ISSN: 2689-1204

Research Article

Journal of Applied Material Science & Engineering Research

Influence of Kaolin and Silica on some Refractory Properties of Pingell, Zircon Sand

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Submitted: 09 July 2020; **Accepted**: 18 July 2020; **Published**: 18 Sep 2020

Abstract

100kg of zircon sand raw material was obtained from Pingell, Toro Local Area of Bauchi State while silica and kaolin were used as the additive materials in different proportions. The materials as received were wet and in large chunks, and was sun dried prior to crushing with Jaw crusher and sieved with the sieve of size 100 μ to obtain fine powder particles. Samples of various compositions were prepared from the powder particles of Zircon sand (X); Zircon sand and silica (Y); zircon sand, silica and kaolin (Z) and mixed together based on the experiment's program with a predetermined amount of water in the mixer. Refractory brick test specimens were prepared by standard methods from samples A, B and C and subjected to refractory test such as apparent porosity, bulk density, cold crushing strength, linear shrinkage, thermal shock and refractoriness in order to evaluate the effects of adding silica and gypsum to Pingell zircon sand and investigate its suitability as raw material for refractory brick production and furnace linings. From the result obtained, the average porosity of X, Y and Z is 13.5, 18.3 and 21.6 % respectively while the respective bulk density are 3.2, 2.0 and 1.8 g/cm3. The values of the cold crushing strength for samples X, Y and Z are respectively 25.5, 23.4 and 18.8 MN/m2 but the firing shrinkage is 4.5, 5, and 6.5 %. Thermal shock resistance of 26, 20 and 22 cycles were obtained respectively for X, Y and Z. Refractoriness of 1600, 1580 and 1610 0C were obtained respectively for samples X, Y and Z. The porosity, firing shrinkage and refractoriness increased with increase in the addition of silica and kaolin to zircon sand whereas the bulk density, thermal shock resistance and cold crushing strength of zircon sand decreased with the addition of silica and kaolin but the addition of silica reduced the refractoriness of the zircon sand. The addition of silica and kaolin in the appropriate proportions improved the refractory properties of the zircon sand and hence will find applications in the production of refractory bricks and furnace lining.

Keywords: Zircon; Refractoriness; Thermal Shock; Porosity; Shrinkage; Brick, Furnace

Introduction

Zircon is the main source of Zirconia (Oxide of Zirconium metal) used for refractory, muffle furnaces, fire bricks for electrical porcelain, best sparking plugs, for refining precious metals, roof of electrical furnaces, white opacifier in enamel industry, paints and lacquers in abrasives and polishing powder and also, as insulator of heat and electricity [1]. Clay is a general term which includes several combinations of one or more clay minerals in association with oxides of metal and organic matter [2]. The main raw materials used for conventional ceramic are clay and non-clay materials. Clay confers plasticity thus greater workability, while non-clay reduces the shrinkage and prevents the fissuration on heat treatment. Non-clay is very paramount in the formation of final microstructure of ceramics [3]. Several researchers have investigated the suitability of their local clay deposits to be used in variety of applications. Studied the Nigerian Ozanagogo clay deposit used for refractories Alexander et al., evaluated the refractory properties of NigerianOzanagogo clay deposit and concluded that the investigated properties gave excellent results for refractory application [4, 5].

Several works have been carried out on the production and development of good refractory materials most especially in Europe and America for over two centuries, the outcomes of which gave rise to the myriads of refractory materials which are presently available in the world market. Most of the developing Countries which are consumers of refractory materials, for example Nigeria, have to spend her hard earn foreign currencies on the importation of these materials to meet their needs. Also, there have been continuous upsurge of interest in the area of the development of good refractory in Nigeria in the last two decades [4]. The factors responsible for the development of good refractory utilizing the locally available raw materials include the growing number of metallurgical industries which are in dire need of these refractory, and the advent of foreign exchange market, a situation that has led to higher and unaffordable cost of procuring the refractory materials needed by these industries. Some of the refractory materials usually employed are fireclay, quartz sand, magnesite, sillimanite, berylia, alumina, chromite, zirconia, boron, nitride, graphite and carbide [4].

Vijayaragavan et al., investigated physico-mechanical properties on mineralogical clay - based ceramic bodies with rock residue and found out that the addition of the rock residue improves the physical and mechanical properties of the clay [7]. Davies et al. investigated the effects of Alumina Cement on the Refractory Properties of Leached Ipetumodu Clay and concluded that the addition of alumina cement, silica sand and sawdust in the appropriate proportions enhanced the refractory properties of the purified clay [8]. The effect of the change of firing temperature on microstructure and physical properties of clay bricks from beruas was investigated by and discovered that the effect of firing temperature significantly improved the microstructure in terms of porosity and the quality of physical properties of fired-clay bricks [9].

In related to fire clay brick application, compressive strength and water absorption are the most priority properties because it indicates the ability to resist face fracture (Nnuka and Agbo, 2000) [10]. Omotoyinbo and Oluwole stated that the other properties of fire clay need to consider are bulk density, true density, cold crushing strength, shrinkage and thermal conductivity, supported by [6, 11]. According to, the main factors involved in manufacturing bricks are kind of raw materials, composition, fabrication technique, drying procedure, firing temperature and firing profile [12]. These factors will affect the quality of the final product. But suggested that the durability and strength of bricks are related to their microstructure and mineralogy [13]. However, this work aims to evaluate the effects of the addition of silica and gypsum on some of the refractory property of Pingell, Toro Local Government Area of Bauchi State zircon sand.

Materials and Method

100 kg of zircon sand was obtained from Pingell, Toro Local Government Area of Bauchi State Nigeria together with silica and kaolin obtained from the Refractory Laboratory of NMDC, Jos Nigeria. The material as received was wet and in large chunks, and was subjected to ambient sun and dried at maximum temperature of 34oC, with minimum 6 hours exposed time for 8 days. Jaw crusher was employed to crush the zircon sand, silica and gypsum to obtain powder of particle size 100 μm. Samples of various compositions were prepared from Zircon sand; Zircon sand and silica; zircon sand, silica and kaolin (X, Y and Z respectively) with the additive materials were mixed together base on the experiment's program with a predetermined amount of water in the mixer.

Apparent Porosity

Five samples each of the material were prepared, dried in the air for 24 hours and subjected to oven drying at 110oC for 24 hours. The samples were fired in a furnace at 110oC, cooled and then transferred into desiccators and the dried weight was taken to the nearest 0.01g. The samples were transferred into 250ml beaker in empty Vacuum Desiccators. Water was therefore poured into the beaker until the samples were immersed completely. The samples were allowed to soak in boiled water for 60 minutes before transferring them into empty Vacuum Desiccators to cool. The soaked weight (W) was taken and recorded. The suspended weight was taken when the samples were suspended in water, using beaker placed on balance. The apparent porosity of all the specimens was determined from equation 1 and the average value recorded.

$$A.P = \frac{(W-D)}{(W-S)} X100$$

Where,
W = Soaked weight
D = Dried weight
S = Suspended weight

Bulk Density

Five samples of each clay bricks measuring 60mm x 60mm x 15mm were prepared. The samples were dried in the air for 24hours before oven dried at 110°C, cooled and the dried weight was taken to the accuracy of 0.0018g. The samples were then transferred into a beaker and subjected to heat for 30 minutes to aid in realizing the trapped air. The samples were allowed to cool and the soaked weight (W) was taken. The suspended weight (S) was also taken and the bulk density was then determined using equation 2 and the average value of each of the sample was recorded

$$BD = \frac{D}{(W-S)} g/cm^3$$

Where,
D= Dried weight
W= Soaked weight (weight of the sample immersed in mercury)
S=Density of mercury

Cold Crushing Strength (CCS)

cold crushing strength was carried out to determine the compression strength to failure of the samples. The test pieces of clay samples were prepared to a standard size of 76.2mm^3 on a flat surface (ASTM D412 1983). The test pieces were fired in a furnace at 110oC and the temperature was maintained for 6 hours. The samples were then cooled to room temperature. The samples were tested for crushing strength using hydraulic strength testing machine. The samples were placed on a compressive tester and load was applied axially by turning the land wheel at a uniform rate till failure occurs. The manometer readings were recorded. Cold Crushing Strength (CCS) was calculated using equation 3 and the average value was recorded

$$CCS = \frac{Load(KN)}{Area(cm^2)}$$

Fired Linear Shrinkage

Test pieces were made into standard slabs of size 100mm x 80mm x 50mm; the test pieces were marked along a line so as to maintain the same position after heat treatment. The distance between the two ends of the slabs was measured with Vernier Caliper. The samples were dried in air for 24 hours and then fired at 110°C for 6 hours in the oven. The test pieces were cooled to room temperature and measurements were taken. The fired linear shrinkage was determined with the equation 4 while the average value was recorded

$$F.S = \frac{(D_1 - F_1)}{D_1} X100$$

Where,
D_1 is the dried length
F_1 is fired length

Thermal shock resistance

Five samples of size 50mm by 75mm were prepared from each of the composition and put in a furnace which was maintained at 1600°C and soaked at the constant temperature for 40 minutes after which the sample was brought out and allowed to cool for 20 minutes. The samples were tested for failure with the aid of a standard rig, when failure did not occur the samples were put back inside the furnace and subjected to further heating for a period of 15 minutes, this cycle of heating, cooling and testing was repeated until failure occurred. The number of complete cycles to produce failure in each sample was then recorded [14].

Refractoriness

The samples were mounted on a refractory plaque together with some standard ones whose melting points were slightly above and slightly below that expected of the test cone. The plaque was put inside the furnace and the temperature was set at a rate of 100°C per minute. The test was continued until the tip of the test cone had bent over level with the base.

Result and Discussion

The outcomes of this work is indicated in table 1 and figure 1 below

Table 1 Refractory property of samples XYZ

Samples	Average Porosity (%)	Average Bulk Density(g/cm3)	Average Firing Shrinkage (%)	Average Thermal Shock Resistance(Cycles)	Average Cold Crushing Strength (MN/m²)	Average Refractoriness (°C)
X	13.5	3.2	4.5	26	25.5	1600
Y	18.3	2	5	20	23.4	1580
Z	21.6	1.8	6.5	22	18.8	1610

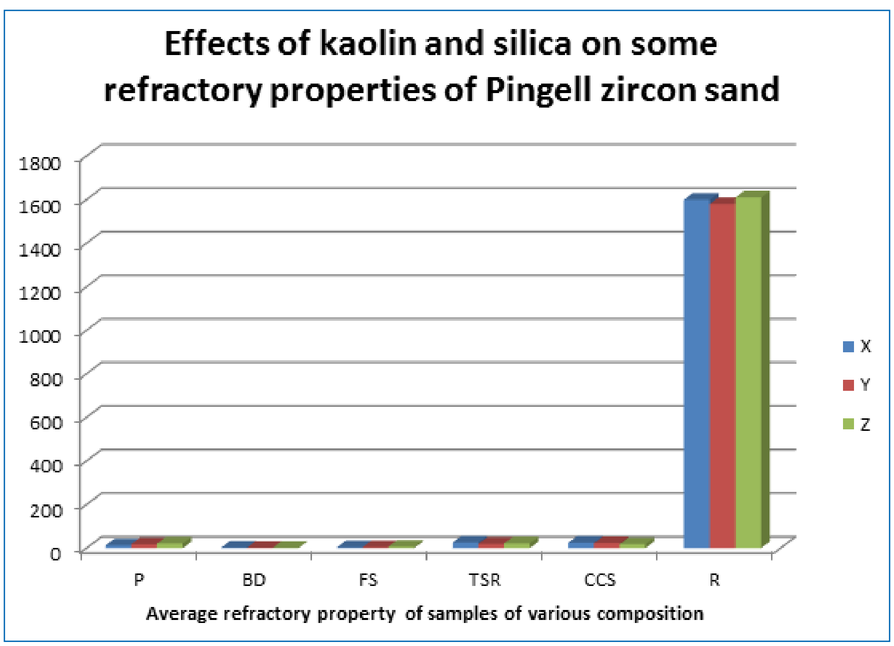

Figure 1: 3-D Colum presentation of the refractory property of samples XYZ

KEYS	
P	Average Porosity (%)
BD	Average Bulk Density(g/cm3)
FS	Average Firing Shrinkage (%)
TSR	Average Thermal Shock Resistance (Cycles)
CCS	Average Cold Crushing Strength (MN/m2)
R	Average Refractoriness

Porosity

The porosity in brick unit depends on the type of clay used in manufacturing and temperature of firing. The porosity of the brick influences its compressive strength, water absorption and permeability. During sintering in the brick manufacturing process, stable initial raw materials transform into complex compounds at high temperatures. New compounds are also formed due to chemical reactions that take place. These compounds have impacts on the stability of the material due to the decrease or increase in the volume of the system [15]. The availability of pores in clay influences its strength by reducing the cross-sectional area expose to an applied load. They also act as stress raiser or concentrator especially in brittle clays [16]. Porosity is among the microstructural variable which ought to be controlled to manufacture a desirable and suitable refractory brick. Strength, load bearing capacity, and resistance to attack by corrosive materials increase as porosity decreases. Also, thermal insulation properties and resistance to thermal shock are reduced. However, the optimum porosity depends on the conditions of service [16]. From table 1 and figure 1 the average porosity of X, Y and Z is 13.5, 18.3 and 21.6 % respectively. It is cleared that sample X which contains only Zircon sand has the lowest porosity Whereas, sample Z which is composed of Zircon sand, silica and kaolin has the highest porosity. Hence sample X has a good Porosity when compared to Y and Z and this implies that sample X will be stronger and possesses good strength than samples Y and Z. Also, sample X will have high resistance to slag attack and more sensitiveness to fluctuations in temperature than samples Y and Z. It can be observed that the porosity increases with increase in the addition of silica and kaolin to zircon sand.

Bulk Density

The Bulk Density property indicates whether or not the refractory material was well fired. Generally, refractory materials are supposed to have good bulk density. From table 1 and figure 1 the bulk density for X, Y and Z are 3.2, 2.0 and 1.8 g/cm^3 respectively. The bulk density obtained for sample X does not fall within the range of the standard specification for fireclays which is 1.7-2.1 g/cm^3 whereas, the values of Y and Z are within the standardize range [17]. From the result above, it is evident that sample X has a higher bulk density compare to sample Y and sample Z. The bulk density of zircon sand decreases with the addition of silica and kaolin.

Cold Crushing Strength

Cold crushing strength is the refractory property of a material which shows how strong the bricks can withstand compressive loading at low temperature. This property is needed to assure the user that the refractory brick is capable of withstanding a high handling condition within a shop or during shipping. From table 1 and figure 1, the values of the cold crushing strength for samples X, Y and Z are respectively 25.5, 23.4 and 18.8 MN/m^2. From the result obtained, sample X has higher cold crushing strength compared to samples Y and Z. Hence, the samples can be able to withstand heavy load at low temperature [18].

Firing Shrinkage

The quality of building of ceramic materials can be certified base on the degree of shrinkage [11, 19]. High shrinkage contributes to the destruction of ceramic material during the process of firing and drying whereas, low linear shrinkage is a good factor which can lead to the reduction in the risk of appearance of cracks and dimensional defects in ceramic samples [20]. Good quality refractory material exhibits shrinkage below 8% [1, 21, 22]. The firing shrinkage for the samples obtains in this work as shown in table 1 and figure 1 are 4.5, 5, and 6.5 % for X, Y and Z respectively and these values are within the recommended shrinkage for fireclays which is 4-10% [18]. All the samples therefore have low shrinkage and hence good refractory materials. The addition of kaolin and silica to Bauchi zircon sand not only improve the shrink-ability of the refractory but also improve the physical and mechanical properties of ceramic bodies.

Thermal Shock Resistance

This is the ability of a refractory material to withstand fluctuation in temperature resulting from heating and cooling without fracture. It is also another source of failure of refractoriness as a result of exposure to rapid temperature changes. In the refractory material thermal gradients induce tension resulted from different changes in the length. The resulting thermal stresses can disrupt the structure of building material. The resistance to the disruption is referred to as the resistance to sudden thermal changes [23]. Refractory materials can exhibit good resistance to cracking provided they possess high strength, high temperature, thermal conductivity, low modulus of elasticity, and low coefficient of thermal expansion [23]. Here, sample X which contains only zircon sand has a thermal shock resistance of 26 cycles. Which means it was at 26 cycles that sample X completely failed while sample Y which contains zircon sand and silica has a thermal shock resistance of 20 cycles and this can be inferred that sample Y completely failed at 20 cycles. Sample Z which contains zircon sand, silica and kaolin has a thermal resistance of 22 cycles as shown in table 1 and figure 1. It implies that sample Z completely failed at 22 cycles. Therefore, it is evident that sample X has high thermal shock resistance than sample Y and sample Z. Hence, the thermal shock resistance of the Bauchi zircon sand decreases due to the addition of silica and kaolin. The thermal shock resistance of the samples is +20 cycles. Therefore, the thermal shock resistance of the samples produced is very good since it falls within the accepted range of 15+ cycles [8, 14]. Therefore, the samples can withstand sudden change in temperature.

Refractoriness

Refractoriness is the measure of fusibility of a material and it also indicates the temperature at which a material softens. From table

1 and figure 1, samples X, Y and Z have refractoriness of 1600^{0}C, 1580^{0}C and 1610^{0}C respectively. Therefore, it means that sample X fused at 1600^{0}C, Y at 1580^{0}C and Z fused at 1610^{0}C. Addition of silica to zircon sand reduces the refractoriness of zircon while the addition of silica and kaolin to the zircon sand slightly increase the refractoriness of the zircon sand. It is also given that the standard refractoriness of any zircon material is from 1580^{0}C-1630^{0}C [17]. Hence, all the samples meet the requirement of good refractory materials.

Conclusion

This work investigated the effects of the addition of silica and kaolin on some of the refractory property of Pingell, Toro Local Government Area of Bauchi State zircon sand. The refractory properties like porosity and firing shrinkage increased with increase in the addition of silica and kaolin to zircon sand whereas the bulk density, thermal shock resistance and cold crushing strength of zircon sand decreased with the addition of silica and kaolin but the addition of silica and kaolin increases the refractoriness of the zircon sand whereas the addition of silica to zircon sand reduces its refractoriness. The addition of silica and kaolin in the appropriate proportions improved the refractory properties of the Pingell, Toro zircon sand and hence the samples produced could be utilized for special engineering applications which include production of refractory bricks and furnace lining.

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