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Investigating the Effects of High Alumina Cement and Silica Sand on the Suitability of Ikere Ekiti Clay for Refractory Applications

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ABSTRACT: *An improvement on the refractory properties of Ikere clay by the addition of high alumina cement (HAC) and silica sand (SiO_2) has been investigated. Atomic Absorption Spectrophotometer (AAS) was used to determine the physico-chemical composition of the clay. Samples containing mixture of different quantities of alumina cement (5, 10, 15, 20, 25 and 30 wt.%), fixed silica sand content of 10 wt.% and a small quantity of water to make them plastic were prepared. Tests of apparent porosity, bulk density, linear shrinkage, thermal shock resistance, compressive strength and refractoriness were carried out on the fired samples. The refractory properties investigated were greatly improved by the addition of silica sand and cement additions. The result revealed that the refractoriness increase from 1450 ^{o}C to 1600 ^{o}C, while compressive strength increased from 4856.50 N/mm^2 to 6522.49 N/mm^2 at 15 wt.% alumina cement before a downward trend was observed above 15% alumina cement. However linear shrinkage, bulk density and apparent porosity of the samples were desirably reduced by the addition of alumina cement. For all the properties tested, 10% silica sand and 10 – 15% alumina cement gave the desired requirement for the production of a refractory material suitable for refractory applications.*

Keywords: *Alumina; silica sand; apparent porosity; refractoriness; compressive strength; physico-chemical.*

I. INTRODUCTION

Refractories are inorganic non-metallic materials which can withstand high temperature without undergoing physico–chemical changes while remaining in contact with molten slag, metal and gases. It is necessary to produce range of refractory materials with different properties to meet range of processing conditions [1, 2]. Kaolinite is the purest form of clays, meaning that it varies a little in composition. It also does not absorb water and does not expand when it comes in contact with water. Kaolinite is a clay mineral, part of the group of industrial minerals with the chemical composition $Al_2Si_2O_5(OH)_4$.

In view of the fact that kaolinite is a unique industrial mineral and a functional ingredient in many industrial applications as well as the need to meet Nigeria kaolinite industrial requirement, there is therefore the need to evaluate the refractory and chemical properties of Ikere–Ekiti kaolinitic deposit and determine its industrial potential that could make it suitable for furnace lining. Generally, the most widely used binding agents are clay-based, this is because they can be recycled in closed systems and their binding characteristics regenerated by the addition of water [3].

Earlier works on clay deposits have shown that they are unsuitable in the as-mined state for high temperature application. They are either high or low in one or more of the important properties desired for good refractory applications or the properties are completely lacking in them [4]. The unsuitability of this clay for high temperature application in the as-mined state has therefore prompted the need for this work, which is aimed at enhancing the clay's refractory properties by adding some additives such as silica sand and high alumina cement in varying proportions.

II. MATERIALS AND METHOD

The materials that were used for this research included a raw clay sample collected from a huge deposit in Ikere–Ekiti, southern part of Nigeria, silica sand from Igbokoda, in Ondo State and high alumina cement (HAC) (Secar 71) from Vesuvius, South Africa.

2.1. Chemical Analysis

Chemical analysis of the Ikere clay as indicated in Table 1 was carried out using Atomic Absorption Spectrometer (AAS), by Ignition Loss Method. The result of the sample confirms that silica and alumina have high percentage. The clay belongs to the fireclay and falls within the range of semi-plastic fireclays [2].

Table 1: Compositional analysis of Ikere clay and silica sand

Constitution	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	L.O.I	TOTAL
Ikere Clay	47.63	28.75	3.87	1.54	2.32	1.24	0.67	0.45	12.02	98.49%
Silica	96.62	0.70	0.62	-	0.03	1.20	0.69	-	-	99.86%

2.2. Mixing

Thorough mixing of the materials plays a vital role in the performance of prepared samples. Samples were prepared in different mixing ratios; containing the Ikere clay, silica sand and varying quantities (5, 10, 15, 20, 25 and 30 wt.%) of high alumina cement. The samples were constituted, using a laboratory weighing balance in measuring the components of the samples to specifications. Each composition was first mixed in the dry state for a period of 10 minutes to facilitate thorough mixing. Water was then added gradually to the dry powder in order to make the mixture plastic and mouldable until no dry powder was left. The plastic paste was then formed into cylindrical specimens of the American Foundrymen Society (AFS) specification of Φ50 x 50 mm height. The samples compositions are as tabulated in Table 2.

Table 2: Composition of Samples

Samples	Kaolin (wt %)	Silica sand (wt %)	Alumina cement (wt %)
A	100	-	-
B	90	10	-
C	85	10	5
D	80	10	10
E	75	10	15
F	70	10	20
G	65	10	25
H	60	10	30
I	55	10	35

2.3. Drying and Firing

The prepared samples were left to dry in the open laboratory atmosphere for 24 hours to make them safe for handling. They were later transferred into the oven for drying at 110 ^oC for a period of 24 hours. The drying was carried out at the rate of 4 °C/min. to remove water of hydration, ensure vitrification and development of stable mineral forms [5].

2.4. Mechanical and refractory testing

Apparent porosity, Refractoriness, Bulk density, Compressive strength, fired linear shrinkage and Thermal shock resistance tests were carried out on the fired samples, in accordance to the American Standard for Testing and Materials (ASTM).

III. RESULTS AND DISCUSSION

3.1 Apparent porosity

The apparent porosity decreases progressively with the addition of alumina cement. Porosity determines the susceptibility of refractory linings to penetration by molten slag, metals and flue gases. It also affects the strength of refractory material [1]. All the samples except A and B exhibited good porosity values which were found to be within the range (20 – 30%) [1]. The highest porosity of 31.02% was recorded for Sample A which was 100% clay. The addition of alumina and silica sand effectively reduces the pores in the mix in the other samples because the pores were blocked as a result of the binding effect of alumina and silica sand which reduced interparticle distance between the grains [4]. The general downward trend is due to the decrease in clay contents and increase in alumina contents. The lowest porosity of 20.42% was recorded in sample G because it contains the highest amount of alumina, which in effect introduced the greatest adhesiveness in the mix. Porosity also depends on grain fineness and firing temperature [6]. High porosity reduces the strength, abrasion and resistance to corrosion. The presence of pores in clay acts as stress raiser or concentrator especially in brittle clays [7]. Silica sand was introduced in the samples to reduce growth combat products at firing and hence reduce the stresses arising therein during firing.

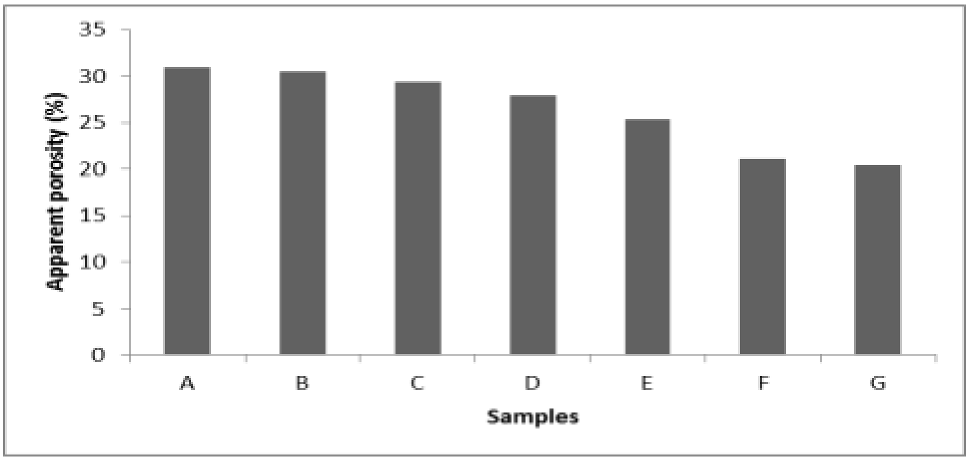

Fig. 1. Variation of apparent porosity of Ikere clay containing 10% of silica sand with alumina cement

3.2 Thermal Shock Resistance

The thermal shock resistance helps in predicting the possible amount of heat that the material can withstand when in use. Thermal shock resistance of a material is influenced by the particle size, coefficient of linear expansion and thermal conductivity of the material. Refractory materials with low thermal coefficient of expansion and coarse textures have increased resistance to sudden changes in temperature [5]. Figure 2 shows that thermal shock resistance increased from 20 cycles at 5% alumina addition in sample C to 25 cycles at 10% addition in sample D and reduces to 23 cycles at 15% alumina addition in sample E. Further alumina addition caused sharp reductions in the thermal shock resistance. The highest shock resistance in sample D is as a result of low coefficient of thermal expansion in the sample. Hassan [8] reported that above 30 cycles as excellent, those in the range 25-30 cycles as good, 20-25 cycles as fair. From the tests conducted, it is evident that addition of 10 and 15% alumina are acceptable for refractory works, 5% alumina is quite fair while 20% and 25% alumina content are very poor for refractory works. Chester [1] reported that the value of 5, 10 and 15% alumina are within the acceptable limit of 20-30 cycles. This indicates that the clay samples could withstand abrupt changes in temperature.

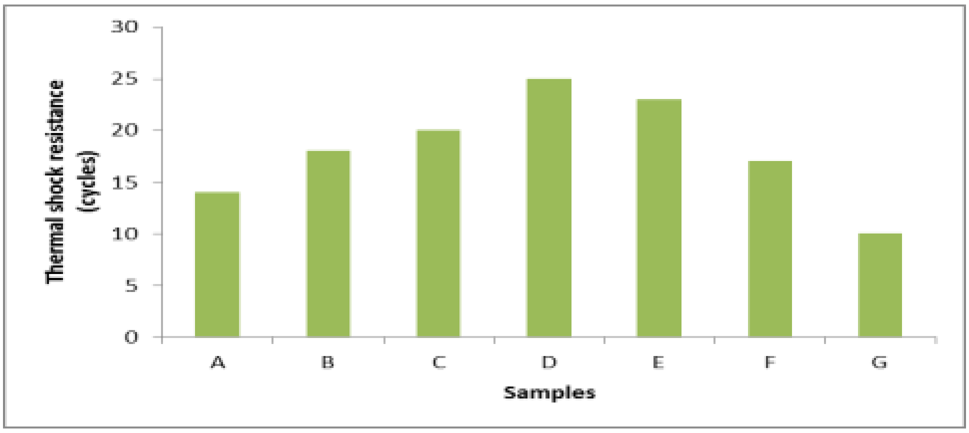

Fig. 2. Variation of thermal shock resistance of Ikere clay containing 10% of silica with alumina cement.

3.3. Bulk Density

The bulk density is a useful property of refractory material and the factors affecting the property include particle size, nature of the materials in the refractory and treatment during manufacture. The results, as shown in Fig. 3 were found to decrease gradually with the addition of alumina, up to 10 wt.% which was still within the range of bulk density for local monolithic lining expected to be used as a furnace lining refractory material and comparable to the value quoted by [9]; that is 1.7 – 2.4 g/cm^3 for fireclays, and to those reported for local refractory in Nigeria [8, 10]. This property is important in the transportation or handling of a refractory material.

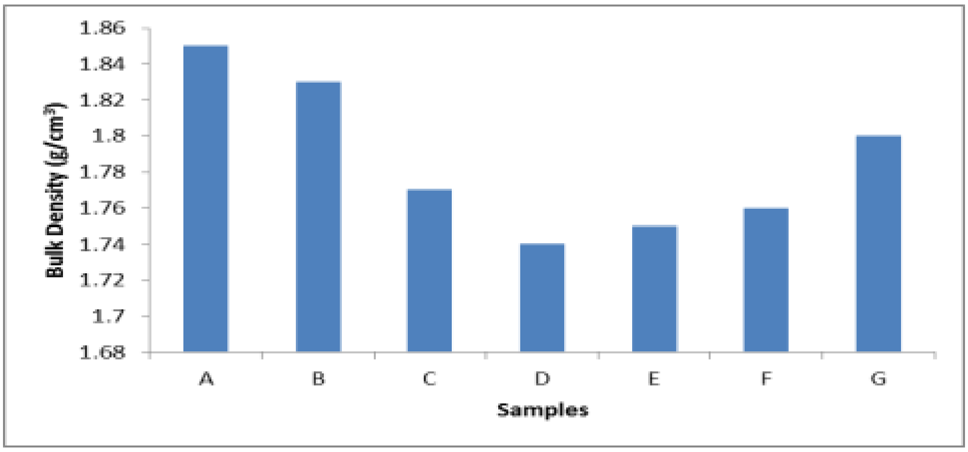

Fig. 3: Variation of Bulk densities of Ikere clay containing 10% silica with alumina cement

3.4. Refractoriness

The samples were observed to have refractoriness not less than 1400 ^{o}C and are within the range of fireclay refractories of 1500 – 1700 ^{o}C. The refractoriness of refractory materials is affected mainly by the chemical composition. Sample D and E have the highest value of 1600 ^{o}C, sample C has refractoriness value of 1500 ^{o}C, while Sample A, F and G had the same value of 1450 ^{o}C. Therefore, it shows that Sample D and E have the highest pyrometric cone equivalent (PCE) of Segar cone 29, as it can withstand the deformation temperature of 1600 ^{o}C before fusing or bend under its own weight. Hence increase in alumina and silica contents is known to increase refractoriness while increase in the fluxing agents such as iron oxide (Fe_2O_3) and alkalis, Na_2O and K_2O reduce this property [9, 11]. Sample B has the lowest refractoriness value of 1400 ^{o}C. The reduction in some samples could be due to presence of impurities in them such as; Fe_2O_3, Na_2O, K_2O, gravel, stones and or other organic matters that was left behind after decantation, leaching and sieving processes. Therefore this clay could be used for the refractory lining of a rotary furnace that could operate at temperature well above 1500 ^{o}C without fear of thermal deformation of the furnace wall if the compositions; (75/10/15) wt.% clay/silica/alumina and (80/10/10) wt.% clay/silica/alumina are used. It was observed that above 15% addition of alumina cement brought about decrease in refractoriness; therefore 15% alumina cement gave the optimum result.

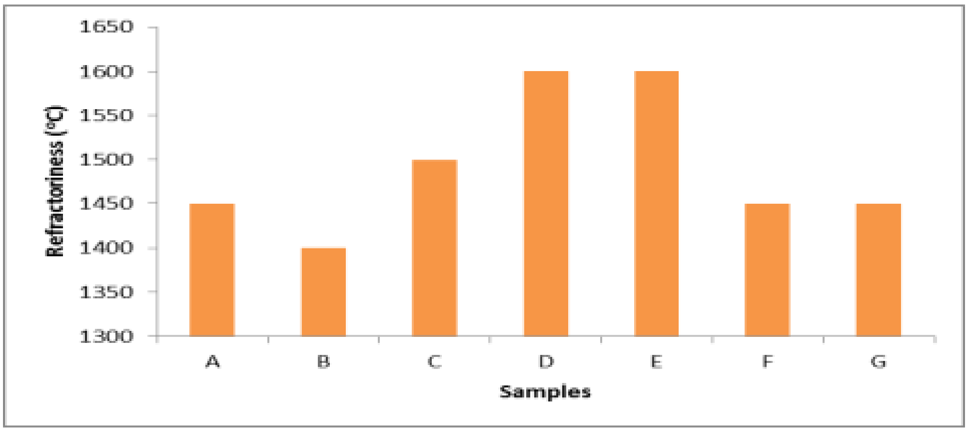

Fig. 4: Variation of refractoriness of Ikere clay containing 10% of silica with alumina cement

3.5 Compressive Strength

The essence of undertaking this test is to determine the ability of the samples to withstand compressive stresses in service. Fig. 5 shows the results obtained from compressive strength tests. It was observed that sample E had the highest strength of 6522.49 N/mm^2, whereas the lowest value of 4856.50 N/mm^2 was recorded for sample A. It therefore shows that there was significant improvement in strength with the maximum addition of 10 – 15% alumina cement. A decrease was recorded for higher percentage of alumina cement contents. Factors of composition, ramming pressure, firing temperature and the amount of water content determine the strength developed by the clay material [8, 12, 13].

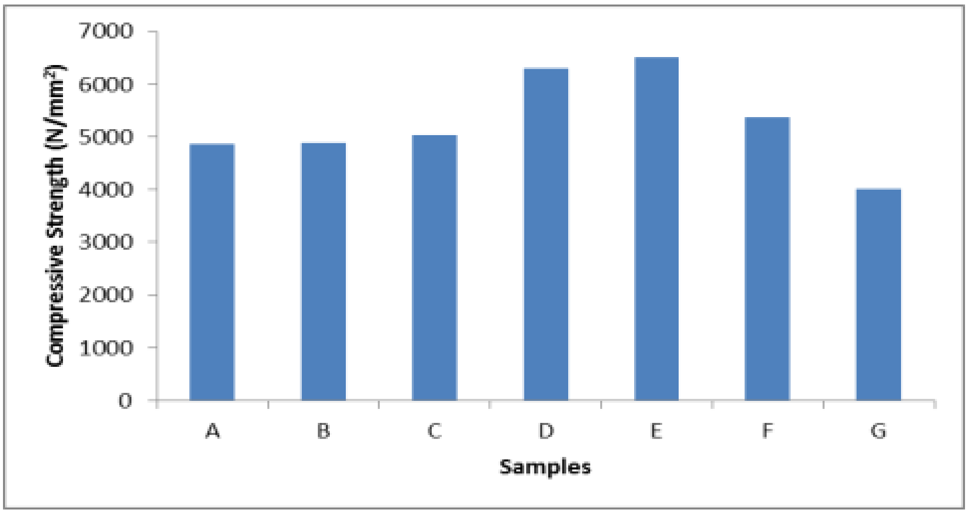

Fig. 5. Variation of compressive strength of Ikere clay containing 10% silica with alumina cement.

IV. CONCLUSIONS

The result of the chemical analysis shows that the clay sample contained aluminum oxide (Al_2O_3) and silica (SiO_2) as major constituents making them suitable as alumino-silicate refractory materials. The refractoriness of 100% Ikere clay was 1450 °C. This implies that it can be used to work low melting point materials not exceeding this temperature. However, linear shrinkage and apparent porosity of the samples were reduced by the addition of alumina. Compressive strength increased from 4856.50 N/mm^2 to 6522.49 N/mm^2 at 15 wt.% alumina cement before a downward trend was observed above 15 wt.% alumina cement.

From the overall research work, the properties of the clay such as refractoriness, compressive strength, porosity and linear shrinkage were effectively improved upon by the addition of 10 wt.% silica sand and 10 – 15 wt.% high alumina cement to Ikere clay. The addition of 10 wt.% silica sand and 10 % - 15 wt.% alumina cement effectively enhanced the refractory properties of Ikere clay. The research has shown that Ikere clay is suitable for refractory works and can safely be used as replacement for imported refractories for refractory applications in the country because refractoriness was improved from 1450 °C to 1600 °C with the addition of alumina cement.

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