E-ISSN: 1116 – 2716 P-ISSN: 3026-8214
MPRI-JAAE | INTERNATIONAL JOURNAL OF APPLIED & ADVANCED ENGINEERING RES.
VOL. 08 NO. 5 - APRIL, 2025

PRODUCTION OF DENSE ZIRCON SAND-ALUMINA REFRACTORY BRICK FROM ZIRCON SAND OF BAKIN RUWA FOR FOUNDRY APPLICATION

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DOI: https://doi.org/10.70382/mejaaer.v8i5.016

Abstract

The study centred on the production of Dense zircon Alumna refractory bricks using Bakin-ruwa zircon sand and Alkaleri kaolin as binder for foundry application. These experiments involved sourcing of materials, size distribution of the sample was evaluated using Sieve analysis mixing of zircon sand binder and water was done on wet and line blending method A [redacted] compaction pressure 150 MPa which is equivalent to (21755.66 PSI) and (150000 kn/m^2) respectively was applied to the bricks. This produced a very dense packing of the refractory brick,

Keywords:
Alumino-silicate, refractory, Binder, zircon sand, foundry, furnace

Introduction

Zircon sand is one of the most refractory minerals known. It is composed of 59–63 percent zirconium oxide (ZrO_2), 32–38 percent silica (SiO_2), and occasionally about 1% hafnium, it has good abrasion, impact and thermal shock resistance. It is stable in chemical conditions and is non-magnetic as well as non-conductive. Zircon has been recognized as a potential structural material

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because of its good combination of physical and mechanical properties, such as excellent chemical stability, thermal shock resistance, strength retention to high temperatures, low thermal expansion as well as low heat conductivity Owing to high demand of zircon (Routray *et al.,* 2021).

Refractories are materials that are capable of withstanding high temperature (usually above 1,580°C) under the physical and chemical action of molten metal, slag and gas in the furnace (Olade, 2019). Silica (SiO_2) and alumina (Al_2O_3) are the principal constituents of Alumino-silicate minerals. The performance of a refractory material in high temperature application depends mostly on the property of the raw material it is made of; better property combination can be developed from the combination of two or more distinct materials. these materials are capable of withstanding high temperatures physically and chemically. High quality refractory materials defy high temperature variation and are good thermal and electrical insulators (Arnold, 2022). The raw materials for the production of various refractory products vary. It is required to produce a range of refractory materials with diverse qualities to meet a variety of processing circumstances. (Groover, 2010; Omowumi, 2011). There are huge amounts of refractory raw materials dispersed over every region in Nigeria, each differing from site to site because of geological variances (Sari *et al.,* 2021).

The exploitation of different deposits which can be a potential source for this mineral is a priority at present. Hence, it has attracted a wide attention of, users to exploit zircons for end use, zircon is a proper material for foundry due to its several good properties such as high heat conductivity as a result, it has a faster cooling process compared to quartz-based foundry, not reactive to other metals, clean-surface, spherical form, this character is appropriate for all binder type, less binder material, stable grain size and neutral pH. (Silva *et al.,* 2020).

Zircon sand is a natural source of many industrial finished products. One such good that has shown to be indispensable in the metallurgical industries is refractory material (Arnold, 2022). In the last few years, there has been an increased awareness of the breadth and importance of refractory materials in the industrial growth of Nigeria). (Silva et al., 2020) With the revamping and development of the iron and steel industry via the rehabilitation of various inland rolling mills and the completion and commissioning of the multi-billion-dollar Ajaokuta Steel Complex

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to produce 1.3 million tons of liquid steel, there will be a great increase in demand for refractory materials (Olade, 2019).

According to Nigerian geological survey agency, (2003). Zircon sand occurs in many parts of Nigeria including Bauchi State and predominantly in Bakin Ruwa, Toro local government area, Bauchi state where it is associated with alluvial tin deposits and mining.

Zircon sand is a bye- product during tin mining and various global research has been on zircon and allied refractory materials such as (Olade 2019, Ameh, 2009, and Ndanusa, 2009). But none of them investigate the potentials of Bakin ruwa zircon sand for the development of dense refractory bricks for foundry use.

The aim is the production of dense zircon sand-alumina refractory brick from zircon sand of Bakin ruwa for foundry application. In view of the growing need of Nigeria's metallurgical industry, it is imperative for prospective entrepreneur to explore the opportunity and invest in local production of refractories especially the basic type which for now is largely imported.

MATERIALS AND METHODS

Raw Material Sourcing

The Zircon sand materials used in this research work were obtained from Bakin ruwa, Toro local government area of Bauchi state, Nigeria.

Beneficiation

The composite Tin ore sample was subjected to a laboratory model, Humphrey's spiral concentrator, with 17½" pitch used to recover total heavy minerals (> 98% grade). The concentrate was subjected to Wet High Intensity Magnetic Separator (WHIMS) to recover magnetic heavies and non-magnetic heavies separately. The non-magnetic fraction contains mostly sillimanite, zircon, rutile, quartz etc. The non-magnetic fraction was then subjected to gravity table (GT) to improve the grade of sillimanite. The concentrate from gravity table was subjected to flotation cell to recover sillimanite in flotation process. The flotation tailing subjected to High Tension Separator (HTS) to recover zircon in non-conducting fraction, it was later subject to scrubbing for desliming. The deslimed feed was subjected to characterization.

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Sieving

Sieve analysis is a laboratory technique used to assess the particle size distribution of a granular material, such as refractory materials. The procedure typically involves passing the material through a series of sieves with progressively smaller mesh sizes, then weighing the material retained on each sieve. The data obtained from the sieve analysis can help determine the suitability of the material for various applications in industries like construction, ceramics, and metallurgy.

Sieving analysis was conducted to evaluate size distribution of the sample. Sieving equipment were set into fraction of 25, 60, 80,120 and 200 meshes ASTM D6913:

Mixing

Ground and sieved zircon sand is mixed with the binding materials in such a way that it becomes plastic and the plasticity is equally distributed through the mass to facilitate easy molding. Mixing can wet. 14 to 20% water is used in wet mixing.

Autogenous mixing of zircon sand binder and water was done on wet blending method by charging the ball milling machine with the appropriate quantity of binder water and zircon sand respectively for one hour. This enabled milled of particle cohesion in the batched when pressed under a clenched fist this was indicative of adequate moisture content. (Ameh, 2019).

Line and wet Blending

Wet blending involves mixing raw materials in a liquid medium, typically water or a binder solution, to form a slurry or suspension. This method facilitates better particle dispersion, improved homogeneity, and enhanced flowability of the mixture. Wet blending techniques include ball milling, attrition milling, and slurry mixing. However, wet blending may require additional drying steps, and binder selection is crucial for maintaining stability and avoiding excessive shrinkage during drying (Cui, 2021)

Table 1: line blending of zircon sand and Kaolin

ZIRCON (%)	100	90	80	70	60	50	40	30	20	10	0
KAOLIN (%)	0	10	20	30	40	50	60	70	80	90	100

Source: Researcher work 2024

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Molds and parts

This mold was made of six parts. The plunger (piston) and the ejector the base, top, and the stand were welded together using arc welding, all of the parts were bond respectively. These make a total of twenty inter-joining parts making a complete unit of unified mold.

Assembly of parts of the twelve mold- piece mold provided what is referred to as the three-dimensional view (3-D View) of the mold. These includes the piston (plunger) and the ejector. The entire mold parts were classified as top and bottom sections, side sections, the rear and front section, the piston and the ejector.

Charging the mold with body material

The batches of refractory mixtures were measured using a weighing balance to ensure that the materials to produce each brick were equal, to avoid error of production. As specified above it was found that about 3.6 kg of the mixed materials was measured for the production of 9" x 4.5" x 2.5" (229mm x 114mm x 64mm) brick size.

Press forming of dense refractory bricks

Refractory brick of a standard size of 228.6mm x 114.6mm x 76.2mm (9" x 4.5" x 3") were successfully made using the press forming method. A compaction pressure 150 MPa which is equivalent to (21755.66 PSI) and (150000 kn/m^2) respectively was applied to the bricks. This produced a very dense packing of the refractory brick, as opined by Chester, **(**Zeng*, et al*.,2020**). And** (Reddy, *et al* 2021).

Discharging the brick from the mold

The forming processes completed by discharging the formed brick from the mold, to make the mold release the brick easily free a layer of unused engine oil was applied to the internal surface of the mold including the plunger and the releasing surface of the ejector which serves as a lubricant which easily separate the mold from the brick after pressing.

Drying the bricks

After pressing, the bricks were discharge from the mold for drying on the drying bat uncovered for 14 days (2 weeks). They were then moved carefully in their

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green stage into the oven and dried at a temperature of 110 0C for the period of 14 days

Drying is done at slow rate to avoid voids and high shrinkage. Drying of molded refractory increases its green strength by removing moisture and thus making them safe for subsequent handling. Drying is usually carried out under shade (not direct sun light) on large drying floors. Floor heated by waste heat from kilns are also used where refractories are laid out in the open arrays. Drying is carried out in pre-determined set of conditions (of temperature and humidity) and drying rate is kept at minimum to avoid higher shrinkage and crack formations.

RESULTS AND DISCUSSION

Sieving

The results showed that Bakin-Ruwa zircon sand was dominated by coarse to medium size fractions, namely fractions of 25, 60, 80, 120 meshes. The weight percent of such fractions is between 10.20 – 35.66% and fraction of - 80+120 acquired the highest percentage, namely 35.56%. The finest fractions (- 120+200 and -200 meshes) provided the least weight percentages, namely 1.11 - 1.20%. which is in consistent with the work of (Silva *et al.*, 2020).

Mixing

A ball mill used for autogenous mixing ensuring that grinding pebbles were not introduced. The 30 minutes to one-hour duration for dry-mixing the zircon sand and binder produced homogeneous mass of refractory batches. This could be seen in the surface crystal structure of the refractories from a cross-sectional view point.

Uniform moisture distribution was achieved when water was introduced to the batch in the ball mill, and milled for one hour. The mixing allowed within the matrix, a uniform distribution of moisture. It also allowed various particle sizes within the batch to gain excellent particle inter-locking contacts. Thorough mixing, in addition to an ageing period of two weeks helped significantly in the frying processes, and the handle-ability of the products without breaking before fire sintering was applied. (ASTM C71)

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Blending and Weighing

Blending of zircon sand, binder and water was done on wet and line blending method by charging the ball milling machine with the appropriate quantity of binder water and zircon sand of different percentages respectively for one hour. This enabled milled of particle cohesion in the batched when pressed under a clenched fist this was indicative of adequate moisture content. And weight of each brick was measured using weighing balance, which collaborate with the work done by (Sullayman, 2018). And (Ndanusa, 2005).

Table 11: line blending of zircon sand and Kaolin

ZIRCON (%)	100	90	80	70	60	50	40	30	20	10	0
KAOLIN (%)	0	10	20	30	40	50	60	70	80	90	100

Source: Researcher work (2023)

Table12: Weight of produced refractory bricks

S/N	Blending ratio	Weight in kg
1.	90:10	6.80
2.	80:20	6.60
3.	70:30	6.50
4.	60:40	6.40
5.	50:50	6.30
6.	40:60	5.50
7.	30:70	4.80
8.	20:80	4.50

Mold Design and Fabrication

Mold design took care of all the inter-joining parts as can be seen with the proportional relationship of parts to the whole and the dimensional ability of the mold while in use. The clamps, made of mild steel provided efficient attachment of the mold to the bed of the press on which compaction was made.

The welding of the mild steel surface to that of a stainless steel was very successful. They were co-joined permanently, without any sign of giving way due

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to the production pressure. The stainless steel used for the internal surface of the mold was corrosion and wear-resistant. It protected the mild steel from wear and corrosion it could have been exposed to if made to carryout the function of the stainless steel (Sullayman, 2018).



Plate 7: Rear view of the mold



Plate 8: Angular view of the mold



Plate 10: Upper view of the mold

Press Forming of Bricks

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Brick Discharge/Removal from Mold

Sufficient coating of the internal surface of the mold provided sufficient lubrication for the outer surface of the bricks that had direct contacts with the

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mold. Through a maximum force of 30 tons used to eject the bricks from the mold bricks that made without the lubricating mold separator got stocked to the mold. Such bricks had to be destroyed to clear the mold before any further production could be embarked upon.

The utilization of new (yet-to-be used) engine oil served as a very useful lubricant/separator for the side walls of bricks mold. On the other hand, petroleum jelly coating between the ejector surface and a polythene sheath was successfully applied as a separator between the ejector and the bricks on one hand, and between the plunger and the bricks surface on the other hand. Bricks made without the polyethylene sheath layer between them and the plunger or ejector surface could not be removed without surface blemishes or distortion.

Drying of Bricks

The bricks after drying for 14 days in an exposed form under room temperature were visibly observed to be dry. They had obvious increase in fragility due to a substantial loss in water of plasticity. Flaking of bricks parts, at the sharp edges became apparent especially in handling and transportation. ASTM C72. And (Lomertwala *et al.,* 2019).



Plate 11: produced refractory bricks using line blending.

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CONCLUSION

Blending of zircon sand, binder and water was done on wet and line blending method by charging the ball milling machine with the appropriate quantity of binder water and zircon sand of different percentages respectively for one hour. This enabled milled of particle cohesion in the batched when pressed under a clenched fist this was indicative of adequate moisture content.

Refractory brick of a standard size of 228.6mm x 114.6mm x 76.2mm (9" x 4.5" x 3") were successfully made using the press forming method. A compaction pressure 150 MPa which is equivalent to (21755.66 PSI) and (150000 kn/m^2) respectively was applied to the bricks. This produced a very dense packing of the refractory brick,

RECOMMENDATION

It is recommended that prospective entrepreneurs and government take interest in refractory production. This will provide a local source for the refractory needs of our foundry furnaces; Further work should be carried out with different binders of different blending ratios with varied temperatures.

It is very imperative to focus on establishment of small and medium scale refractory firms within the identified deposits (environments) in order to enhance local capacity building, reduce unemployment in Nigeria and abate the nations over – dependence on single commodity- oil.

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