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ALUMINUM REDUCTION TECHNOLOGY

Potline Operations – Control

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UNDERSTANDING AND MANAGING ALUMINA QUALITY FLUCTUATIONS TO MINIMISE IMPACT ON CELL PERFORMANCE AND METAL QUALITY

Maryam Mohammad Al-Jallaf[1], Andries Louw[1], Gregory Meintjes[1], Arvind Kumar, Daniel Whitfield[1], Mohamed Tawfik Boraie[1], Ghedyer Hamad[1], K.G.Venkatasubramaniam[1], Akhmetov Sergey[1]
[1]Dubai Aluminium, P.O. Box 3627, Dubai, U.A.E.

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Abstract

The continuous technical improvements in Bayer process should improve alumina quality overall, which is not evident in the alumina shipments received at Dubal. Dubal receives alumina from various refineries in order to secure operations and optimise costs. However multi-sourcing can result in significant variation in process efficiencies and metal quality unless it is well controlled.

This study attempted to apply fundamental and practical knowledge about the impact of alumina quality by deployment of Silo Management Strategy to minimize the negative impact of the alumina and maximize value-added product. Moreover improvements in signal processing such as "near AE logic" and enhancements in alumina feed logic and operational procedures have been implemented to ensure that product metal quality is unaffected although such efforts incur significant costs and time.

An attempt has been made to financially quantify the impact of changes in alumina quality to balance the efforts of managing quality versus cost.

Alumina Manufacture

For this discussion it is useful to refer to the process flow chart for alumina manufacture as shown in Figure 1. The final morphology of the product, especially the particle size distribution and the crystal structure depends on the process conditions and ore type.

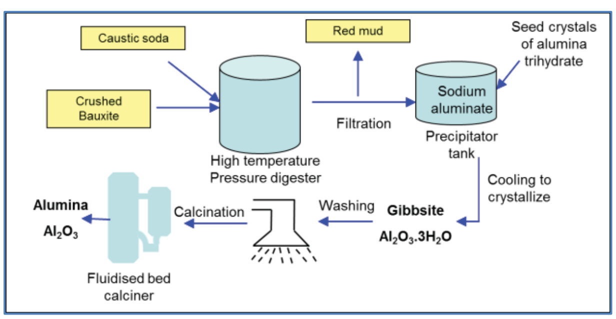

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Figure 1: Bayer process for alumina manufacture

The Bayer process includes a desilication step to remove any reactive silica that goes into solution as sodium silicate. Vanadium impurities that initially dissolve in caustic soda are removed as vanadium sludge by precipitating under controlled conditions. The particle size of alumina can be controlled at the refinery primarily at the precipitation stage when alumina trihydrate crystallizes out [1].Thus, the refineries have many methods at their disposal to control the quality of alumina. Many of these controls have been described [2].

During the last several decades, there have been many improvements in the Bayer process such as:

- Improved control of silica [3].
- Improvement in energy efficiencies of the various stages such as digestion [4], calcination [5] etc.
- Reducing soda loss [6].
- Developments in hydrate washing and solid –liquid separations [7].
- Improving the red mud filtration process [8].
- Applying process models /simulations [9].

Alumina Quality

Aluminium smelters negotiate contractual specifications with refineries for alumina since it a major raw material impacting electrolysis process efficiencies and quality of the molten metal delivered to the casthouse. The effects of alumina quality on the smelter are well understood [10] and some of the key issues are:

- Metallic impurities content is critical to end product quality.
- The flowability of alumina in handling systems and the dissolution of alumina affects many key operating parameters such as current efficiency, cell stability, energy efficiency etc.,
- Poor dispersion and dissolution characteristics can increase the probability of anode effect (AE) occurrence and also make it difficult to terminate AE quickly, thus causing increased perfluorocarbon (PFC) emissions that contribute to the greenhouse effect. Frequent or long anode effects affect cell performance and metal purity as well.

<u>Metallic Impurities</u>

Na_2O is a major impurity that can be controlled at the alumina refinery. Alkali and alkaline earth metal oxides react with AlF_3, consuming it to generate bath as described.

$$3Na_2O + 4AlF_3 \rightarrow 2Na_3AlF_6 + Al_2O_3 \qquad \textbf{Eq. 1}$$

$$3CaO + 2AlF_3 \rightarrow 3CaF_2 + Al_2O_3 \qquad \textbf{Eq. 2}$$

Varying Na_2O level makes bath chemistry control more difficult for smelters, while excessive CaF_2 levels in bath leads to alumina solubility issues. Both these can contribute to losses in current efficiency. In addition, AlF_3 being expensive, it is important for smelters to minimise its consumption. Therefore it is important for smelters that Na_2O as well as CaO in alumina are controlled by the refineries at optimum levels. Bath temperature control is one of the major contributing factors for efficient pot performance [11]. Limits for impurities such as oxides of Fe, Si, V, Ti, Zn and Ga [12] are contractually stipulated by most smelters as they affect the end product quality.

Particle Size Distribution and Flowability

In the older bar breaker designs alumina is typically fed once in half hour to an hour in fairly larger quantities ranging up to 50 kg and hence alumina concentration in bath is maintained at high levels far from levels that may induce anode effect. For these cells flowability of alumina is not so important. However, with the advent of point feed technology adopted in modern cells, alumina flowability has assumed more importance [13] since point feed cells operate in a narrow alumina concentration range, typically 2-3%, and only few kilograms of alumina is fed every minute. Thus, any deterioration in the flow characteristic can lead to anode effects. Hence smelters typically test the flowability using a flow funnel test and also measure the angle of repose.

Uniform particle size distribution with low content of fines (-40 µm) and superfines (-20 µm) is important for good flowability and the Bayer process can control particle size distribution. While smelters typically specify upper limits for fines and superfines, the size distribution within the fine fractions is also important. High percentages of fines (>15%), especially super fines (>7%), will lead to an increase in dust formation and less alumina entering the bath. Coarser "sandy" alumina produced by fluidised bed calcination is preferred by modern smelters as it flows better and is more uniform in quality as compared to the finer "floury" alumina produced by rotary kilns.

Fluctuating fines can cause severe temperature swings as shown for a Dubal potline section in Figure 2. As fines % increases, dump weight reduces and pot comtrol system increases the alumina dumps to adjust for this. Thus the number of dumps is an indirect indication of fines being fed to the cell. In the figure it is seen that as dumps increase the temperature increases and vice versa. Fines % has increased in the alumina received at DUBAL over the years significantly as seen by comparing averages of 3-4% a decade ago vs. 7-10 % currently. Perhaps this is due to the productivity / economic pressures on refineries.

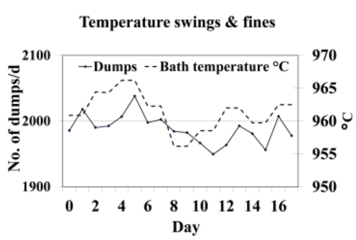


Figure 2: Temperature swings & alumina quality

Another related property is the alumina particle strength, usually specified by the attrition index, a measure of how much the alumina grains break down during pneumatic conveying. This is a useful indicator to control dusting. Lower attrition is desirable. Testing of the attrition index is difficult, and there is no single industry wide standard [14].

Alumina Dissolution

As mentioned earlier, fluorides of Ca (as well as that of Mg and Li) reduce the saturation solubility of alumina in molten cryolite. Each 1 % increase in CaF_2 content in bath can reduce saturation solubility of alumina in bath by ~0.2% [15]. The saturation solubility influences the alumina dissolution speed. High percentage of CaF_2 increases the bath density and can lead to bath metal mixing and loss of current efficiency (CE).

As modern cells operate at lean alumina concentrations, anode effect (AE) occurs if dissolution rate is slow [16]. The particle size distribution, flowability, alpha content and Loss on Ignition (LOI), of alumina influence the dissolution. High alpha content in alumina reduces dissolution rate and forms sludge in cells causing higher cathode drops, loss in efficiencies as well as poor crusting. A decade ago the alumina supplies received at Dubal used to be having alpha content consistently close to 2-3% whereas currently there are significant number of shipments being received with 6-7% perhaps due to the changed operating parameters at the alumina refinery. High LOI can increase fluoride emissions from the cell, though the turbulence created by release of moisture aids dissolution.

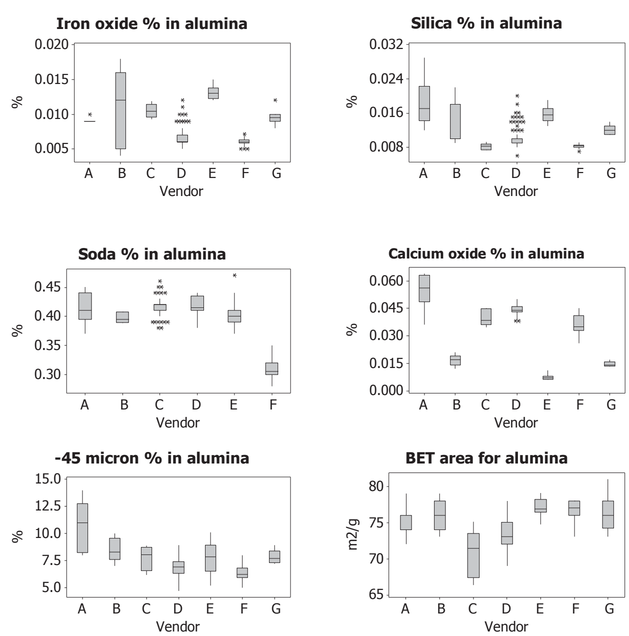
Control of Alumina Concentration and Risk of AE

Since point feed cells use a volumetric feeder, the bulk density of alumina needs to be within a narrow range and alumina should flow well. For this, a consistent particle size distribution is important. With fine alumina, flowability and dump weight get reduced and at times the control system can't increase the alumina concentration quickly enough before AE occurs. Also, the number of breaker feeder operations per day increases, along with increased breaker wear and air consumption.

Thus, it is seen how the various chemical impurities and physical properties can impact metal quality and potline, FTP operations.

Variability in Alumina Shipments Received at Dubal

Variation in some of the important alumina quality parameters is shown in Figure 3 covering shipments to Dubal for about five years. This has been described using box plots as this provides an effective visual representation for comparing groups of data.



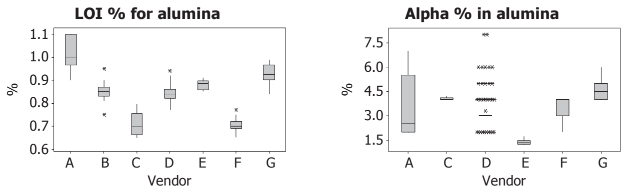


Figure 3: Variability in alumina shipment quality

The graphs in Figure 3 are indicative only and a direct one to one comparison of the vendors cannot be carried out based on these graphs since the number of shipments from the vendors vary from a few to many as illustrated in Figure 4.

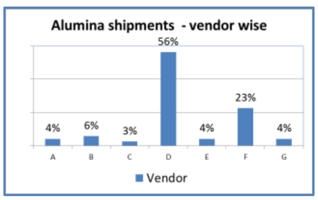


Figure 4: Distribution of alumina shipments across vendors

It is evident from these graphs that the quality of alumina from the different vendors is not the same and points to the need to manage distribution and consumption of the aluminas from different vendors effectively so that the variation affects neither the end product metal quality nor the process efficiency significantly.

The adsorption of moisture by alumina during handling depends on access to humid air as well as the quality. For each vendor, the monthly average moisture/LOI data was plotted against the corresponding monthly average relative humidity percentages to see if there is any correlation and none seen for any of the data sets. Two of the graphs from one particular vendor are shown as examples in Figure 5. Perhaps the robust handling systems used at DUBAL provides little opportunity for adsorption of moisture during ship unloading and storage and hence there is no effect if the humidity on moisture or LOI.

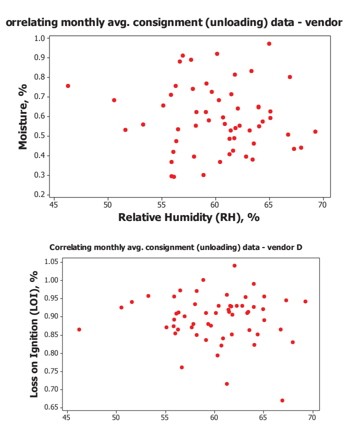


Figure 5: Lack of correlation of moisture and LOI with RH

Similar graphs plotted for other vendors showed no correlation as well.

Additional Concerns for the Smelter

Besides the alumina quality issues discussed so far, there are a few concerns faced by Dubal and possibly other smelters that source alumina externally.
Negative trends in some parameters:
There has been also a noticeable increase in alumina fine content received in shipments to Dubal over the last several years as seen in Figure 6. This contrasts with the advancements in the Bayer process control technologies listed earlier. Clearly, other factors are at play.

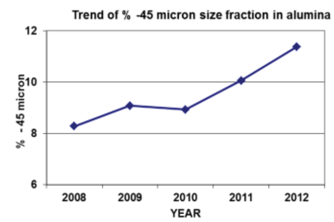


Figure 6: Trend in alumina fines

There has also been trend towards increasing soda levels in alumina, especially from some of the vendors which increases cost to Dubal in terms of higher AlF_3 consumption and increased bath generation.

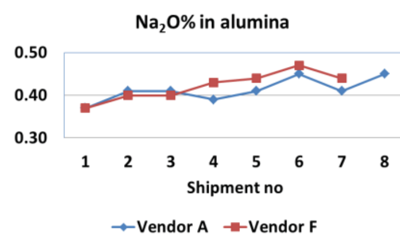


Figure 7: Trend in soda in alumina

Dust Recycling by Refineries

Another point of concern is the presence of cyclone dust in alumina. Due to economic reasons, refineries recycle fine dust captured at the electrostatic precipitator by blending it with the alumina shipped [17]. This is undesirable for the smelters due to its particle size and some of this dust may be lost in handling as well. In addition, the dust contains substantial amount of gibbsite, that can cause "geyser" formation in point feed cells [18] affecting delivery of alumina into the cell as shown in **Figure 8**. Unfortunately, gibbsite content is not always specified in many of the contractual agreements or monitored.

Feedback obtained from most refineries revealed that gibbsite is not monitored in the end product especially since only small amounts were expected and there was no method available to carry out such a measurement easily. It has been mentioned that control of gibbsite to very low levels is possible using modern calciners [19]. The difficulty in measurement of gibbsite in alumina refineries is acknowledged in a recent paper published [20] which describes a new method based on near infra-red reflectance as an alternative. Despite the limitations mentioned, an attempt was made to find if the presence of $Al(OH)_3$ could be at least qualitatively detected in the consignment alumina received from different refineries by using classical X-ray diffraction. Out of ten samples that were scanned, $Al(OH)_3$ was detected in eight, though the species were detected in some cases as Nordstrandite or Doyleite, these being polymorphic forms of Gibbsite. No quantification was possible due to lack of standard procedures and possibly the low amounts present.

Figure 8: Geyser formation

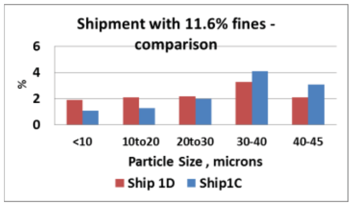


Figure 9: Size distribution of fines

Issues Related to Specifications and Testing

While there are many alumina properties that are tested by all the refineries, there is no standard criterion that has been agreed to between refineries and smelters for issuing test certificates. For example, some of the trace element impurities or the attrition index may not be measured. Very few smelters ask for particle size distribution curves for the alumina or for the minus 20 micron and just specify the minus 45 micron content, even though most refineries possess the equipment to measure the size distribution using laser based analyzers and such data is available. To illustrate this point the particle size from 45 microns and below for several consignments were measured using a laser scattering method and comparison of two results is shown in **Figure 9**. Even though both aluminas have 11.6% fines (minus 45 micron) shipment 1C is superior as it has lower amount of very fine material. Gibbsite is another property that is seldom discussed between refiners and smelters even though it is accepted generally that higher gibbsite content is not desirable.

Another issue is the method of testing. Not all refineries use the same measurement method. For example there is no common industry-wide method for attrition index [14].

Managing the Impacts

Dubal is managing the variations in alumina quality through a multi-faceted strategy that encompasses:

- Alumina silo management and management of distribution to potlines.
- Improvements in signal processing that have been developed in house as part of the DX and DX+ technologies and being cascaded to the other potlines at Dubal; a specific example is the "near AE logic" that detects AE in the incipient stage and quenches before it becomes full-fledged.
- Improvements in the alumina feeding logic that adjust to changing alumina quality so that disturbance to the process in minimised though not eliminated.

These actions ensure that the end product metal quality is not affected, although Dubal incurs significant costs and time due to the extra efforts taken.

Silo Management and Distribution

Dubal dock receives alumina shipments of sizes varying from 25000 to 60000 mt unloaded into six silos that provide flexibility for isolating different shipments and managing distribution to the 15 potline primary silos through road tankers of 40-50 mt capacity. Four silos (60t ea.) are used to store alumina at the anode baking kiln FTP's.

Stakeholders in the various areas of the process stream from dock to cast house are involved in the planning. Shipment schedules, sizes and sources are reviewed quarterly and plans made for distributing shipments to specific silos and from there to specific potlines. Impact of alumina on metal production is estimated taking into account the casthouse commitments to meet customer specific needs. However, for spot shipments, where the source is known only before shipping, test certificate and loading sample is received a month prior to scheduled ship arrival date and this analytical data utilised in decision making. The flow of alumina to potlines is depicted in Figure 10.

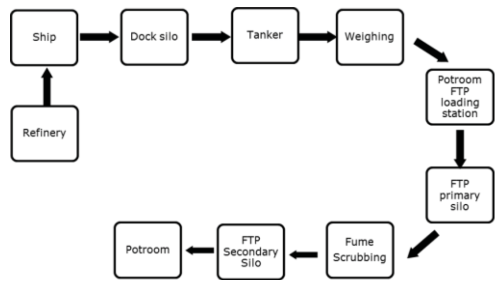


Figure 10: Flow of alumina from refinery to potlines

Typically planning will specify how alumina is withdrawn from specified silos and supplied to nominated potlines. Planning will target to isolate a poor quality shipment and mix or blend it with other shipments and avoid sending it specific areas of the potlines where the alumina may cause more problems. These instructions will be accompanied by a table detailing the dock silo levels, type(s) of alumina stored in them and the analysis.

When silo levels become low, the discharged material will be finer due to fines getting deposited at the sides during discharge. To minimize impact of such material, flow time for alumina is measured by sampling each tanker prior to dispatch and if more than a predetermined limit the tanker is declared as "fine tanker". Distribution of fine tankers to the same location is restricted so as to dilute the impact. Typically, more than 120 tankers are issued to potlines daily, so this requires good coordination all around.

There are several limitations in managing the silo filling and supply to potlines, and keeping the strategy simple enough to execute is also important. The limitations are as follows:

- Persistent deterioration of quality as shown in Figure 6, can constrain the smelter's ability to mitigate deleterious effects.
- Disruption due to machine breakdown or shipping problem can affect the planning. Furthermore delay in the unloading is expensive, as it has a demurrage of about 10,000 US$/ day and more depending on the ship size.
- Frequent variation in properties such as Na_2O or fine fraction has more impact than a steady change.

- Dubal supported the startup of Emal smelter by receiving their alumina shipments then trucking to Emal through road tankers. During this time, flexibility in silo allocations was limited and the number of tanker trips per day increased by 81% as compared to normal internal requirements.
- Dubal has been continuously ramping up production through the years, but the silo capacity has not kept pace as demonstrated in Figure 11. This further reduces the flexibility in managing alumina storage and supply.

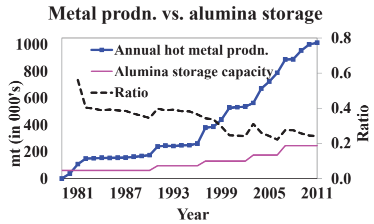


Figure 11: Production trends & silo capacities

Thus, many of the steps for managing aluminas from different sources and supplying to specific potlines can minimise the negative impact of alumina quality fluctuations subject to the above limitations.

Improved Signal Processing and Controls

The link between alumina fines and AE and thus the environment as well as operational efficiency was mentioned earlier. If excessive fines are present in the alumina, typical pot control systems will over feed the pot, in an attempt to correct the alumina concentration in the bath, resulting in more sludge being formed. Improved signal processing combined with the near AE logic developed by Dubal has helped overcome the risk of this over feeding and sludge formation.

Good Operational Practices Reduce Load on Scrubber and Alumina

There is a need to compromise between adequate surface area of alumina to absorb HF in the scrubber and minimizing pick up of moisture during handling. Recirculating alumina in scrubbers to minimize emissions contributes to degradation of particle size.
It is known that emissions from cells increase dramatically due to open holes in crust [21]. DUBAL has good operational controls to maintain cells with good cover on the crust. By sustaining such practices, the load on the scrubber and potential degradation of the alumina should reduce. At DUBAL, a cell meeting all requirements is expected to have an in house index measure of 100%. The histogram shows that most cells are at 98% and above.

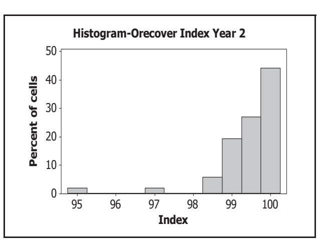


Figure 12: Excellence in cell covering practices

Improved Control Strategy

Several other continuous improvement activities at the Dubal smelter [22,23,24] also contributed to mitigating the negative effects of variable alumina quality, some of these being:

- Improving energy balance in the electrolysis cell for better alumina dissolution, by adjusting the feed rates and durations for the different feed windows.
- Optimising the anode setting practices and energy inputs during anode setting, and combining with improvements in feed control during and following anode settings.
- Fine tuning the logic for automated base feed rate adjustments, to respond quickly to changing alumina quality.
- Involving the workforce in improvements, refreshing their knowledge and sharing best practices across potlines.

In summary, Dubal has managed the fluctuations in alumina through a combination of effective silo management, implementation of new signal processing and control systems as well as improved control logic for alumina feeding, supported by involvement and training of the workforce. While Dubal has been mitigating the effects of variation in quality, there are still costs incurred by the smelter. The saying "there is no free lunch" is apt to mention here. When these costs start increasing, it is likely that the smelter would need to impose financial penalties as part of the contractual agreement for alumina supply.

While some of these, such as increased efforts in management are more complex to assess financially, though there are some effects which can be quantified financially and the following section addresses this aspect.

Financial Impact

In this section, it is illustrated how the effects of changes in alumina quality can be quantified financially as this will be of interest to all the stakeholders in refineries and smelters. Impact of out of specification alumina on the process has been estimated thorough a mixture of empirical and theoretical analysis for several parameters as illustrated in Table 1.

Major Impurities

The impact of high Na_2O and CaO is mainly due to the additional AlF_3 required to maintain the appropriate AlF_3 concentration level as shown earlier in Eq. 1 and Eq. 2.

Fines (-45 micron)

The impact of alumina fines was estimated from previous experience [25]. Simple linear correlations were used to give an approximate estimate of the impact of high fines on specific energy and AE frequency.

$$\Delta SE = 0.023 \times (Fines\,\% - 10) \quad \textbf{Eq. 3}$$

$$\Delta AEF = 0.014 \times (Fines\,\% - 10) \quad \textbf{Eq. 4}$$

Where: ΔSE = Change in specific energy
ΔAEF = Change in AE frequency
Fines % = -325 mesh

Minor Impurities

The increase in metal impurities from high Fe_2O_3, SiO_2 in the alumina was calculated using a simple mass balance and the results used to estimate the change in metal grades distribution, and consequently the loss in premium. Various impurities have been claimed to adversely impact current efficiency and one such impurity is silica. Using the coefficients published [26] changes in the silica level of the alumina can also be expected have an economic impact as shown in Table 1.

Moisture/LOI

Inadequate calcination of alumina leads to increase in moisture content. Thus increase cost of alumina to the smelters proportionately as they pay for moisture rather than alumina. The additional moisture is expected to increased HF emission at time of alumina dissolution and put more load on the FTP operation, though the economic impact of the later is complex to estimate.

Table 1: Economic impact due to off spec alumina (example)

Spec.	Above specs.	Issue	Value	US$/ mt Al
Si	5 ppm	Lower CE,%	0.023	0.14
		Less premium grades, mt	365	1.23
Na_2O	0.01 wt.%	Higher AlF_3 consumption kg/mt Al	0.39	0.47
CaO	0.005 wt.%		0.05	0.09
-45 micron	5.7%	Higher SE DC kWh/kg Al	0.13	4.64

Conclusion

DUBAL, a high quality aluminium producer secures its alumina supplies from around the world but this introduces variability in the quality. The smelter has employed several techniques to manage these supplies and ensure product metal quality is maintained.

The first one is the deployment of silo management to manage receipts, storage and dispatch of alumina to the potlines. Another initiative to deal with anode effects caused by alumina solubility, fines or related quality issues, was the improvement in signal analysis and processing. This was part of the new DX and DX+ cell technology development cascaded to all the potline. Another was introduction of new logic such as the "near AE" logic introduced to detect and prevent AE occurrence at the nascent stages. These initiatives were supported by improvements in alumina feed control strategies and operational practices and complemented by involvement and training of the workforce. No doubt, such initiatives mitigate the negative effects of alumina quality fluctuations but the smelter incurs a cost due to the efforts taken and the residual effects that are not neutralized by such initiatives. When the costs become significant, the smelter would then need to include financial penalties related to quality as part of the contractual agreement.

The issue of deterioration in alumina quality in the light of enhanced controls available at the Bayer plant merits further discussion. The need for a uniform industry wide alumina specification and testing standard has also been highlighted.

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