The Effect of Alumina Attrition Index on Breakage in Transport and Handling

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Abstract

Particle strength is one of the important quality characteristics for alumina and is influencing the breakage and generation of fines during transport and handling. The industrial standard for defining the breakage potential is the "Attrition Index" measured with the ISO 17500 method. However, there are some limitations with the analytical method; it is known to be a "rough" method that may not reflect the breakage in applied conveying systems in a smelter; it does not give any information of the breakage products; and the inter-laboratory reproducibility of the method is poor. To obtain more knowledge about the correlation between the Attrition Index value and the breakage in a smelter, extensive sampling has been carried out in Neuss smelter involving 3 different alumina sources with medium and high attrition indexes. Analyses of Particle Size Distribution have been carried out for both primary and secondary alumina and the actual smelter attrition has been compared with the Attrition Index.

Keywords: Alumina Attrition Index, alumina handling, alumina breakage, alumina quality.

1. Introduction

The Particle Size Distribution (PSD) and the Attrition Index (AI) are some of the important parameters for alumina quality. High levels of fines (-45 μm) and the super-fines (-20 μm) are known to negatively influence both transport and handling, gas scrubbing and pot room performance; for example, anode effect frequency, sludging and instability. The result can be poor pot line performance (loss of current efficiency and increased emissions. Hence, most smelters prefer an Attrition Index as low as possible.

Many Smelter Grade Alumina (SGA) producers include the Attrition Index parameter in the shipment Certificate of Analyses (CoA). The parameter is a measure of the alumina's potential breakdown during transport and handling and is defined as the change in the +45 μm (or +325 mesh) fraction. The most common method to determine alumina breakage is the Forsythe-Hertwig Attrition Index ISO 17500 method.

There are some challenges related to the parameter:

- The Forsythe-Hertwig method is known to handle the alumina roughly, i.e. the AI may be an over-estimate when it comes to the resulting increase of fines in a smelter.
- The result is influenced by the initial fines content in the primary alumina
- The size and number of the breakage products are not considered.
- The inter-laboratory reproducibility for this method is relatively poor. It is hence necessary to carry out Attrition Index analyses of different alumina sources in the same laboratory in order to compare values between different suppliers.

The above points give challenges when it comes to understanding the correlations between the Attrition Index reported on the CoA and the effect this parameter has on the smelter performance of the alumina source.

2. Experimental

Neuss smelter is used to handling different alumina sources. In this study, we have focused on three aluminas with different Attrition Indexes and studied the resulting fines content at different locations throughout the handling systems. Table 1 below outlines the size fractions and the measured Attrition Index of the primary alumina. The values are based on internal analyses of shipment samples. As shown in the table, the aluminas have significantly different Attrition Indexes and it could therefore be expected that alumina C would lead to more fines generation than alumina A and B.

Table 1. Particle Size Distribution and Attrition Index of the primary alumina sources.

	+150 µm (%)	-45 µm (%)	-20 µm (%)	Attrition Index (%)
Alumina A	1.4	10.2	1.76	12.4
Alumina B	2.6	10.4	1.85	23.2
Alumina C	0.1	8.1	0.82	46.0

It should be noted that the results for alumina B are average values of analyses of several shipment samples of this alumina. The samples were from 2016-2017 but not the exact shipments in the study. However, they do represent the quality of this source.

Alumina A was used in both lines in Neuss for a time period of approximately 2 months. The shipment was mixed with shipments from alumina B in transport and handling during this time, hence the results do not give a clear picture of the performance of alumina A and may not represent the breakage with pure alumina A. Thereafter, the aluminas B and C were separated and run in parallel in the two lines simultaneously (alumina B in line 1 and alumina C in line 2) for one and a half month. This period has been referred to as the “Test Period” and shown with vertical lines in the result figures. The alumina sources have been separated in different storage silos and mixing of the aluminas has been limited. The purity of the alumina regarding source has been confirmed by trace elements and phase analyses.

2.1. Alumina Handling Systems and Operation

The alumina is shipped to the port in Rotterdam, then further to Neuss harbour, where it is placed in the main storage, consisting of 10 storage silos. In the conveying loop, various equipment is used. Belt conveyers, air lifts, air slides, vehicles, vacuum unloader and dense phase pneumatic conveying. Of these handling types, the most aggressive to the alumina, when concerning particle breakage, is the high pressure/high energy pneumatic systems, i.e., air lifts and dense phase systems.

Although conveying systems are of the same type, one knows by experience that not any systems will operate and be 100 % the same. Hence the outcome can often be different from seemingly equal systems.

2.2. Alumina Sampling

The shipment samples delivered by the producers were used as primary alumina reference samples. In addition, the following sampling program was followed:

Primary alumina:

- Primary alumina samples taken from air slide entering FAT (Förder- Und Anlagentechnik) pressure vessels transporting into two of the GTCs (Gas Treatment Centres), as shown in Figure 1.a. There is one sample point in system 1 and one sample point in system 2.
    - The sampling was mainly carried out during the consumption of alumina B and C, only limited results are available for alumina A.

Secondary alumina:

- Automatic samplers for secondary alumina after the GTCs; one in system 1 and one in system 2. See Figure 1.b. The samples are taken daily.
- Pot feeding samples are taken from the point feeders. One cell from line 1 and one cell from line 2 were dedicated for this purpose.
    - A 250-gram grab sample was taken from the ladle used for collecting the feeding dose. i.e. the whole feeding dose was not included in the sample.

a) b)

Figure 1. a) Sample point for Primary alumina FAT samples and b) Automatic sampler for secondary alumina.

2.3. Analytical Methods

All samples were analysed for Particle Size Distribution by use of a laser instrument. Most samples were analysed in Neuss smelter and some were analysed in Porsgrunn research centre. In Porsgrunn, a Coulter LS200 instrument was used to determine the particle size distribution by laser diffraction. The Mie model for light scattering by particles was used.

The Attrition Index has been determined using the standard ISO 17500 method.

In addition, Trace elements (XRF) and alpha content (XRD) were determined in order to trace and identify the alumina sources throughout the system. The results are not included in this paper.

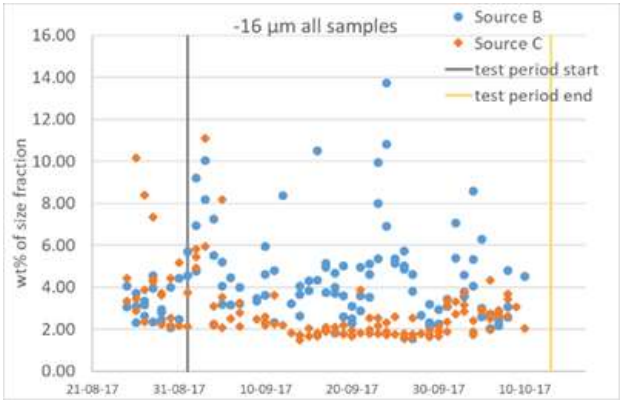
3. Results

3.1. Primary Alumina FAT Samples

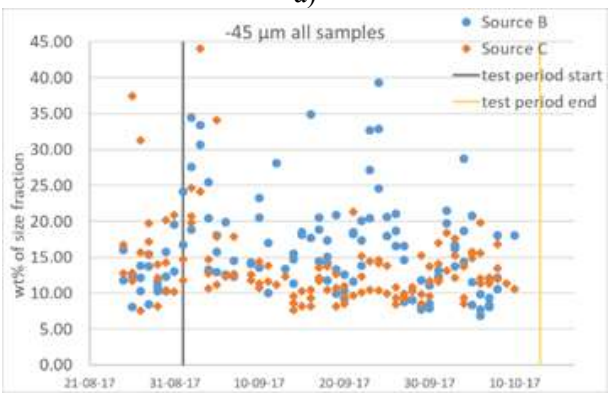
The PSD for the primary alumina samples is summarized in Table 2 and shown in the Figures 2 – 3. Alumina C (orange dots) have a lower content of superfines (-16 µm) than alumina B in the other system. The content of fines (-45 µm) is also lower for alumina C, but the differences are less clear than for the -16 µm. This could partly be due to the lower original fines (-45 µm) content in alumina C compared to alumina B. The alumina C samples have also significantly lower levels of coarse particles than the other aluminas. This is expected, considering the very low original content of coarse particles in alumina C.

Table 2. Summary of the results of the FAT samples.

FAT samples		-16.00 µm (%)	-45.00 µm (%)	+125 µm (%)
Alumina B Line 1	**average**	**4.50**	**16.88**	**15.59**
	St.dev	2.24	6.96	5.30
	Rel. St.dev	50%	41%	34%
	count	97	97	97
Alumina C Line 2	**average**	**2.60**	**13.17**	**6.71**
	St.dev	1.36	5.07	4.62
	Rel. St.dev	52%	38%	69%
	count	100	100	100



a)



b)

Figure 2. a) Super-fines and b) fines content in primary alumina taken before the FAT pressure vessel.

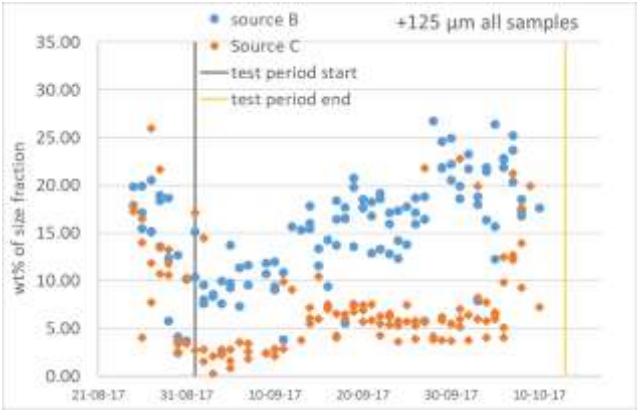


Figure 3. Coarse particle content in FAT samples.

3.2. Secondary Alumina Automatic Samplers

The PSD results of secondary alumina from the automatic samplers in both lines are shown in the figures below. Results from both Porsgrunn and Neuss are included. This is shown with different colours in the figures below. Note that the size fractions for Porsgrunn analyses are slightly different for the coarse alumina (+121.8 vs +125 µm) and the super-fines (-15.65 vs -16 µm).

It could seem like both the super-fines and the fines content generally are lower in line 2 than in line 1. The differences between the lines are clearer during the test period, especially for the super-fines. These results could indicate different operation or state differences between the GTCs for line 1 and 2. It also seems that the spread in the data is higher for line 1 in the period prior to the test period.

The results for alumina B and C have been compared for the timeframe shown by the vertical lines. The findings show the following:

- As seen in Figure 4 the super-fine contents are significantly lower in line 2 for alumina C.
- It seems the fines (-45 µm) increase for both lines in this time period. As for the super-fines, the fines seem to be somewhat lower in line 2 than in line 1. This is shown in Figure 5.
- The coarse fraction is much lower for alumina C in line 2, this is expected due to the initial low content of coarse particles in this source.

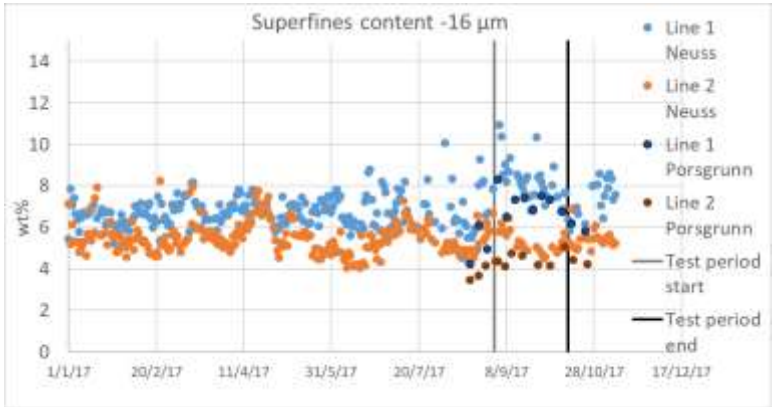


Figure 4. Super-fines content in secondary alumina from the automatic samplers.

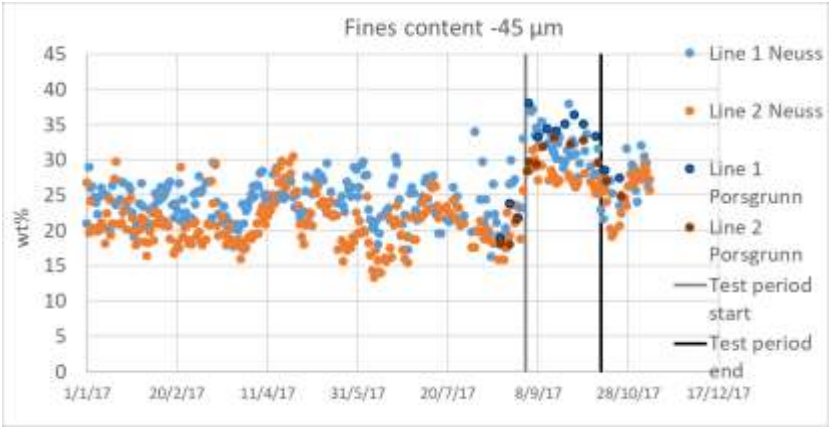


Figure 5. Fines content in secondary alumina from the automatic samplers

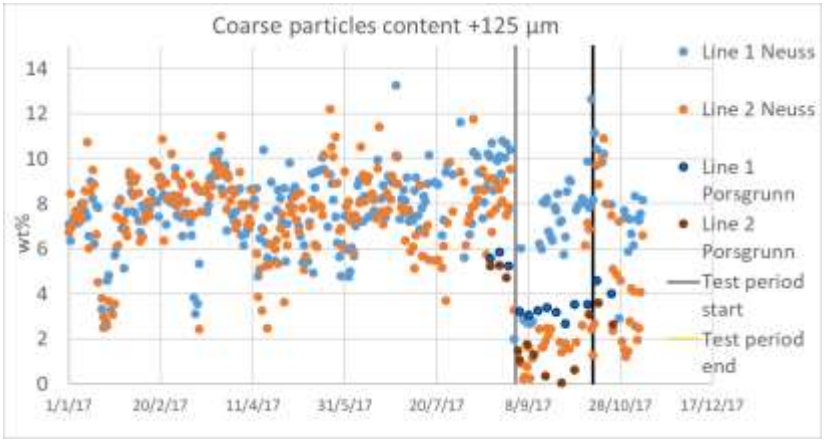


Figure 6. Coarse particles content in secondary alumina from the automatic samplers

3.3. Pot Feeding Samples

The PSD of the pot samples have been analysed in both Neuss and Porsgrunn. Some samples have been analysed at both labs. The results are shown in figures 7-9 and the average values and standard deviations for the two time-periods and both lines are summarized in Table 3 below. Note that the results for Porsgrunn are given as -20 µm and +150 µm.

The results of the Pot samples follow the same pattern as for the secondary alumina automatic samplers:

- Lower level of fines and superfines for pot samples of alumina C in line 2 compared to pot samples of alumina B in line 1.
- The fines levels seem to increase in both pots during the studied time period.

Table 3. Summary of average values and standard deviations for pot samples taken during different time periods.

Pot Samples		Neuss analyses				Porsgrunn analyses		
		<16.00 µm	<45.00 µm	<125.00 µm	>125 µm	<20 µm	<45 µm	>150 µm
Line 1								
Pre- Test Period: Source A (not pure)	average	6.98	**25.68**	92.37	7.63	6.96	**27.33**	2.00
	std.dev.	0.92	**3.17**	2.60	2.60	1.32	**5.80**	0.90
	count	27	**27**	27	27	3	**3**	3
Source B in Line 1 during Test Period	average	7.86	**31.62**	94.97	5.03	9.57	**32.70**	2.04
	std.dev.	0.93	**2.46**	2.32	2.32	2.00	**4.56**	0.76
	count	51	**51**	51	51	24	**24**	24
Line 2								
Pre- Test Period: Source A (not pure)	average	5.58	**21.58**	92.82	7.18	5.56	**22.30**	1.93
	std.dev.	0.40	**1.91**	2.01	2.01	0.20	**1.45**	0.59
	count	26	**26**	26	26	3	**3**	3
Source C in Line 2 during Test Period	average	5.35	**27.70**	98.66	1.49	5.76	**29.58**	0.51
	std.dev.	0.70	**2.72**	0.80	1.33	0.99	**2.13**	0.45
	count	52	**52**	52	53	28	**28**	28

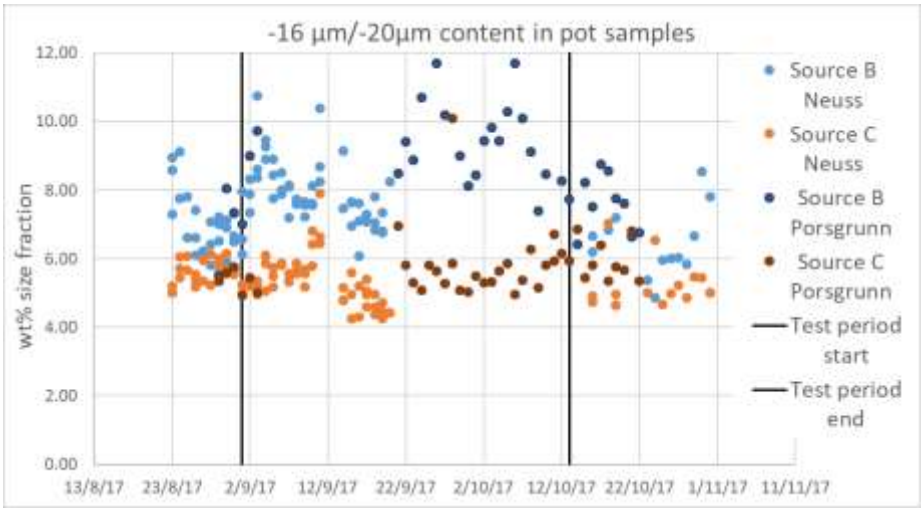


Figure 7. Superfines content in pot samples of Source B (Line 1) and Source C (Line 2).

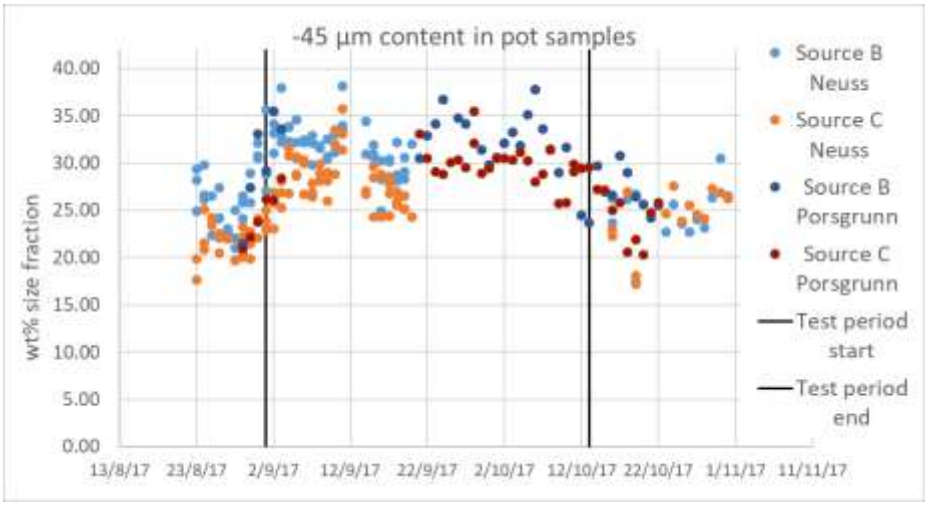


Figure 8. Fines content in pot samples of Source B (Line 1) and Source C (Line 2).

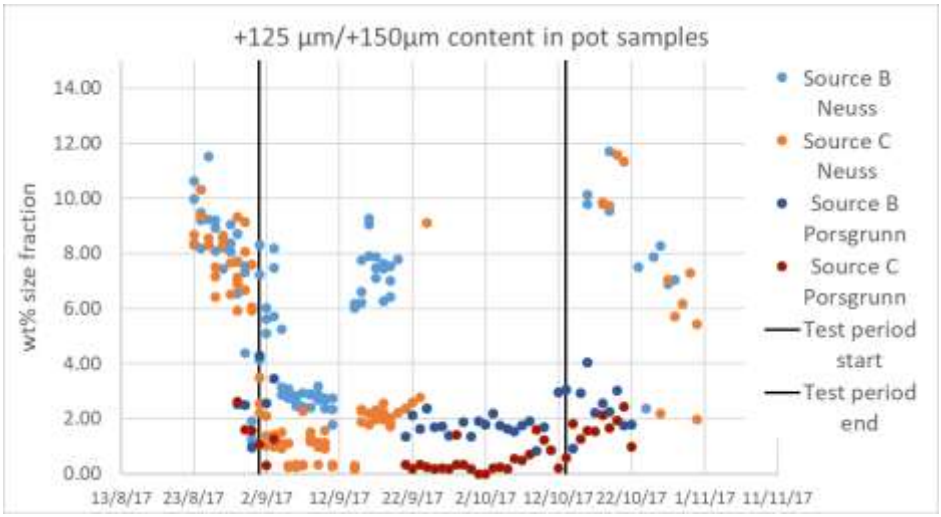


Figure 9. Coarse particle content in pot samples of Source B (Line 1) and Source C (Line 2).

3.4. Calculation of Smelter Breakage

Table 4 gives a comparison between the particle breakage during transport and handling of alumina in Neuss (smelter breakage) and particle breakage measured as the Attrition Index with the standard lab method. The Smelter breakage is calculated the same way the Attrition Index is calculated. As can be seen, the Attrition Index for alumina source B is the same as the resulting smelter breakage, whereas for alumina C the smelter breakage is half of the measured Attrition Index parameter value. If then subtracting approximately 2.5 – 7.5 % contribution from dust in the fines, the results are indicating that the Neuss handling system is not as rough as the AI method.

Table 4. Attrition Index (lab measurement on shipment sample) and corresponding smelter breakage calculated from the difference in fines content between the shipment samples and pot feeding samples.

	<45 µm (%)		Breakage (%)	
Alumina	Original content (shipment sample)	Pot samples	Smelter	Attrition Index
Alumina A line 1	10.2	25.7	17.2	12.4
Alumina A line 2	10.2	21.6	12.7	12.4
Alumina B line 1	11	31.6	23.2	23.2
Alumina C line 2	8.1	27.7	21.3	46

Some information regarding the table:

- Pot analyses values are based on Neuss data
- Alumina B "Original fines" content is based on CoA data from 32 barges/shipments to Neuss in the period July-October 2017 (internal analyses are not available)
- Attrition Index for Alumina B is based on Porsgrunn analyses of 7 shipment samples from barges/shipments to Neuss in 2016/early 2017 (internal analyses for the shipments during the test period are not available).
- Original fines content for alumina source A and C are based on Porsgrunn analyses of the shipment samples.

4. Discussion

Based on the high Attrition Index of alumina C, a significant increase in breakage during transport and handling was expected compared to alumina B. However, both the primary alumina samples from the FAT, the secondary alumina samples from the automatic samplers and the pot samples show less fines content in Line 2 and alumina C. This is surprising but suggests that smelter operation and experiences need to be considered when evaluating the effect of alumina quality in general and breakage during handling especially. A fact that needs to be considered, is the re-cycled dust contribution from the cell off gases. Hence, higher fine content in secondary alumina can not only be blamed on attrition/breakage. From our experience this dust can be assumed to be 2.5 - 7.5 % (found by determination of fluoride content in secondary alumina). However, this will vary depending on dust concentration the in raw gas from the electrolysis cells. From this the increase in fine content (-45 μm) due to particle breakage is realistically less than measured.

There are a few challenges when it comes to the Attrition Index parameter. The method is known to be "rough" and may give more breakage than what takes place in many smelter systems. Alcoa found that the Actual AI % of a smelter may be roughly equal to the % Attrition Index reported on the CoA, or it could be much lower with an Actual AI % being only 1/25 of the reported CoA AI value [1]. This is in line with previous investigations from Hydro smelters, which have shown lower breakage and resulting fines in smelters compared to the fines generation determined by the Attrition Index measurement [2].

As mentioned before, the transport and handling system in Neuss is as for many plants a mix of systems. And as can be seen, the fines content in the secondary alumina from alumina source A and B were similar as the fines content resulting from the Attrition Index measurement, whereas the smelter breakage for alumina C was significantly lower than the AI.

The Attrition Index measurement is based on of a high velocity jet agitation resulting in high kinetic energy collision between particle-particle and particle-wall in the attrition apparatus. Such high velocities (AI apparatus) is never seen in any sensible kind of handling in an aluminium smelter. Hence, degradation of alumina in such a test will always be extreme compared to actual handling.

The breakage pattern can be different for different aluminas. It can vary based on the Bayer process itself (hydrate strength) and calcination technology.

The reasons for the low agreement between the smelter degradation and AI, has many potential explanations. Initiated at the production of the alumina in combination with downstream handling. Theories that address aggregate stability [3] defining voids available for movement and hence shear tension in bulk and other theories for powder storage and conveying could probably be explored for a future crushing explanation based on measurements.

Other methods such as time-based AI, i.e. running step wise AI until fully 15 minutes could also better correspond with smelter degradation. Moreover, an earlier published method named Flow Titration [2], which involves varying energy input in an educator, and from there determine the fines generation, could also be an alternative.

All the above given, the AI method is accepted as a standard and has its purpose until it can be replaced with another accepted standard. In the meantime, each plant must aim to understand the AI in conjunction with its own plant's systems of handling. It makes sense to study the Attrition Index in conjunction with handling of primary alumina, when the handling type is of

the rougher nature (dense/dilute pneumatic conveying). And also, distinctly include return dust from the electrolysis when applying Attrition Index calculation as “smelter” attrition.

5. Conclusions

Particle strength is one of the important alumina properties and breakage into fine material is known to have significant negative effects on smelter operation. However, both this study and literature references show that the smelter will not get sufficient information based on the CoA with regards to the expected content of fines and superfines at cell feeding. Smelters need to know their own systems and how the alumina sources they use behave in those specific systems in order to predict the resulting fines generation and to evaluate the suitability of the different alumina sources.

The results show a good agreement between the Attrition Index and the smelter breakage for alumina source A and B. For alumina source C, the fines content is significantly lower than expected considering the Attrition Index measured in the laboratory.

It is also shown that the different transport systems give a difference in fines content. It is suggested that as much 2.5 – 7.5 % can be returned dust from cells, but the rest is either crushing or segregation, and since the samples are taken daily or more over a period of time, the increase in fines are most likely to be degradation.

Alumina sourcing should consider the conveying and handling systems in the respective smelter scheduled to receive the alumina. In a greenfield smelter, the handling systems should be standardized and preferably mechanical based or air slide based.

Until a better method is developed, the standard method attrition index should be followed and reported. The fines and breakage are problematic and should be avoided.

6. Acknowledgement

The authors would like to thank Andreas Steube, Christian Lintzen and Wolfgang Schaedel for their contribution regarding data and information, Herbert Appelstiel for sampling as well as Marco Nierfeld and Kristin Sundby for their contribution regarding analyses.

7. References

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