KN14 - Alumina Properties and Challenges Ahead

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Abstract

The author explores non-traditional approaches for dealing with the challenges that Smelter Grade Alumina may pose to end-users at primary aluminium reduction plants. These are not entirely aimed at identifying what Bayer process refineries may be able to do for Hall-Héroult process reduction plants. The author encourages primary aluminium smelters to adopt a stance of empowerment and self-determination before looking for solutions from others. A part of this approach includes establishment of regular customer-supplier dialogues in the manner of Customer Satisfaction Indexes. Additionally, the author encourages development and offers a first draft proposal of a set of minimum standards for Smelter Grade Alumina that will serve to better define the generic moniker of SGA.

Keywords: Smelter grade alumina (SGA), Customer satisfaction, Minimum standards, Product quality, Guaranteed limits.

1. Introduction

From the perspective of users of Smelter Grade Alumina, SGA, the challenges ahead include more than a few uncertainties.

- Alumina refineries are exploring ways to lower their CO_2 footprint and to become more energy efficient. This may require advancements in technology for the Bayer process, especially in the area of calcination.
- Aluminium smelters continue to creep amperage using platforms of modified base-technology. This introduces challenges to adequate dissolution between feed shots.
- Amperage creep is also beginning to increase fluoride evolution rates that challenge all but the most modern dry scrubbing systems.
- Production of aluminium in the People's Republic of China is capped at 45 million annual tonnes. But this cap has no impact upon plans for additional refinery capacity that could drive China to become a regular exporter of metallurgical grade alumina.

These and other changes on the horizon place aluminium smelters and alumina refineries in a position of need for greater definition of desirable and acceptable product quality. This in itself may be a challenge for an industry that has not yet clearly defined the meaning of terms such as "sandy" or "floury" alumina, or metallurgical grade alumina vs. SGA. Even the term "calcined" alumina begs additional meaning with the advent of concerns around pore sizing requirements for efficient dry scrubbing of hydrogen fluoride. This also extends to a need for greater clarity on acceptable Loss On Ignition, LOI, content which is a primary contributor to the production of HF by Hall-Héroult reduction cells.

2. Product Quality Concerns

Product quality concerns are often focused on: variation in fines content, sodium oxide content, attrition index, and/or specific chemical or physical properties. Underlying issues with SGA properties may be linked to process operations at the refinery, the type of bauxite that is processed, and the design of the alumina refinery itself. Underlying issues may also have more to do with individual users of SGA adopting an external focus with regard to product quality issues. Thus, an alumina refinery can become the focal point for problem-resolution efforts that may be able to be more effectively addressed by the smelting client.

Solutions or partial solutions are often more readily available to reduction plants when an internal focus on problem solving is chosen as a starting point or as a parallel path of effort as with management of alumina fines [1].

Examples for reflective problem resolutions include:

- Placing appropriate focus on Fe_2O_3 levels in SGA when the iron content of alumina usually accounts for less than 15 % of the Fe that reports to aluminium metal.
- Placing appropriate focus on Attrition Index values when the attrition "footprint" of alumina handling systems and inadequate de-scaling of fluorinated alumina processing and handling systems contribute greatly to the generation of fines.
- Placing appropriate focus on the variation in fines content from shipment-to-shipment when there is no active silo management strategy in place to minimize particle segregation at the receiving port facility or aluminium smelter.
- Placing appropriate focus on alpha-phase content due to bottom sludge formation that may be more closely linked to superheat and the kilograms of alumina per hour that must be delivered by each point feeding device.

Some issues, such as high sodium oxide content, high P_2O_5 content, or low flowability of product may best be directed to the attention of the alumina refinery [2]. However, this oftentimes includes a caveat. As with aluminium electrolysis, alumina refining is a continuous process that does not have an abundance of independent variables. Client smelters that ask for a change in one parameter are often inadvertently asking for changes in other product quality parameters that may be counter to their own best interests.

A textbook example is illustrated with the calcination sub-process. Requesting a change in BET Surface Area also serves as a request to change the alpha-phase and LOI content of product [3]. Refer to Figure 1. Adjusting the target may also alter the pore size distribution of SGA which may not be favorable for dry scrubber removal of hydrogen fluoride.

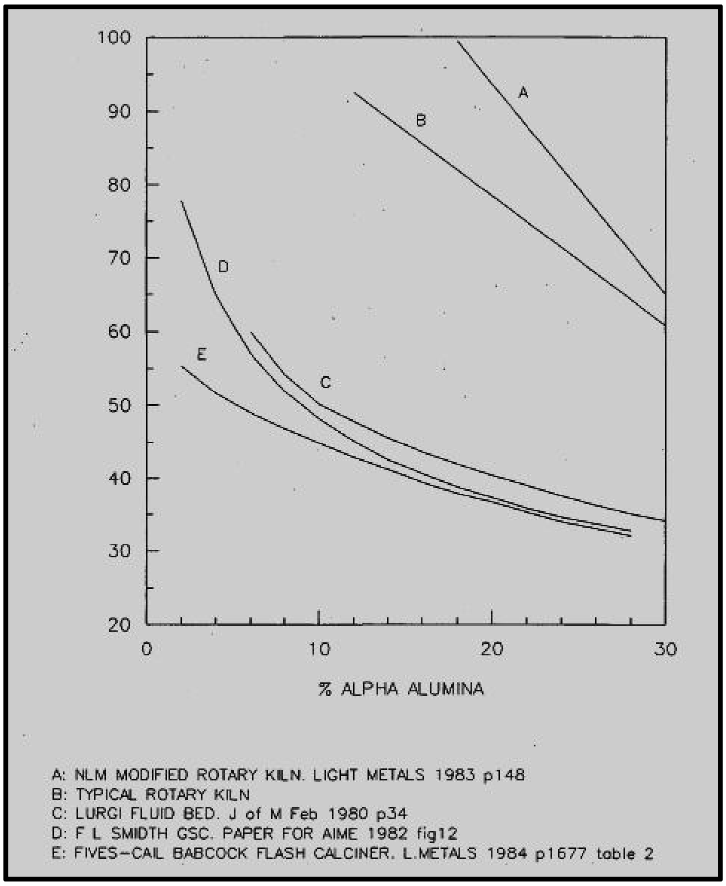

Figure 1. BET Surface Area vs. alpha-phase content of SGA with various types of calcination kilns [3].

Likewise, requests to reduce the Na_2O content of product may also deliver some unwelcome side-effects. The sodium oxide content of SGA is determined in the precipitation sub-process where particle sizing, morphology and toughness are also determined. Asking a refinery to reduce Na_2O content may serve as a request to increase fines content and Attrition Index. Refer to Figure 2. Reducing Na_2O content may also reduce the production capability of the refinery and its sustainability.

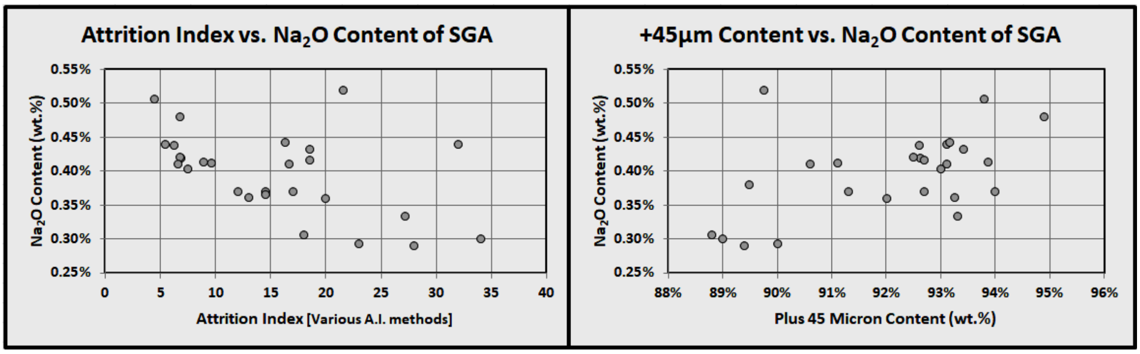

Figure 2. Plots of typical values of Attrition Index and +45 micron fraction vs. sodium oxide content for a variety of alumina refineries outside of China.

These provocative examples are intended to have consumers of SGA think about approaching product quality concerns differently. The point on starting with internal reflection has already been made. Aluminium smelters do not rely upon original equipment manufacturers or technology providers to optimize anode aggregate formulations or to improve Faraday efficiency. Process operations within a reduction plant chart their own courses for improvement activities. Taking control of one's own destiny is often more productive and less expensive than trying to outsource it, or to live with a problem so long as there is an external party to blame.

The long-term view of any aluminium smelter should place greater focus on how to successfully be able to adapt to a wide variety of alumina sources. Placing a strong focus on having a primary source or single source of alumina getting things just right for downstream reduction plant operation is a dead-end street. Smelters that can only use one source of alumina can face hard lessons when that refinery has a major upset condition or goes out of business.

Another difference in approach is to engage in regular, periodic meetings between reduction plants and alumina refineries. One such process has been described by the Customer Satisfaction Index approach that multiple alumina and aluminium producers have adopted [4].

Within vertically integrated producers the mission statement for an SGA satisfaction group may well be to avoid sub-optimizations and to focus upon "Do what is best for the business enterprise." With 3rd party alumina suppliers, it may not be possible to have all client smelters represented together. To have regular exchanges between SGA producers and consumers is still important. It allows the participants to understand and to sense levels of urgency or importance from the interaction. However, each client reduction plant must also recognize that most refineries produce only one product and a balance must be maintained that fits the needs of all customers.

These two approaches; charting your own course for improvement and engaging in regular dialogue with SGA suppliers deliver quicker results, often at low cost and avoids the risk of asking for a particular property of SGA to be changed without understanding the possible ramifications.

3. Definition of Terms

The primary aluminium industry uses the term Smelter Grade Alumina, SGA, as a generic moniker for a variety of similar forms of sandy, metallurgical grade alumina that have generally uniform properties related to grain sizing, specific impurities, and the ability to be used by dry scrubbing devices. The SGA produced at each alumina refinery does vary and each has its own set of chemical and physical attributes. As such, the norm in the industry has been for each alumina producer to share limited listings of typical properties and guaranteed maximums or minimums for shipment lots. The properties list seldom includes items such as the content of Gibbsite, K_2O or Li_2O. Metrics on product variability are absent, although the standard deviation of minus 45 micron content in sub-samples during shipment loading would be a useful metric on the management of inventory by refinery port facilities [5].

Consumers have a reasonable idea of what they want, but alumina consumers as a whole have yet to establish uniform specifications for SGA. Only a few primary aluminium companies have written specifications for the SGA that they firmly stand behind.

This is not the case for many other industries. One only needs to look to aluminium fluoride production for an example. Refined fluorspar has various grades based on its level of purity. A set of Minimum Standards are used for this purpose. Acid grade material, used in the production of HF, requires 97 wt% purity of calcium fluoride. Ceramic grade material falls into the range of 85 to 95 wt% CaF_2 and metallurgical grade fluorspar is normally in the range of 60 to 85 wt% CaF_2.

The purity of Al_2O_3 in SGA produced by the Bayer process is not a focal point for consumers at primary aluminium reduction plants. Differences between refineries in physical and chemical properties plus product consistency from shipment-to-shipment differentiate the quality of alumina for end users.

4. Minimum Standards

Is SGA a commodity that is merely a precursor to the production of another commodity? Is production of aluminium metal its' only important trait, or are there others?

Historically, SGA has not been actively traded on commodity exchanges, including trading of derivatives or futures. Only recently have futures for alumina produced inside the People's Republic of China begun to be traded on the Shanghai exchange [6]. Is this a wake-up call for the primary aluminium industry?

Commodities often have benchmarks such as: Brent crude for oil, 99.5 % minimum purity for gold, or 62 % Fe content for iron ore. SGA has no specific quality benchmark, nor is the term "SGA" clearly defined, leaving the moniker at risk of representing an even wider range of product quality in the future.

Depending upon the market conditions of any given year only 20 % to 30 % of alumina production outside of China is traded on the open market. Most SGA is sold under direct contracts or transferred within vertically integrated companies [7]. Price Reporting Agencies such as Platt's and Metal Bulletin keep the world abreast of transaction prices, but they fail to report upon 70 % to 80 % of the world's supply of SGA. During weeks with no reported trades these agencies rely upon bid/ask spreads based on market surveys.

This is a far cry from day-to-day market price changes for oil, gold or silver. The Price Reporting Agencies also provide no differentiation of product quality. This ignores established trends that preferred suppliers of SGA do better in long markets and suppliers of last resort only come into play during tight market conditions. Thus, SGA product quality does matter to producers and consumers alike, although there is no official quality grading system or benchmark that is used as a standard.

There is another point to consider. SGA is not conducive to long-term storage. It suffers issues with: segregation, cementing of particles, and gradual reversion to Bayerite caused by fluctuations in humidity of the ambient air. When what goes in may not be equivalent to what comes out of storage silos there are clear obstacles to SGA becoming fully traded as a commodity.

This brings the discussion back to: What exactly is SGA? The Chinese alumina market may go into a position of substantial over-supply vs. domestic consumption during the years ahead [8]. Table 1, adapted from the Chinese Standard GB/T-24487-2022, offers at least a partial definition of product quality for alumina produced in the People's Republic of China [9].

Table 1. Reproduction of the Chinese standard for alumina quality specified in document GB/T-24487-2022.

STANDARDS of the PEOPLES'S REPUBLIC of CHINA - ALUMINA								
	Chemical Properties						Physical Properties	
Grade	Al_2O_3 max. (wt%)	SiO_2 max. (wt%)	Fe_2O_3 max. (wt%)	Na_2O max. (wt%)	CaO max. (wt%)	LOI max. (wt%)	BET Surface Area Minimum (m^2/gm)	Minus 45 micron maximum (wt%)
AO-1	98.6	0.020	0.020	0.45	0.03	1.0	60	20
AO-2	98.5	0.040	0.020	0.55	0.04	1.0	60	25

Table 1 specifies minimum standards for two grades of Aluminium Oxide, AO-1 and AO-2. Note that the measurement methods used with these standards vary from those that are used by much of the rest of the industry.

The minimum standard for minus 45 micron content of both grades and the minimum standard for SiO_2 content of Grade AO-2 would stretch the current, de-facto definition of SGA of the western world. The other minimum standards in Table 1 are aligned with, or even better than western producers of SGA, although the list is not as extensive in the number of physical and chemical properties with guaranteed minimums or maximums. It also does not include minimum standards for certain impurities of concern such as potassium, lithium or phosphorus content.

Challenges to the de-facto definition of SGA may also be on the horizon for western producers. Reducing the CO_2 footprint of alumina refineries may force upon the industry the need to adapt to changes in physical and chemical characteristics of SGA in order to accommodate more energy efficient approaches to its production.

A more clear definition of what SGA is, and what it isn't, is becoming more urgent and important. It has been said that the term itself, Smelter Grade Alumina, makes it obvious that the primary aluminium industry should establish user specifications or a set of uniform minimum standards to define the product. As shared above, the People's Republic of China has already done so for domestic production of "alumina" [10].

Few primary aluminium smelters currently have specification limits or minimum standards in place that are closely enforced. Some primary aluminium technology providers do have guidelines for alumina that is either; preferred, acceptable, processable or not acceptable. These guidelines are used primarily for the purposes of technology performance guarantees and not necessarily for SGA supplier selections.

This leaves the western world with a wide variety of specifications, guaranteed limits and typical product quality values. Refer to Table 2 for a cross-section of the guaranteed product quality limits of twenty different alumina refineries outside of China. The cells that have been highlighted indicate guaranteed maximums or minimums for various properties. Cells highlighted in blue are minimum limits, those highlighted in yellow are maximum limits.

Table 2. Cross section of guaranteed product quality limits for various alumina refineries.

	Supplier A	Supplier B	Supplier C	Supplier D	Supplier E	Supplier F	Supplier G	Supplier H	Supplier I	Supplier J	Supplier K	Supplier L	Supplier M	Supplier N	Supplier O	Supplier P	Supplier Q	Supplier R	Supplier S	Supplier T
+150 microns Guaranteed Max.	14%	14%	10%	15%	8.0%	10%			5%	15%			10%		7.0%		10.0%	5%		10%
+75 microns Guaranteed Min.			50%																	
+75 microns Guaranteed Max.					80.0%															
+45 microns Guaranteed Min.	88%	88%	85%	88%	90%	90%	90.0%	90.0%	88%	88%	90%	88.0%	88%	90.0%	90.0%	87%	88.0%	90%	85.0%	88.0%
-20 microns Guaranteed Max.	3.0%	3%	2%	3.0%		2.0%	4.0%							2.0%						1.20%
Attrition Index Guaranteed Max.					20.0	20							25	25						
Loose Bulk Guaranteed Min.			920	900						950										
Loose Bulk Guaranteed Max.			1080	1050						1050										
Angle of Repose Min.										30										
Angle of Repose Max.										35										
BET Surface Area Guaranteed Min.			60	60	60	65	60	60		60	65		60	60		65	60		67	60
BET Surface Area Guaranteed Max.			80	80	80	85	80	80	80	80		90		85	88.0		80	82	83	80
Alpha Phase Guaranteed Max.	10%	10%	10%		10.0%				40%	10%	10%		30%				8.0%			
Moisture on Ignition Guaranteed Max.					1.00%															
Loss on Ignition Guaranteed Min.														0.5%						
Loss on Ignition Guaranteed Max.	1.0%	1.2%	1.3%	1.1%	1.00%	1.0%	1.0%	1.0%	1%	1%	1%	1.2%	1.0%	1.2%	1.00%	0.6%	0.90%	1.0%	1.0%	1.20%
Moisture on Ignition Guaranteed Max.											1%									
Na_2O Guaranteed Min.						0.30%														
Na_2O Guaranteed Max.	0.55%	0.55%	0.50%	0.50%	0.50%	0.54%	0.50%	0.50%	0.5%	0.5%	0.45%	0.60%	0.45%	0.55%	0.45%	0.50%	0.60%	0.40%	0.38%	0.50%
CaO Guaranteed Max.	0.060%	0.060%	0.030%	0.060%	0.02%	0.046%	0.050%	0.050%	0.025%	0.05%	0.03%	0.070%	0.040%	0.060%	0.030%	0.010%	0.050%	0.030%	0.010%	0.025%
SiO_2 Guaranteed Max.	0.025%	0.025%	0.020%	0.020%	0.025%	0.021%	0.025%	0.025%	0.03%	0.02%	0.025%	0.030%	0.020%	0.017%	0.025%	0.010%	0.020%	0.020%	0.010%	0.020%
Fe_2O_3 Guaranteed Max.	0.020%	0.025%	0.020%	0.020%	0.025%	0.011%	0.025%	0.025%	0.025%	0.015%	0.025%	0.030%	0.010%	0.015%	0.025%	0.025%	0.020%	0.020%	0.020%	0.030%
TiO_2 Guaranteed Max.	0.007%	0.007%	0.005%	0.005%	0.007%	0.0017%	0.005%	0.005%	0.01%	0.004%	0.008%	0.005%	0.005%	0.003%	0.005%	0.003%	0.005%	0.005%	0.003%	0.005%
ZnO Guaranteed Max.				0.020%	0.008%	0.0012%	0.005%	0.016%		0.0008%	0.002%	0.020%	0.002%	0.0012%	0.006%	0.005%		0.003%		0.004%
MnO Guaranteed Max.					0.002%	0.013%								0.0020%				0.001%		
NiO Guaranteed Max.						0.003%														
P_2O_5 Guaranteed Max.				0.003%	0.002%	0.0007%	0.003%	0.003%	0.002%	0.002%	0.002%	0.009%	0.002%	0.0015%	0.003%	0.002%	0.001%	0.002%	0.0010%	0.0025%
V_2O_5 Guaranteed Max.				0.005%	0.005%	0.0018%	0.005%	0.003%	0.005%	0.002%	0.004%	0.005%	0.005%	0.0045%	0.003%	0.005%	0.003%	0.003%	0.002%	0.006%
Ga_2O_3 Guaranteed Max.				0.010%		0.013%													0.020%	
Al_2O_3 Dried Basis Guaranteed Min.	98.3%	98.3%	98.3%							98.5%	98.5%						98.5%		98.0%	
Al_2O_3 Fired Basis Guaranteed Min.	99.0%	99.0%	99.0%					98.6%					99.3%					99.0%		

The summary of various de-facto minimum standards from Table 2 are summarized here in Table 3.

Table 3. Compilation of multiple, de-facto, minimum standards for SGA quality.

Summary of Table 2 Maximums and Minimums		Guaranteed
Chemical		
Aluminium Oxide – Dried	Al_2O_3 Minimum	98.0 %
Aluminium Oxide – Fired	Al_2O_3 Minimum	99.0 %
Sodium Oxide	Na_2O Maximum	0.60 %
Calcium Oxide	CaO Maximum	0.070 %
Iron Oxide	Fe_2O_3 Maximum	0.030 %
Silicon Oxide	SiO_2 Maximum	0.03 %
Phosphorus Oxide	P_2O_5 Maximum	0.009 %
Zinc Oxide	ZnO Maximum	0.020 %
Titanium Oxide	TiO_2 Maximum	0.008 %
Vanadium Oxide	V_2O_5 Maximum	0.006 %
Physical		
Specific Surface Area	BET method Minimum	60 m^2/gm
Alpha Alumina	Maximum	40 %
Attrition Index	Maximum	25
LOI	(300 – 1000^{o}C) Maximum	1.3 %
+150 microns (100 mesh)	Maximum	15 %
-45 microns (325 mesh)	Maximum	15 %
-20 microns	Maximum	4.0 %

Taken individually many of these minimum or maximum values would be deemed to be material that is "not processable" or "not to be used" by certain reduction cell technologies. However, each of these values reflects what at least a few primary aluminium producers have agreed to accept as guaranteed minimums for product quality. It's also fair to say that most primary aluminum producers focus on the typical properties of SGA sources and hope that they never encounter minimum standard quality in a shipment.

It isn't news that the industry as a whole has not been able to come together to create a unified product quality specification or a clear definition of SGA. Perhaps it is time that select members of this conference from various producers and consumers come together to establish minimum standards as a first step.

The incentive extends beyond the avoidance of some of the worst cases that are shared in Table 3. Metallurgical grades of alumina produced from diasporic bauxite deposits in the People's Republic of China could change the general meaning of SGA. The literature has reported upon significant levels of; potassium, lithium, magnesium and beryllium in Chinese bauxite and alumina [11, 12, 13, 14, 15]. Elevated levels of minus 45 micron content ZnO, and P_2O_5 have been reported in some sources of Chinese alumina.

To be certain, much of the 45 million annual tonnes of aluminium produced in China is supported by domestically produced sources of alumina. Mining and refining also continue to evolve. Domestic, karst bauxite is in limited supply. Bauxite imported from Africa brings with in new challenges for established refinery configurations. The sub-processes of digestion, precipitation and calcination vary substantially from western producers of alumina.

Aside from the harmful effects that phosphorus, beryllium or elevated fines content may cause, impurities of potassium, lithium and magnesium risk other matters such as contamination of the electrolyte. The only remedies to this are through costly purging/disposal or dilution of electrolyte. Either could produce quantities of excess bath that is undesirable in the marketplace. The option of disposal of contaminated electrolytic bath may only accelerate actions to restrict its movements and badge it as an industrial waste.

Potassium contamination of electrolyte also poses a serious threat to the longevity of cathodes. In the book, Cathodes in Aluminium Electrolysis it states “potassium is capable (to) destroy both graphite and amorphous carbons totally” [16].

Development of minimum standards for SGA can serve to protect; cathode life, the quality/value of electrolytic bath and key performance indicators of primary aluminium production as well.

A committee that is comprised of ISCOBA members representing alumina refineries and aluminium smelters is suggested for undertaking such a task. The liberty has been taken here to create a first draft proposal of what a set of minimum standards may look like. Refer to Table 4.

Table 4. First draft proposal for SGA minimum standards.

Minimum Standard for Smelter Grade Alumina To be consider as Metallurgical Grade Alumina if any one (1) or more of these limits are not met.		Proposed Limits
Chemical		
Sodium Oxide	Na_2O Maximum	0.55 %
Iron Oxide	Fe_2O_3 Maximum	0.025 %
Silicon Oxide	SiO_2 Maximum	0.025 %
Phosphorus Oxide	P_2O_5 Maximum	0.005 %
CaO/Na_2O Ratio	Maximum	14.0 %
K_2O/Na_2O Ratio *	Maximum	1.0 %
Li_2O/Na_2O Ratio *	Maximum	3.0 %
*If typical ratio is <0.25 % only needs to be re-confirmed annually		
Physical		
Specific Surface Area	BET S.A. Minimum	70 m^2/gm
Alpha Alumina	Maximum	10 %
Attrition Index	Maximum	25
Dry Scrubbing Ratio (BET Surface Area/(LOI % x 100))	Minimum	85
+150 microns (100 mesh)	Maximum	15.0 %
+75 microns (200 mesh)	Minimum	60.0 %
-45 microns (325 mesh)	Maximum	12.0 %
-20 microns	Maximum	3.0 %

Some non-traditional metrics are included in this table. The ratios of potassium oxide and lithium oxide contents to sodium oxide content mimic the CaO to Na_2O Ratio that is already tracked by multiple aluminium producers. Potassium and lithium are included as a measure of precaution against damages that may be caused to electrolyte, cathodes and metal products. Both K and Li are normally at trace levels or non-detectable in the alumina produced by most refineries. Nonetheless a minimum standard is required for these impurities to protect against common degradation of what is commonly accepted as SGA in global markets.

This is not meant to exclude producers of metallurgical grade alumina from being able to offer their products to market. It serves as something of an equivalent to the approach that has already been taken within the People's Republic of China to identify alumina quality by grading, AO-1 and AO-2.

Creation of a set of minimum standards is also not intended to have alumina refineries downgrade their existing guaranteed product quality limits. Doing so would risk damaging brand name and customer perceptions of premium product that is more desirable in a long market.

5. Conclusion

Challenges for Smelter Grade Alumina are tied to a range of uncertainties that include technology changes in alumina refineries and in primary aluminium reduction plants. New entries into global alumina markets add additional factors of concern.

To meet these challenges as they emerge two not so common approaches are endorsed. Aluminium smelters should look inward to develop new solutions or counter-measures to alumina-based concerns. Closer ties of regular communication between aluminium smelters and alumina refineries are also advised. From such interactions alumina refineries can also take the opportunity to be more introspective around the question: Are we making a preferred product that satisfies the needs of the customer base?

Beyond this a need for better definition of the term "SGA" is needed now more than ever. There have been attempts to develop more universal specifications for Smelter Grade Alumina. None of these have gained universal traction towards acceptance. Perhaps it is best to begin to define SGA with a set of minimum standards. Identification of what is not SGA only serves to classify products into two grades, as with the example given for the quality of fluorspar. These may come to be known as SGA and MGA for Metallurgical Grade Alumina.

Perhaps the future may see grading systems that identifies product quality by well-defined monikers such as: SGA, MGA, AO-1 and AO-2. The last two of these have already been defined. It is time to create greater definition for SGA and it is hoped that the draft shared in Table 4 provides a starting point for that discussion.

6. References

1. Stephen Lindsay, Attrition of Alumina in Smelter Handling and Scrubbing Systems, *Light Metals* 2011, 163-168.
2. Stephen Lindsay, Customer Impacts of Na_2O and CaO in Smelter Grade Alumina, *Light Metals* 2012, 163-167.
3. A.R. Kjar and A.J.Crisp, Impact of Bauxite Source, Quality and Alumina Plant Design on Alumina Quality, *The proceedings of the 1st Alumina Quality Workshop*, Gladstone, Australia,1988.
4. Stephen Lindsay, Customer Satisfaction Indexes, *The proceedings of the 8th International Alumina Quality Workshop*, Darwin, Australia, October 2008, 6-10.
5. C. Duwe, Smelter Grade Alumina from Bauxite – History, Best Practices, and Future Challenges, Chapter 12, *Alumina Storage and Handling*, Springer, 2022, 649-678.
6. https://www.nasdaq.com/articles/chinese-regulator-gives-nod-for-alumina-futures-on-shanghai-exchange (Accessed on 29 September 2023).
7. https://media.ega.ae/alcoa-and-emirates-global-aluminum--sign-major-long-term-alumina-supply-agreement (Accessed on 29 September 2023).
8. https://www.bloomberg.com/news/newsletters/2023-05-08/china-s-futures-expansion-plan-is-hitting-a-glut (Accessed on 29 September 2023).
9. https://xueqiu.com/3161724413/249316208 (Accessed on 30 September 2023).

10. https://www.chinesestandard.net/PDF/English.aspx/GBT24487-2022 (Accessed on 29 September 2023).
11. Gu Songqing, Chinese Bauxite and Its Influences on Alumina Production in China, Zhengzhou Research Institute of Chalco, *Light Metals* 2008, 79-83.
12. Kun-Yue Ling et al., Mineralogical characteristics of the karstic bauxite deposits in the Xiuwen ore belt, Central Guizhou Province, Southwest China, *Ore Geology Reviews*, March 2015.
13. J.B. Metson, D.S. Wong, J.H. Hung and M.P. Taylor, Impacts of Impurities Introduced into the Aluminium Reduction Cell, University of Auckland, *Light Metals* 2013, 9-13.
14. Feng Naixiang, Peng Jianping, Wang Yaowu, Di Yuezhong, You Jin and Liao Xian'an, Research and Application of Energy Saving Technology for Aluminum Reduction in China, School of Materials and Metallurgy, Northeastern University, Shenyang, China, *Light Metals* 2012, 563-568.
15. Stephen Lindsay and Barry Welch, A Review: Understanding the Science and the Impacts of Impurities upon the Electrolytic Bath of Hall-Héroult Reduction Cells, *Journal of Metals*, February 2021, 1196-1209.
16. Morten Sørlie and Harald Øye, *Cathodes in Aluminium Electrolysis*, 3rd edition, Aluminium-Verlag, 2010, 232-234.