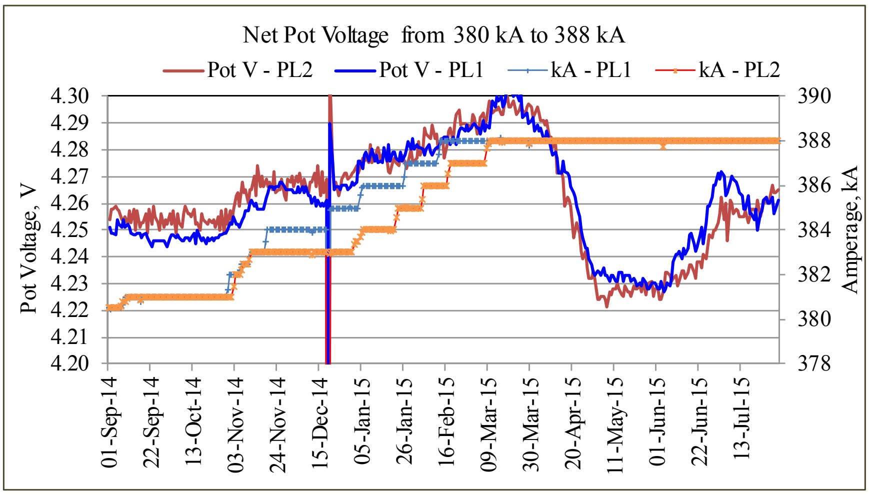


**Figure 8. Net pot voltage during 380 kA to 388 kA increase**

Figure 9 shows the BRSP reduction for established G2 pots (age > 56 days), after reaching 388 kA. At the end of this transitional period there were only 120 established G2 pots which were operating at 0.08 μΩ lower BRSP and 28 mV lower pot voltage than the G1 pots.

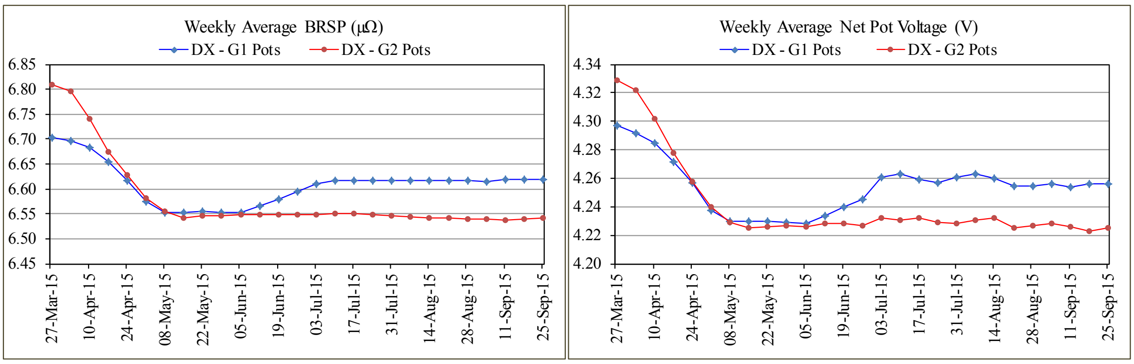


**Figure 9. BRSP and net pot voltage of G1 and G2 pots at 388 kA.**

## 5. Other control parameters at various stages of amperage

Monthly average side shell temperature, excluding red shells, as well as the temperature distribution at various stages of amperage increase, is shown in Figure 10. The shell temperature increased by approximately 50 °C during the amperage increase from 366 kA to 380 kA. Thereafter, the temperature remained at that level, indicating thinner side ledge than at lower amperages, but there were no pots with no freeze. The decrease in average potshell temperature from April to August 2015 is due to the G2 pots being included in the samples. The potshell temperature of G2 pots is approximately 60 °C lower than temperature of G1 potshells.

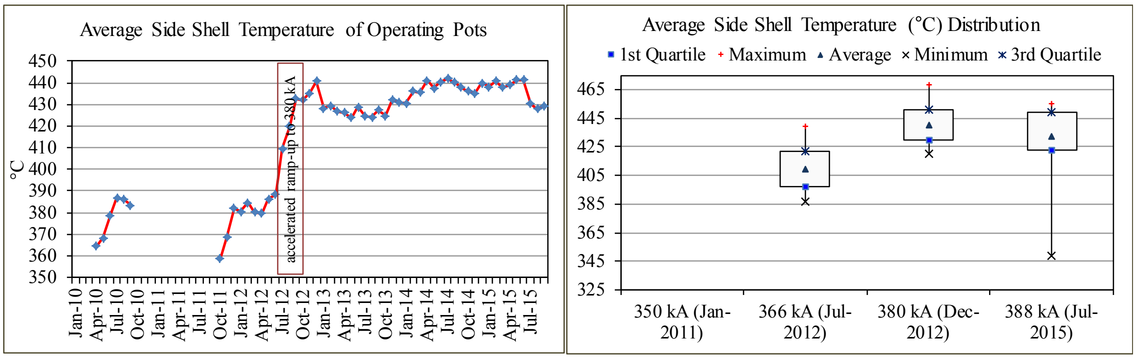


**Figure 10. Side shell temperature trend and distribution at different amperage levels.**

Figure 11 shows the age distribution of the operating pots, cathode voltage drops, metal levels and metal reserves as a function of amperage increase for G1 pots. The cathode voltage drop (CVD) increase is mostly due to amperage increase. The average metal level has been on target, which is constant at 18 cm for amperages from 366 kA. The gradual increase in metal reserve is the result of cathode erosion in old pots.

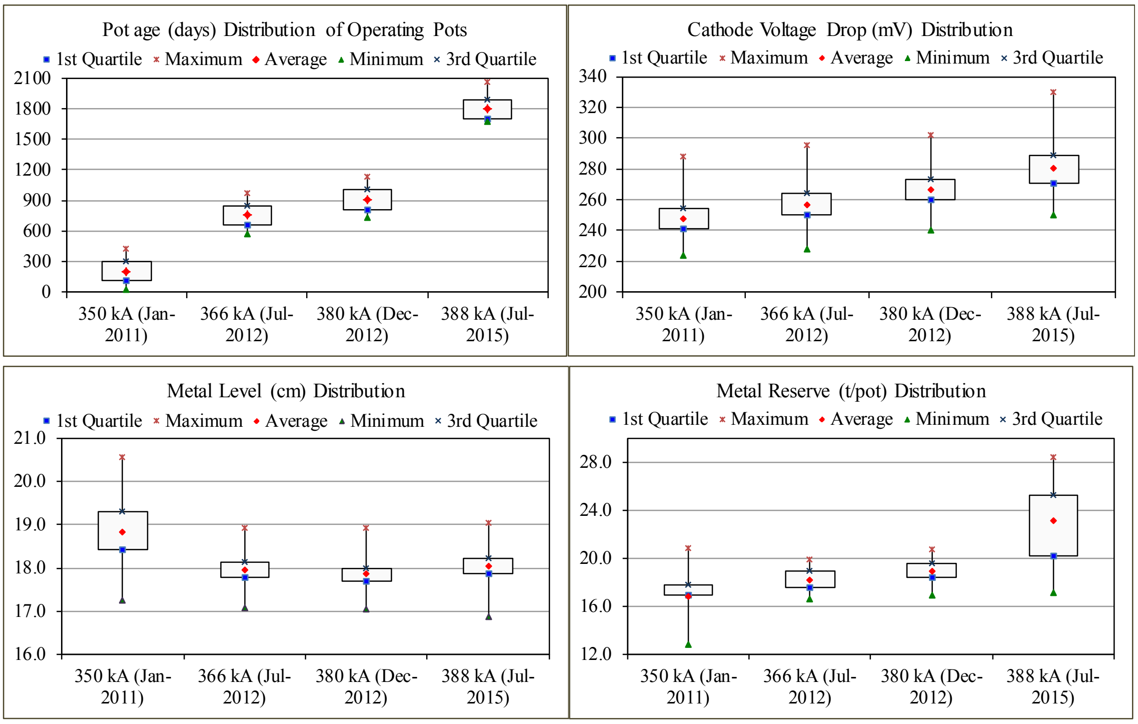


**Figure 11. Pot age, cathode voltage drop, metal level and metal reserve in operating G1 pots during various amperage levels**

Figure 12 shows weekly average values and standard deviation (SD) of Excess $AlF_3$ and bath temperature for G1 pots during the amperage increase. The excess Fluoride and bath temperature increased slightly during the whole period and as a consequence the superheat increased as shown in Figure 13. On a daily basis, the correlation between excess $AlF_3$ and bath temperature is used to identify abnormal pots with anode or $AlF_3$ feeder problems. Effective monitoring and control during the amperage increase resulted in low SD on Excess $AlF_3$ (< 1.5 %) and bath temperature (< 8 °C). The increase in SD observed from April 2015 is mainly due to an increase in anode problems.

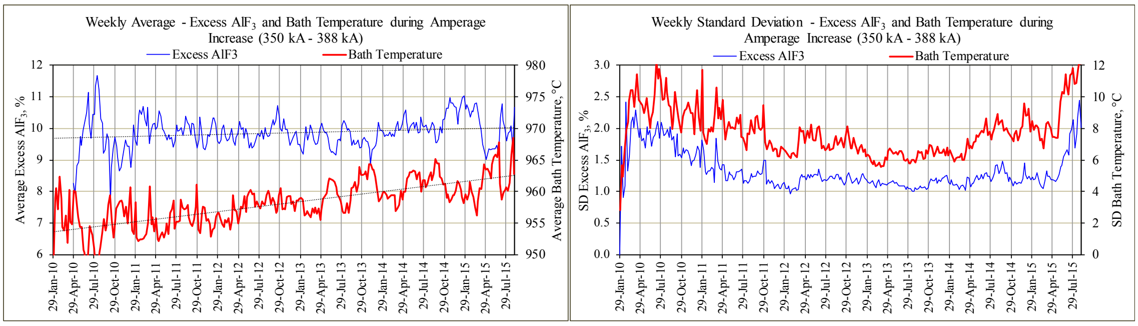


**Figure 12. Weekly average and standard deviation of Excess $AlF_3$ and bath temperature for G1 pots during amperage increase from 350 kA to 388 kA.**

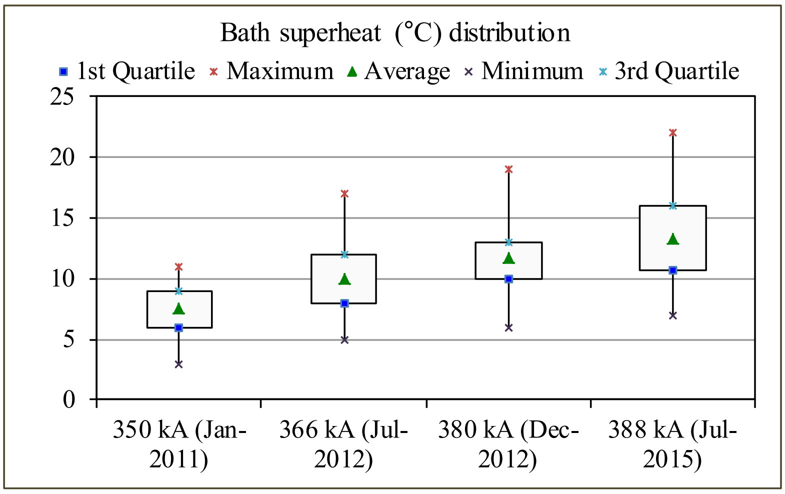


**Figure 13. Bath superheat distribution for G1 pots during various amperage levels.**

During the process of amperage increase, in order to facilitate heat loss at increased amperage, the anode cover thickness in G1 pots was decreased from 13 cm at 350 kA to 9 cm at 388 kA, as shown in Figure 14. During the same period, pot gas flow rate was increased slightly from 8 500 $Nm^3/h$ to 8 800 $Nm^3/h$.

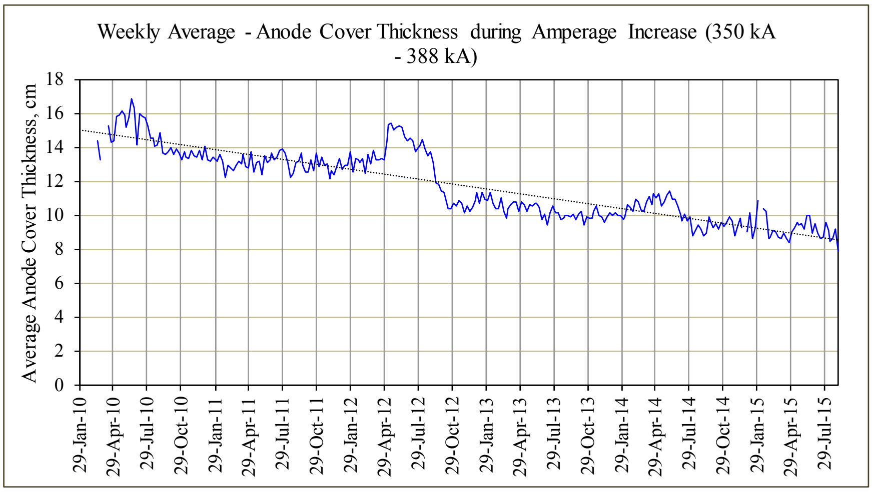


**Figure 14. Anode cover thickness for G1 pots during amperage increase (350 kA - 388 kA).**

Figure 15 shows the trend of iron (Fe) and silicon (Si) in metal during the period. Normal variation between 0.020 % and 0.040 % caused by changes in raw material is observed for Si which is indicating good side freeze stability. The increase in Fe seen from July 2014 is caused by a combination of anode problems and collector bars attack in some pots before cut-out for relining.

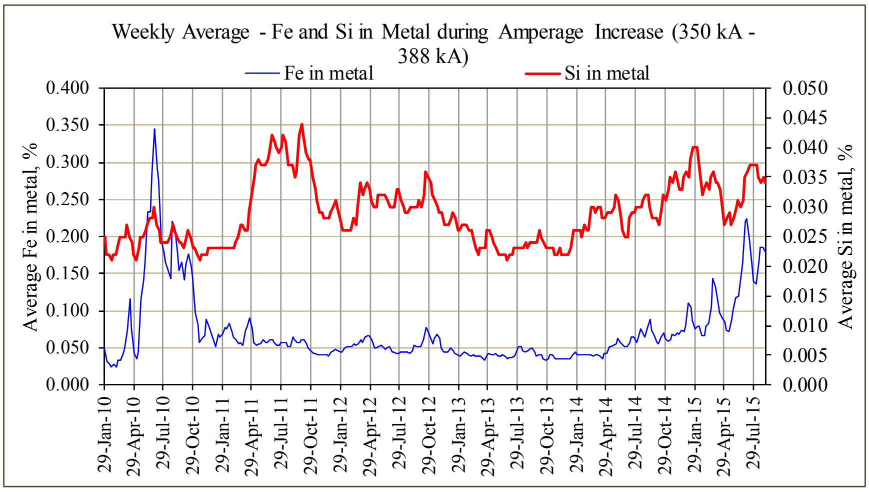


**Figure 15. Fe and Si in metal during amperage increase (350 kA - 388 kA).**

## 6. DX pot performance at EMAL

The operational performance of EMAL Potlines 1 and 2 has been reported earlier for different amperage stages [1, 3, 5]. Table 3 gives the key performance indicators (KPIs) of established pots (age > 56 days) during the whole period from start-up until 30 September 2015 and two other periods, at 380 kA and 381 kA to 388 kA. The performance was excellent throughout the whole period. Decrease in current efficiency is seen at 388 kA as shown in Figure 16, which is mainly due to an increase in anode problems experienced from April to August 2015 and due to intentional metal reserve build-up in July 2015.

**Table 3. KPIs of established pots.**

| KPI | Units | DX EMAL Jan. 2010 – Sept 2015 | DX EMAL Nov. 2012 – Jul. 2014 | DX EMAL Aug. 2014 – Sept 2015 |
|---|---|---|---|---|
| Amperage | kA | 368.7 | 380.0 | 385.3 |
| Current efficiency | % | 95.0 | 94.4 | 93.7 |
| Metal production | kg/pot-day | 2821 | 2887 | 2907 |
| Net cell voltage | V | 4.25 | 4.24 | 4.27 |
| DC net specific energy cons. | kWh/kg Al | 13.32 | 13.40 | 13.57 |
| Gross carbon consumption | kg C/t Al | 0.544 | 0.542 | 0.542 |
| Net carbon consumption | kg C/t Al | 0.418 | 0.418 | 0.418 |
| Bath temperature | °C | 958 | 960 | 961 |
| Excess $AlF_3$ | % | 9.9 | 9.8 | 10.1 |
| Fe | % | 0.051 | 0.040 | 0.069 |
| Si | % | 0.030 | 0.025 | 0.031 |
| AE frequency | No./pot- day | 0.10 | 0.06 | 0.06 |
| AE duration | seconds | 37 | 12 | 17 |
| PFC emissions $CO_2$ equivalent* | kg/t Al | 71 | 13 | 17 |

*$CO_2$ equivalent is calculated as in Reference [6], using the Tier 2 method and SAR (Second Assessment Report).

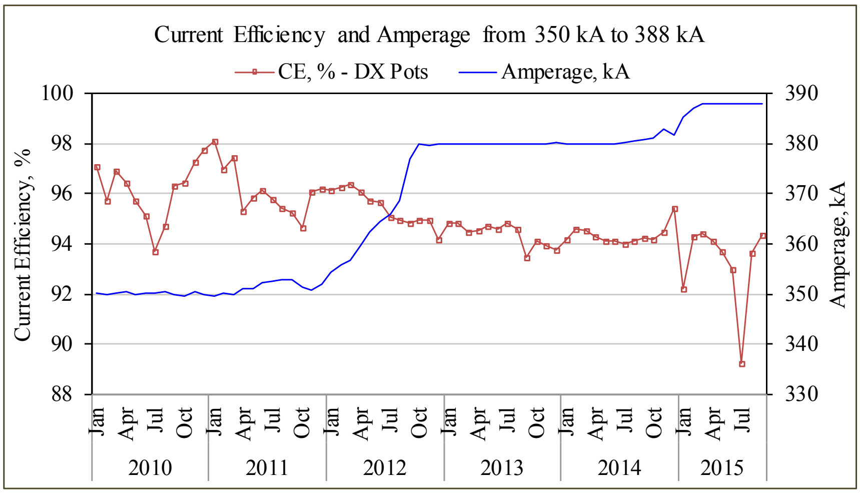


**Figure 16. Monthly average current efficiency of DX pots during amperage increase.**

## 7. Conclusion

EMAL Potlines 1 and 2 have successfully increased amperage from 350 kA to 388 kA, which increases the annual metal production by approximately 80 000 tonnes. The KPIs during the whole period were maintained at an excellent level. The potlining performance was also excellent with no failures during the first five years of operation. The potential for further amperage increase has been proven in DUBAL Potline 8, which opens the path to the future for EMAL potlines 1 and 2.

## 8. References

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