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KEY PHYSICAL PROPERTIES OF SMELTER GRADE ALUMINA

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Abstract

The properties of Smelter Grade Alumina, SGA, vary from refinery to refinery, and they also vary over time. Some physical properties, such as high fines content, have the potential to impact key smelting performance indicators more than others. These may affect production efficiency as well as environmental performance. Often the barriers to optimal performance have as much to do with the equipment that is used to handle alumina, its layout, and how alumina inventories are managed, as with the physical properties of SGA. In this paper the author offers insights into which parameters are key focal points; for the properties of SGA, and upon handling equipment & methods.

Introduction

When one thinks of the physical properties of SGA the factors that are related to particle size distribution first come to mind. The focal points may be; the %+325 mesh, or the %-20μm in shipments. These certainly are of importance. They also help to define other physical properties such as; angle of repose, loose bulk density, packed bulk density, and Hausner ratio, H_r, (P.B.D./L.B.D.) [1]. The properties of SGA also give indications about what the alumina will be like at the point of feeding.

The Attrition Index, or %A.I., is often reported on the Certificate of Analysis, or CoA. It is a measure of particle toughness, particularly at velocity in an airstream [2]. However, %A.I. testing methods are not standardized across the industry. Comparing the results from one supplier to another for this parameter can be difficult. The %A.I. also only tends to have particular meaning when a client smelter clearly understands its own propensity towards breakage of alumina particles.

Physical properties such as flowability may or may not be reported on the CoA. As with %A.I., there is no standardized test method across the industry. This is unfortunate, as ultimately, the factors that put alumina particle size distributions on a level playing field are those that are important during handling and at the point of feeding. Flowability is one of these parameters.

When alumina arrives to the reduction cells the; %-325 mesh, %-20μ, angle of repose, loose & packed bulk density, and the flowability have changed from those of pure alumina. But, these properties at the point of feeding are seldom measured. In many cases the smelter only has the data that is reported on its CoAs.

The purpose of this paper is to provide insights on how to interpret and apply information provided on alumina shipments. It also touches upon the factors that smelters should measure and study themselves with regard to physical properties of alumina at the reduction cells. These include considerations on attrition of particles by handling equipment and segregation of alumina in storage and in transit.

Discussion – Impact upon Process Outcomes

Lillebuen reports that "It is not possible to get maximum current efficiency unless we maintain a clean cell bottom…Maximum current efficiency therefore requires alumina with stable quality; low in fines and superfines…"[3]

Behrens has reported that "In their work (Karlsen & Dyroy) they have demonstrated that a significant part of excess dust emissions and anode effects can be correlated to pulses of fine material passing through the alumina transport system."[4][5][6] Similar claims about fines content and poor flowability have been made RTA Bell Bay on the causes of anode effects.[7][8]

Wang reported that particle size distribution, "PSD, especially superfines (-21 μm)" had a strong impact of the maximum dissolution rate of alumina and the tendency to form muck that leads to instability and current efficiency loss.[9]

Data from multiple smelting locations and various cell technologies confirm these statements. Examples from Location A are shown for one smelter in figures #1 and #2.

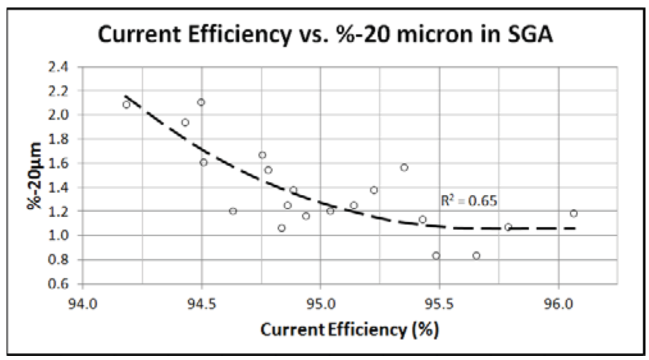

Figure 1 – Example #1 of current efficiency vs. %-20μm in SGA

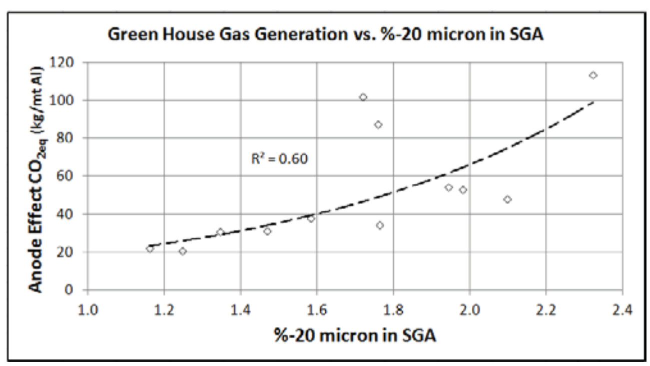

Figure 2 – Example of %-20μm vs. Green House gas generation

As the data indicates, correlation exists between process outcomes and the physical properties of alumina that are related to -20 micron content. However, there is nothing that is fundamentally different about an alumina particle that is 18 µm in length along its secondary axis vs. a particle that is 22 µm in length. Both affect the packing and flowability of alumina powders [10] quite similarly. How these particle sizes interact with the remainder of the PSD is what is important. The affect of -20 µm content upon the packing and flowability of an underlying coarse PSD is much different than that its affect upon a relatively fine PSD.

This interaction effect is at the core of many of the physical properties of bulk alumina including; loose bulk density, packed bulk density, Hausner ratio, and angle of repose.

Experimental Method – Data Analysis

Before going in to greater detail on these matters some discussion on the experimental method, or data analysis methodology, that has been applied, is appropriate.

There are many common causes and special causes of variation that can affect process outcomes such as current efficiency, energy efficiency, and the generation of green house gas from aluminum reduction cells. Thus, the signal to noise ratio of the weaker effects can be difficult to discern. The impact of small shifts in particle size distribution may easily go undetected. Of course, there have been some notable exceptions with some special causes of variation to alumina quality. In these cases the signal has been quite clear as to the cause of muck formation and disturbances to cell thermal stability and performance.

To separate the signal from the noise under normal conditions it is common to apply filtering techniques. This has been done with historical process data from a number of Alcoa smelting locations.

Accurate assessments of shifts in current efficiency can be particularly difficult. Short term measurements on individual pots can be both time consuming and expensive with the application of special methods.[11] Since the data studies considered here have involved long periods of time (years in most cases) during which the physical properties of alumina were either manipulated by intent or for other reasons an accurate period for the assessment of current efficiency was all that was needed.

Month by month data was first considered with some measure of success. But, the time required to accumulate muck caused by moderate shifts in alumina particle sizing ($\geq$0.3% shift in -20 µm content) and flowability ($\geq$3.5 sec 4mm funnel) can easily extend beyond periods of weeks. Quarterly averages were then selected for analysis with a greater degree of success. While data from one annual quarter to the next is auto-correlated, not independent, it does supply a sufficient analytical window for being able to observe both cause and effect of shifts in alumina PSD.

Even with this amount of data filtering the signal does not always emerge from the noise for every smelter. So, some general rules have been developed for this type of analysis:

1) The period of study must be over at least 15 months of stable operation with no major process upsets or changes.
2) There must have been one, or more, shifts over 3 months of duration, of $\geq$0.3% -20 µm or $\geq$3.5 seconds of Alcoa 4 mm orifice flow funnel time.
3) If a process change has been made that can have a significant impact on the rate of alumina dissolution, then this data must be considered separately. An example of this is the addition of slots to anodes.

Obviously, these conditions can be difficult to meet over long periods of time at many smelters. It is difficult to maintain well-controlled experimental conditions, especially in an operating environment. For this reason the method has generally been most successful when there have been distinct and moderate to severe changes in the physical properties of alumina being used. When these conditions have been met some very interesting data has emerged from the background process noise.

Discussion – Flowability

Hsieh, Matocha, and Elbiki have all described the relationship between the flowability of alumina through a funnel of precise dimensions and the %-20 micron content of SGA.[12][13][14] When known quantities of sized, -20 micron, material has been added to an SGA baseline sample excellent correlations to flowability have been clearly observed. Refer to figure #3.

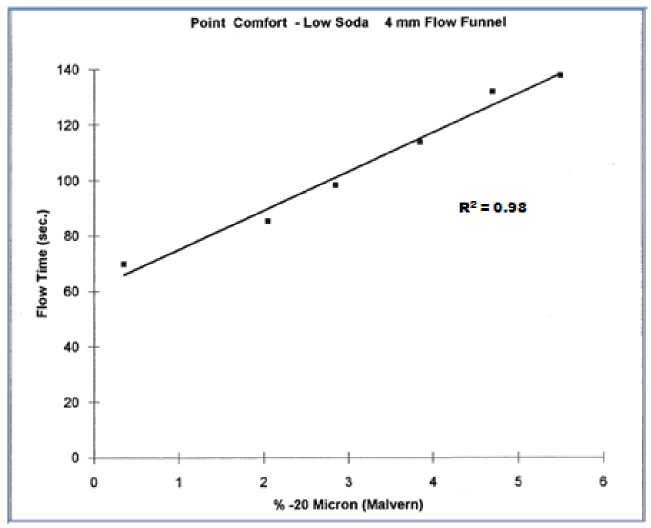

Figure 3 – Example of funnel flow time vs. %-20 µm content

Elbicki noted that "The empirical relationship between % -20 micron fines and flow time is linear, but a universal line does not exist. The slopes and intercepts are not the same for different locations." These differences have been ascribed to variations in the overall PSD of alumina. However, the trend is clear. Finer particles do have a clear and predictable impact upon flowability.

This trend was consistent for all types of alumina that were studied. But, some had much better flowability than others. The alumina that typically had the highest %-20 µm content in shipments had much better flowability results than SGA from some other refineries. The underlying PSDs were quite different. A coarse particle size distribution can accommodate more superfines and maintain a desirable level of flowability more so than a fine PSD can accommodate.

These results also translate into observations made at operating smelters. SGA with a coarse PSD and higher -20 µm content gave was able to match the performance of an SGA source with a fine PSD and low -20 µm content even though the average superfines content was 0.5% higher. The difference was related to better overall flowability of the SGA with the coarser PSD. See these results for Location B in figure #4 below.

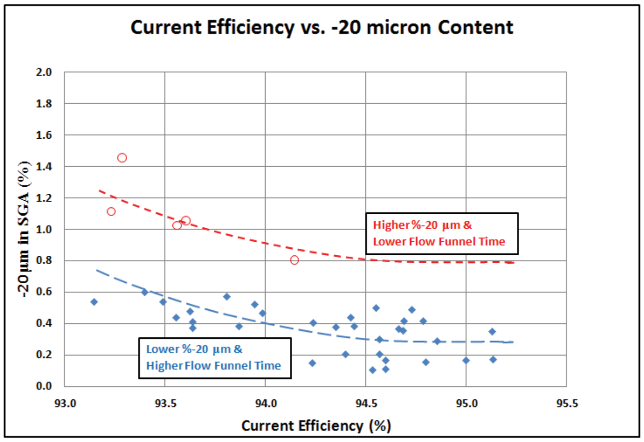

Figure 4 – Example #2 of current efficiency vs. %-20µm in SGA

This illustrates how following one certain screen fraction, such as %+325 mesh, or a certain particle size such as %-20 micron fraction can paint an incomplete and confusing picture. The essence of quality is associated more with the physical property of flowability than the fraction of the product that is >325 mesh or <20 microns. Unfortunately flowability, as represented by flow funnel time, is not measured by all refineries. Nor, does an industry wide standard for measurement currently exist.

Discussion – Impact of Alumina Handling

Referring again to Figures #1 & #2, note that the negative impacts upon process outcomes such as current efficiency and anode effects diminish when the -20 µm content is low and flowability would be higher. This implies that:

- At some level of "good" flowability that the importance of fines and superfines in alumina diminishes.
- The flowability of alumina at the point of feeding is likely to be of greatest importance.

A lot can happen to an alumina particle between the time that it is loaded into a ship, and when it is finally discharged into the bath.

The %Attrition Index of SGA may be important to the final result of alumina at the point of feeding. But, extensive studies that have previously been published by Lindsay [15] indicate that the alumina handling systems and dry scrubbing equipment are much more important. These studies illustrate how a smelter using SGA with %A.I. of 10.5% had more severe particle degradation than other smelters using SGA with %A.I. of 15% to 17%.

Alumina refineries do not select the handling systems that are used at smelters. They also do not operate them. Examples of common conditions that can contribute to particle attrition in alumina handling and dry scrubbing equipment include; inleakage, improper air flow rates, excessive recirculation in gas treatment centers, or higher velocities due to accumulations of hard gray scale when the alumina is fluorinated. Other examples are also cited in literature that has been published by Dando and Lindsay. [16][17]

These certainly can affect the flowability of alumina at the point of feeding. When we re-visit the data presented in figure #1 for Location A, with additional data added, as shown in figure #5, more information emerges.

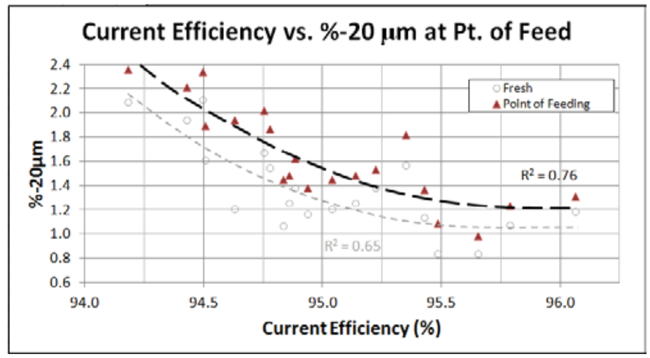

Figure 5 – Example #3 of current efficiency vs. %-20µm at pot

The %-20 µm in alumina increases, as one would expect. The percentage of variation explained by the difference in superfines content (and flowability) increases substantially. The increase in the R^2 value indicates that the impact of particle attrition that happens in the smelter has a greater bearing on process outcomes than the flowability of the raw material.

When examined in the light of the overall particle size distribution this makes a lot of sense. Alumina refineries produce a wide range of particle sizes including a small percentage of very fine particles. Breaking off sharp, crystalline edges and rounding off corners only reduces the diameter of a parent particle by a small amount. But, "daughter" particles that are produced are all very small.

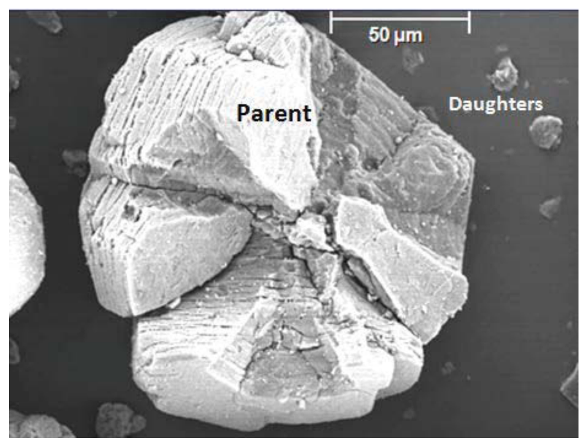

Figure 5 – Illustration of alumina particle attrition

The importance of having good flowability in SGA is clear to most smelter operators. But, the importance of proper selection and operation of alumina handling equipment may easily be masked by lack of data along the path to the point of feeding.

Segregation of fine particles in a silo does not change the overall PSD of what has been purchased from a refinery. It can have a very large impact on the consistency of product delivered to the pot and its flowability. In this case the responsibility may be shared by both the refinery and the smelter.

Some refineries face issues with segregation in large, port silos. When silo inventory levels are low the fines and superfines content in certain zones of a shipment may be substantially elevated. In such cases the average result reported on the Certificate of Analysis may not tell a complete story of how the shipment of alumina will perform.

There are no commonly recognized metrics, such as standard deviation, or box & whisker plots on how to measure such variation. To do so and to have meaning across refineries would require standards on lot sizes and the preparation of composites.

The better port facilities either have excellent blending capability or they measure and control variation in %+325 mesh and/or -20 micron content as they load into a ship from various zones of multiple port silos.

Most smelters have issues with segregation in pure alumina silos. To make matters worse, most smelters also have no data on how variable the alumina may be over time at the discharge point of main silos. Extremely few smelters have had silos constructed with excellent blending capabilities.

In Alcoa, the better smelting locations have multiple small silos and practice strict fill and drain routines, or they manage unloading from various storage zones by using a 6 mm orifice Alcoa Flow Funnel in the field. A strict fill and drain routine means to partially, or completely fill a silo and then to completely drain it. Draining while filling and vice-versa are strictly prohibited as this can easily enable the creation of larger pockets of segregated fine material.

Discussion – Reducing the Impact upon Process Outcomes

In Light Metals 2009, [18] Lillebuen also reported that: "Alumina quality is often considered to be the main parameter for alumina dissolution control. Modern sandy alumina has quality variations that represent challenges for point feeding control, but more and more we have come to see that these variations may be less critical than the heat and mass transport conditions inside the cell." Data from multiple smelting locations in Alcoa also confirms this statement.

In this case let's revisit the data from figure #4 from Location B.

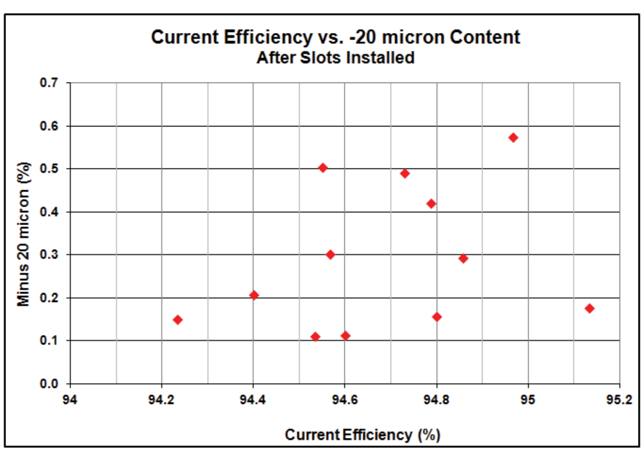

Figure 6 – Current efficiency vs. %-20µm after slotted anodes

The addition of slotted anodes changed the heat and mass transport conditions in the cell. The "signal" that was related to alumina flowability has once again become lost in the noise using the filtering technique described above.

By increasing agitation and mixing caused by gas discharge from anode slots towards the center, feeding channel the signal has certainly been attenuated. It is reasonable to presume that the conditions related to flowability remain. They just have become less important as contributing factors to process outcomes such as current efficiency, energy efficiency, and green house gas generation.

There are other factors that can change the conditions in the cell that are related to alumina dissolution rate. Changing from cell control based upon bath temperature to control based upon superheat is one factor that addresses consistency in heat transfer. Raising the superheat target can be another that may involve some trade-offs against other outcomes.

Changing the number of point feeders in a cell, the size of an alumina shot, and/or permutations on how aggressive overfeed/underfeed strategies are designed can be applied to the mass transport conditions of the cell.

There is also the possibility to change the alumina source to one with better flowability and dissolution characteristics. But, this often comes at some substantial cost for transportation.

As a general guideline Alcoa has found that some locations and cell technologies demand an Alcoa flow funnel time, AFFT, of ≤85 seconds to perform well. This is using a 100.0 gm sample, properly prepared and run through an Alcoa flow funnel with a 4 mm orifice. Other smelting locations and technologies have observed little or no impact on process outcomes at flow funnel times of ≤95 seconds. All locations and technologies had negative impacts when multiple shipments of SGA with flow funnel times of >100 seconds have been used.

Figure #7 is an example of various considerations that may be taken to determine the appropriate AFFT target for a location or cell technology. The factors given here are for example purposes only. In most real world cases multiple factors are considered with none of these being the single most important factor.

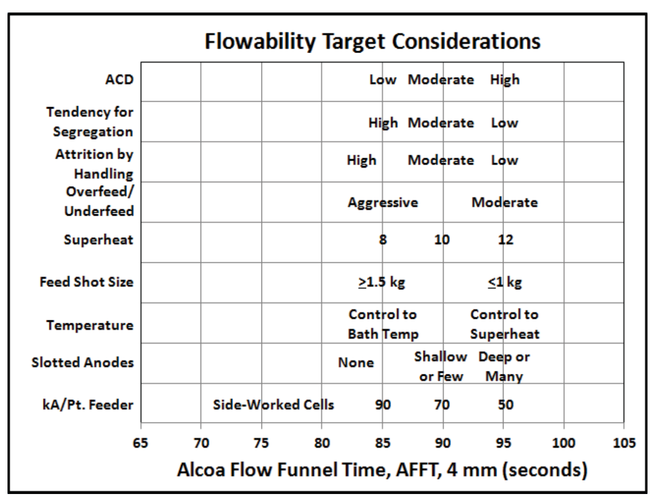

Figure 7 – Example considerations for alumina flowability targets

Conclusions

We have seen in the data presented here that the physical properties of alumina can play a significant role in the determination of important process outcomes.

The focal point of measurement in these studies has primarily been the minus 20 micron content of SGA. Data has been presented to demonstrate that a coarse particle size distribution with a relatively high -20 µm content performs equally as well as a fine PSD with a low -20 µm content. This has been presented as an illustration of the importance of the physical property of alumina flowability.

It has been stated that alumina flowability currently is not measured by all producers in the industry. There also is no universally accepted test method for the flowability of SGA.

We have seen data on daughter particles caused by the attrition of larger particles of SGA. These appear to have an impact on process outcomes that is as, or more important, than an equivalent fraction of fines or superfines added to SGA. It has also been stated that few aluminum smelters truly understand how alumina undergoes attrition as it passes through their bulk handing systems and gas treatment centers.

Finally we have seen data that supports how changes in heat and mass transport conditions within the reduction cell can act to render slight to moderate changes in flowability to be reduced to being insignificant to key process outcomes.

While "problems with alumina" will certainly continue to occur in our industry, it is important for us as smelter operators to take our fate into our own hands to have the best chance of arriving at a favorable outcome.

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