FBA: FIRED BAUXITE AGGREGATE

AN INNOVATIVE SINTERED AGGREGATE ALTERNATIVE TO BFA FOR MORE SUSTAINABLE REFRACTORY APPLICATIONS

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ABSTRACT

FBA (Fired Bauxite Aggregate) is a new high – alumina refractory raw material (92% Al_2O_3, bulk density > 3.5 g/cm^3), developed by ARCIRESA as a technical, strategic and more sustainable alternative to Chinese imported BFA (Brown Fused Alumina) for refractory applications. The manufacturing of sintered FBA includes 2 firing stages (calcination + sintering) of BauxST^{AR} ore, the highest purity gibbsitic refractory-grade bauxite ore in the world (First Bauxite's deposits, Guyana). This paper describes the properties of the new aggregate, presents a brief overview of its production process and the results of FBA-based refractories testing in AMC bricks (lab-scale) and blast furnace runners castables (on site). The FBA role to support refractory producers and refractory consuming industries to reach their sustainability targets is also discussed. FBA introduction to the market is scheduled for the first quarter of 2023.

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CHALLENGES FACING REFRACTORY RAW MATERIALS PRODUCERS

Over the past 3 decades, the global refractory industry became extremely dependent upon Chinese imported brown fused alumina, partly based on the traditional outlook that 'higher Al_2O_3 content meant better performance' for most high–alumina refractory applications. Therefore, refractory producers have had to cope with supply uncertainty and variations in the quality and price of Chinese brown fused alumina (BFA) and also refractory-grade bauxite (RGB) for many years. Operation shutdowns by strict China's anti-pollution controls and regulations, a decline in Chinese bauxite ore availability and Covid-19 related restrictions have recently impacted the supply chain in the form of shortage and delays, quality issues, increase of spot prices and surging logistics costs.

In addition to the strategic and technical targets of manufacturing high-quality products at optimised costs to ensure a continuous, reliable supply of high-alumina aggregates for the refractory market, as an alternative to Chinese productions, a crucial challenge facing refractory raw materials manufacturers is the development of more sustainable aggregates and production processes as an important strategy to the overall reduction of the environmental impact of the refractory sector and user industries. In fact, many refractory consuming companies have set clear targets to reach carbon-neutrality and the implementation of circular economy production and consumption models in the next decades. The production of more sustainable refractory aggregates plays a key role to support the global refractory-related industry in these new challenges.

For the above reasons, Arcillas Refractarias, S. A. (ARCIRESA) has focused its recent innovation strategy and investment (BAUXACEM project, 2019–2021) on the research and development of 2 new high-alumina refractory raw materials:

1. BauxST^{AR} 90, a premium refractory-grade fired bauxite with unique properties (92% Al_2O_3, < 0.8% Fe_2O_3, 3.2–3.3 g/cm^3 bulk density), that make this bauxite stand out in

a class of its own. Since its launch onto market, many customers have successfully included BauxST^{AR} 90 in their formulations.

2. FBA (Fired Bauxite Aggregate), high–alumina sintered aggregate (> 92% Al_2O_3, bulk density > 3.5 g/cm^3) with high potential to replace Chinese BFA in various refractory applications and also for upgrading RGB-based refractory solutions.

This paper focuses on the properties of the new FBA aggregate, outlines its production process and presents the conclusions of FBA-based refractories testing in AMC bricks (lab-scale) and blast furnace runners castables (on site). The FBA role to improve the sustainability of the refractory applications is also discussed.

PROPERTIES OF FBA (FIRED BAUXITE AGGREGATE)

The test samples used for the evaluation of FBA properties were full–scale aggregate prototypes resulting from the first industrial production trial conducted by ARCIRESA, with a total output of 50 tonnes of the new refractory raw material.

The chemical composition of FBA samples was analysed by X-ray fluorescence (XRF) (table 1). The aggregate is a highly-refractory sintered material with Al_2O_3 content > 92 % and minor quantities of SiO_2 (ca. 3.5 %) and TiO_2 (ca. 3.2 %). The major impurity is Fe_2O_3 (ca. 0.5 %) with almost negligible amounts of CaO, MgO, Na_2O and K_2O.

The physical properties of FBA (bulk density, water absorption and apparent porosity) were determined according to ASTM C 357-94 standard (table 1). FBA grains exhibit a bulk density of 3.55 g/cm^3 and highly reduced values of water absorption (ca. 0.8 %) and apparent porosity (ca. 3 %).

The quantitative phase analysis of samples was performed by X-ray diffraction (XRD) (table 1). The major phase of FBA aggregates is corundum (ca. 84 %) with mullite (ca. 11 %) and tialite/aluminium titanate (ca. 5 %) as minor phases. Regarding the particle-size distribution (PSD), FBA will be commercially available in various sizes (2 - 6 mm, 1 – 3 mm, 0 – 1 mm, 0 – 0.5 mm, 0 – 0.2 mm and DIN 70) (figure 1).

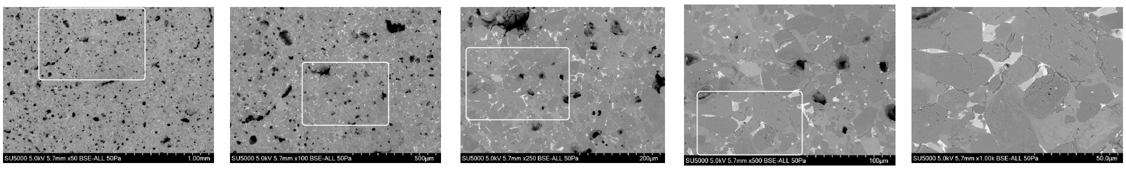
Table 1: Physical properties, chemical and phase analyses of FBA

Chemical analysis			**Physical properties**		
% Al_2O_3	92.5	Min. 92%	Bulk density, g/cm^3	3.55	Min.3.50
% SiO_2	3.5	Max. 4.5%	Water absorption, %	0.8	Max. 1.2
% TiO_2	3.2	Max. 4%	Apparent porosity, %	2.9	Max. 4
% Fe_2O_3	0.5	Max. 0.7%	**Phase analysis**		
% CaO	< 0.1		Major phase	Minor phases	
% MgO	0.15		corundum	mullite	tialite
% Na_2O	< 0.1		(α-Al_2O_3)	($Al_{2.4}Si_{0.6}O_{4.8}$)	($TiO_2 \cdot Al_2O_3$)
% K_2O	< 0.1		83.9 %	10.8 %	5.3 %
Available sizes	DIN 70, 0–0.2 mm, 0–0.5 mm, 0-1 mm, 1-3 mm, 2-6 mm				

FBA grains **FBA 2 – 6 mm** **FBA 1 – 3 mm** **FBA 0 – 1 mm** **FBA DIN 70**

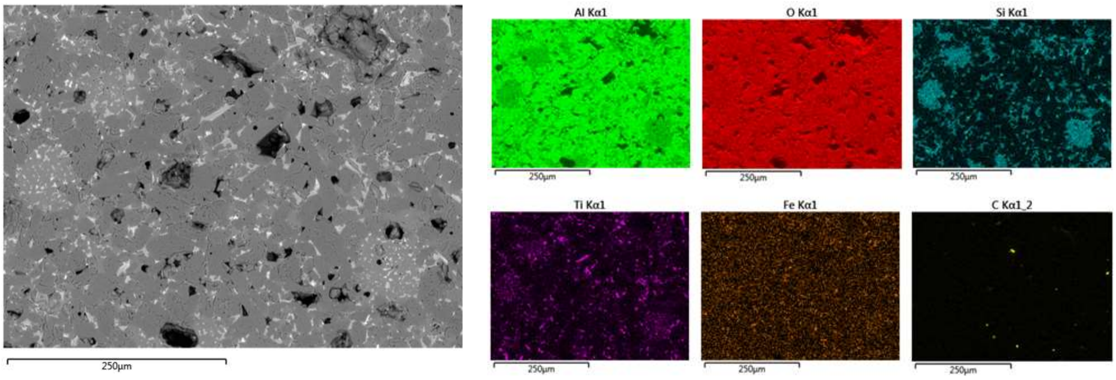
Figure 1: ARCIRESA FBA (Fired Bauxite Aggregate)

The microstructural properties of FBA test samples were studied by scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS). Observation of microstructure by SEM (figure 2) reveals that FBA particles surface show inter-granular and intra-granular porosity, which is inherent of aggregates produced by the sintering process route. The elemental mapping of FBA by EDS shows the uniform distribution of minor elements and impurities through the matrix thus ensuring a highly homogeneous aggregate (figure 3).



Particle surface x50 | Particle surface x100 | Particle surface x250 | Particle surface x 500 | Particle surface x1000

Figure 2: Scanning electron microscopy (SEM) of FBA



Electron microscopy image **Elemental mapping (microstructural level)**

Figure 3: Energy dispersive X-ray spectroscopy (EDS) of FBA

Mercury intrusion porosimetry (MIP) technique and He pycnometry test were utilized to evaluate the pore size distribution, the volume of accessible pores and other important index parameters of FBA pore structure. According to results of MIP analysis, the open porosity associated to accessible pores > 1 μm, i.e. pores that can be easily infiltrated by molten metal and slag, is limited to ca. 2 % volume, thus ensuring high corrosion resistance of the FBA aggregate.

For the purpose of comparison, key parameters of FBA, BFA and premium refractory-grade fired bauxite BauxST^{AR} 90 are listed in (table 2). The different process routes of BFA (fusion) and FBA (calcining + sintering) have significant impact on the aggregates properties. FBA bulk density (3.5 – 3.6 g/cm^3) is lower when compared to BFA (3.85 g/cm^3), which is mainly due to closed internal porosity in sintered aggregates and the

FBA mullite content. However, it is important to note that FBA properties with a major influence on resistance corrosion, such as water absorption, open porosity and volume of accessible pores > 1 μm, are at comparable level to BFA. A distinguishing feature of FBA is its mullite content (11%), which is not present in BFA, thus upgrading thermal shock resistance, mechanical strength and creep behaviour of refractory formulations.

Table 2: Comparison of BauxST^{AR} 90, FBA and BFA key properties

Chemical analysis	**BauxST^{AR} 90**	**FBA**	**BFA (95% China)**
% Al_2O_3............................	92.0	92.5	95.4
% SiO_2..............................	4.0	3.5	1.1
% TiO_2..............................	3.4	3.2	2.6
% Fe_2O_3............................	0.5	0.5	0.2
Physical properties	**BauxST^{AR} 90**	**FBA**	**BFA (95% China)**
Bulk density, g/cm^3...........	3.25	3.55	3.85
% Water absorption...........	3.00	0.80	0.50
% Apparent porosity..........	9.80	2.90	2.00
% Accesible pores > 1 μm	9.4	2.0 - 2.5	1.5 [1]
Phase analysis	**BauxST^{AR} 90**	**FBA**	**BFA (95% China)**
Major phase.......................	Corundum	Corundum	Corundum
Minor phases.....................	Mullite	Mullite	
	Tialite	Tialite	Tialite

PRODUCTION PROCESS OF FBA (<u>F</u>IRED <u>B</u>AUXITE <u>A</u>GGREGATE)

The production of FBA is based on 2 high–temperature firing stages (calcination + sintering) of BauxST^{AR}, the highest purity gibbsitic refractory-grade bauxite ore in the world and mined at First Bauxite’s unique Bonasika deposits in Guyana (figure 4). The installation of the new FBA manufacturing line is successfully on-going at ARCIRESA main production facility (Asturias, Spain). FBA introduction to the market is scheduled for the first quarter of 2023.

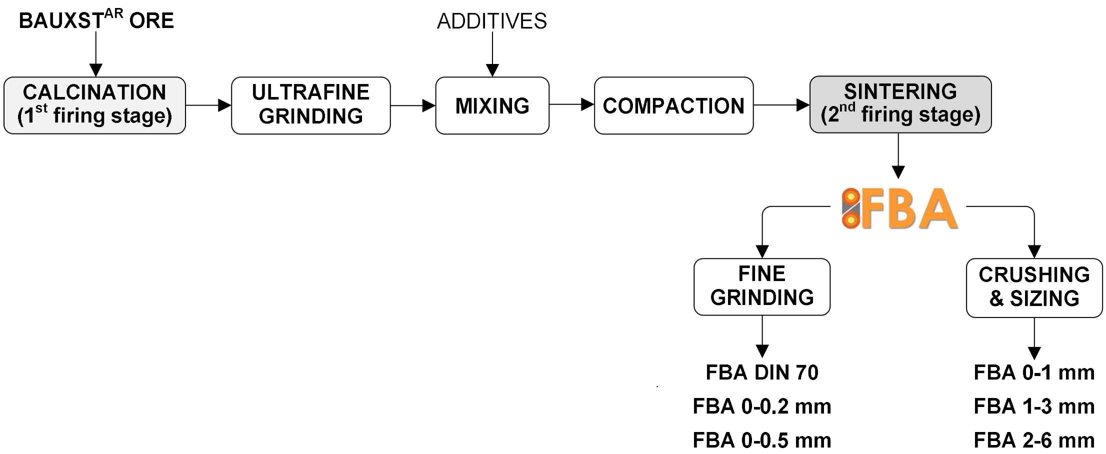


Figure 4: Production process of ARCIRESA FBA sintered aggregate

TESTING OF BFA IN REFRACTORY APPLICATIONS

FBA-based refractories have been tested in the formulation of AMC bricks (lab-scale) and blast furnace runners castables (on site) as an alternative to BFA-based products.

Al_2O_3–MgO-C (AMC) bricks are characterized by an optimal corrosion resistance that is required to withstand the aggressive operational environment of the steel ladle. Typical formulations of AMC bricks are based on high-alumina aggregates (BFA and RGB), magnesia, carbon (graphite) and different matrix components. The slag resistance of high-grade AMC bricks based on FBA and on a mixture 50% FBA + 50% BFA was evaluated in comparison to 4 commercially available grades of AMC bricks based on BFA (premium and high quality grades) and RGB (medium and low quality grades). The test was conducted in a rotating furnace in accordance with ASTM C847 standard. Although the bulk density of FBA-based AMC bricks was found to be 4.5 – 6.3% lower than BFA-based formulations, the corrosion resistance performance is at comparable level to commercial premium and high-grade AMC bricks based on BFA.

A challenge facing operators of blast furnace runners is reducing the loss in production due to down-times for refractory maintenance. Thus, the campaign life of the system is a key parameter to evaluate the performance level of applied refractory products. Most common aggregates used in the formulation of castables for blast furnace runners are BFA and silicon carbide (SiC). On-site testing of FBA-based castables for blast furnace runners was conducted at ArcelorMittal Asturias plant (Gijón, Spain). The formulations tested in the industrial application trial were based in the total replacement of BFA by FBA and applied in the form of skimmer blocks and plates for the main through, pre-cast shapes for the pig-iron runner end, pre-cast shapes for the slag runner end (INBA) and wear lining for the slag runner. The tested specimens successfully completed the targeted campaign life of the blast furnace runners or alternatively the expected service life extension between general and partial repairs, which reveals a level of performance comparable to BFA-based formulations in terms refractory durability.

SUSTAINABILITY OF FBA AND FBA-BASED REFRACTORY APPLICATIONS

Brown fused alumina (BFA) is produced by batch or semi-batch fusing of pre-calcined non-metallurgical grade bauxite in an electric arc furnace at temperatures > 2,000 ºC. Thus, the manufacturing of high-alumina aggregates by the fusion process route is a highly demanding energy technology. FBA production is based on the sintering of pre-calcined bauxite ore in a rotary kiln, requiring lower energy input (figure 4). Considering the global impact of high energy consumption and its influence on the emissions of greenhouse gases, it becomes obvious that sintered FBA aggregate is by itself a more sustainable choice than BFA. Therefore, the total or partial BFA replacement by FBA in refractory formulations has an impact on the reduction of carbon footprint towards the future target of net-zero emissions in the refractory industry.

Additionally, refractory solutions based on FBA were found to exhibit comparable levels of performance to BFA-based grades in various refractory applications (AMC bricks and castables for blast furnace runners) with a comparatively lower bulk density, which improves the sustainability of the FBA-based refractory products and their industrial applications by reducing the specific material consumption. It is important to note that a first step towards the challenge of circular economy is the reduction of the quantity of material resources to achieve equivalent performance.

CONCLUSIONS

FBA (Fired Bauxite Aggregate) is a new highly-refractory sintered raw material with an Al_2O_3 content > 92 % and bulk density > 3.5 g/cm^3. The major phase of FBA aggregate is corundum (ca. 84%) with mullite (ca. 11%) and tialite (ca. 5%) as minor phases. FBA grains exhibit inter-granular and intra-granular closed pores, which is a microstructural characteristic of sintered aggregates. Thus, the bulk density of FBA (3.5 – 3.6 g/cm^3) is lower when compared to BFA (3.85 g/cm^3). However, it is important to note that FBA water absorption (0.8 %), apparent porosity (2.9 %) and volume of accessible pores > 1 μm (2 %), which are key factors for corrosion resistance of refractory formulations, are at comparable levels to BFA. Additionally, mullite has a positive impact on thermal shock resistance, mechanical strength and creep behaviour of the refractory products.

The results from the laboratory tests and industrial validation trials of refractory FBA-based products evidence the potential of the new high-alumina sintered aggregate to become a technical alternative for the total or partial substitution of BFA in diverse refractory applications, such as AMC bricks and blast furnace runners castables, and also as a raw material to up-grade refractory formulations based on RGB.

The replacement of BFA by sintered FBA also provides a more sustainable choice for the refractory producers and end-user industries in terms of lower material specific consumption for comparable performance of refractory solutions (circularity challenge) and the contribution of the new sintered aggregate to reduce the carbon footprint of the refractory products based on it (net-zero emissions challenge).

Acknowledgments:

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