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Original Research Article

Consequence of Variations in $Al_2O_3.2SiO_2.2H_2O$ and Grog Percentages on the Properties of Dense Refractory Bricks

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Abstract

Development of high temperature dense refractory bricks using clay minerals and grog has been carried out with a view to determining the consequence of variation in percentages of $Al_2O_3.2SiO_2.2H_2O$ and grog on the properties of locally produced dense bricks. The raw materials were used to compose five batches (of five samples each) from all the clay minerals and their blends (ED1–EN5). The clay bodies were hydraulically shaped and oven dried at 110^0C. The properties of the produced bricks investigated after sintering at 1350^0C indicated that samples ED1–EN5 had shrinkage ranging from 8.4%-11.5% with corresponding bulk density of 1.57g/cm^3–2.26g/cm^3 respectively. The investigation revealed that samples ED1–EN5 of the bricks as stated above had compressive strength ranging from 13.5MPa–23.1MPa with corresponding porosity ranging from 12.84% -23.39% respectively. The estimated refractoriness using shuen's formula shows that samples ED–EN5 had 1666^0c-1768^0c, while the result of the refractoriness using pyrometric cone equivalent indicated that samples ED1–EN5 had cone 30(1660^0C)– <34(<1750^0C) respectively. The spalling-count test result revealed that samples as stated above had number of cycles ranging from 19-35 respectively. It was discovered that the higher the grog content, the lower the shrinkage, bulk density and compressive strength while the higher the porosity, spalling-count-cycle with refractoriness, and vice versa when considering blended samples with increase in $Al_2O_3.2SiO_2.2H_2O$ content. However, sample EN4 gave the most apposite result when considering the properties stated above. Therefore sample EN4 is recommended for mass production of dense refractory bricks for high temperature applications.

Keywords: Refractory, Refractoriness, Edda clay, Ekebedi clay, Grog.

1.0 INTRODUCTION

Refractories are chemically and physically unwavering materials at elevated temperatures, depending on the in service environment, they require to be resistant to thermal shock, be chemically inert, with precise array of thermal conductivity and co-efficient of thermal expansion. They are quite essential in contemporary industries because of their ability to survive high temperature or act in response with the environment without melting [1]. These materials are immobile to many fluxing conditions and they posses reversible thermal expansion and resistance to thermal shocks. They can also be referred to as non-metallic materials with chemical and physical characteristic that make them appropriate for structures, or as components of systems, that are exposed to environments above $1,000^0$ F (538°C) [2]. Refractory is a material that can resist an action of corrosion by solids, liquids, gases and high temperatures. It can be generally categorized with reference to their fusion range as low refractories melting in the range of 1580 - 1780°C, high refractories in the range of 1780-2000°C and supper refractories above 2000^0C [3].

Also, refractories could be classified into categories based on their level of porosity which includes; dense and porous refractories. Dense refractory contains porosity in the range of 15-20% and are used in contact with hot liquid glass, metal and gases. They are used at high temperature or as backup firing of kilns and furnaces. Porous refractories (also known as porous firebricks) comprise one of the refractory groups that are most frequently used today for heat insulation in industrial applications. Porous refractories contain porosity as high as 80%, they are light weight refractories that have much lower thermal conductivity and heat capacity more than other refractories. The high temperature insulation bricks are known as hot face insulation brick while the backup insulation bricks are called cold face insulation brick. It is palpable that the characteristic requirements of refractories vary considerably with respect to the application and use in diverse processes. Therefore, individual refractories need to be premeditated with characteristic properties for precise systems since the requirements differ with diverse high-temperature processes [4, 5].

Refractories are the strength of industrial because they are indispensable for all thermal and chemical processing globally. They play a very important role in diverse areas of the industrial machines predominantly in high temperature industries. The machine tools industry which used refractors as abrasives, electrical and electronic industries as insulators, nuclear power industries as moderators in nuclear fuel, aerospace industries, ceramic industries, glass industries and Iron and steel industries that consumers more than 70% refractory for kiln, furnace and others are some of the industries that are desperately use refractories [6].

In construction (lining) of furnaces, kilns, incinerators, reactors and crucibles, refractory materials plays a vital role. The service environment of refractories determines the requirement for particular refractories for furnaces, kilns and others linings which are quite often used to be the combination of corrosive environment, high mechanical stress and high temperature [7]. The shapes of refractory include; precast cement and fused or sintered refractory products that are shaped prior to installation in furnaces, boilers, or other high temperature equipment. They are hard, heat resistant materials and products which includes alumina, bricks, fire clay, silicon carbide, precast shapes, cement or monolitics and kiln furniture [8].

The intensifying requests for refractory bricks in high temperature industries with some other chemical processing and power generation industries have called for research into a variety of alternative uses of more economical materials. Consequent to the diverse technological advancements and increasing in needs of refractory bricks in our industries, the researcher resolute to investigate the production of high temperature dense refractory bricks that can give the requisite engineering properties of international standard.

2.0 MATERIALS AND METHODS

2.1 Collection of Raw Materials

The Edda clay used was sourced from Izi Edda in Afikpo South Local Goverrment of Ebony State. $Al_2O_3.2SiO_2.2H_2O$ (Nsu clay) was collected from Ehime-Mbano Imo State and Ekebedi was sourced from Ikwuano-Oboro Local Government of Abia State. The grog used was made from Unwana clay and sourced from Unwana Community, Afikpo North Local Government of Ebonyi State, all in Nigeria.

2.2 Chemical Analysis of the Materials

Chemical analysis of Edda**,** $Al_2O_3.2SiO_2.2H_2O$(Nsu clay), Ekebedi and grog (Unwana clays) were carried out to determine the % oxide compositions of the samples using buck model 210 VGP Atomic Absorption Spectrophotometer (AAS) at BETA Glass, Ugeli, Delta State.

2.3 EXPERIMENTAL DETAILS

2.3.1 Preparation of Raw Materials

The clay minerals were subjected to proper drying in an open air for seven (7) days and in an electric drying cabinet (oven) at temperature of 110^0C for four (4) days. The dried clay (Unwana clays) was sintered in the kiln (J W Ratchliff, P U 131 type of kiln) at temperature of 1000^0C whereby the clay loses its water of plasticity and became less plastic (grog). The clay minerals with grog were crushed separately using Pascal engineer machine Edge mill and graded with the aid of sieve into three particle sizes: Fine, Medium and Coarse particles sizes.

2.3.2 Weighing of the Raw Materials

The raw materials used were weighed accurately using a chemical weighing balance Metra TL 3000 model. The raw materials were weighed accurately as stated in table 1 below.

Table-2. 1: Table of Composition

Clay	Batch	Sample	Clay (%)	Grog (%)
Edda	ED	ED1	100	0
		ED2	80	20
		ED3	70	30
		ED4	60	40
		ED5	50	50
$Al_2O_3.2SiO_2.2H_2O$ (Nsu clay)	NS	NS1	100	0
		NS2	80	20
		NS3	70	30
		NS4	60	40
		NS5	50	50

Clay	Batch	Sample	Clay (%)	Grog (%)
Ekebedi	EK	EK1	100	0
		EK2	80	20
		EK3	70	30
		EK4	60	40
		EK5	50	50
Edda and $Al_2O_3.2SiO_2.2H_2O$ (Nsu clay) Blend	EN	EN1	90	10
		EN2	70	30
		EN3	50	50
		EN4	30	70
		EN5	10	90

2.3.3 Body Preparation and Production Processes

The sample 'ED1' percentage of the first batch was weighed and mixed thoroughly before addition of water (18-22%). The sample was properly mixed and allowed to aged for 24 hours. The mixed clay body with required moisture content was uniaxially compacted using hydraulic press under a pressure of 35 MPa into a lubricated mould (lubricated with heavy oil inside). The dense brick was demould after two (2) minutes of proper compression (shaping). This process was repeated for the remaining samples. The samples were left to dry in open air for two (2) weeks on the floor with continuous turning of the samples to give room for even drying. The specimens were loaded into dryer (oven) at temperature of ±110°C for period of one week for proper drying. The properly dried samples were sintered at temperature of 1350^{O}C using front loading electric, J W Ratchliff, P U 131 type of kiln.

2.4 Determinations of properties of the bricks

2.4.1 Determination of Linear Shrinkage

Eleven specimens from each sample were given mark (line) with sharp object measured 10cm length at center point of the top side of each specimen at wet stage. Changes in length of the marks (line) were determined after drying and firing to reveal drying shrinkage, firing shrinkage and total (linear) shrinkage of the specimens.

% Drying shrinkage = $\frac{WL(cm)-DL(cm)}{WL(cm)} \times 100$………. (1)

% Firing shrinkage = $\frac{DL(cm)-FL(cm)}{DL(cm)} \times 100$ …....... (2)

% Total (linear) shrinkage = $\frac{WL(cm)-FL(cm)}{WL(cm)} \times 100$ ... (3)

Where DL = Dry length, WL = Wet length, FL = Fired length.

2.4.2 Determination of Bulk Density

The specimens' length (L), breadth (B) and height (H) were measured and recorded in cm with their weights to the nearest gram with the aid of venier-caliper and chemical weighing balance Metra TL 3000 model. The obtained results were used to calculate the dense bricks' bulk volume and bulk density in g/cm^3.

Bulk Volume of Brick = (L x B X H) cm^3
= LBH cm^3

Let weight of Bulk (Brick) = Wg

Therefore, Bulk Density = $\frac{W}{LBH\, g/cm^3}$ …….. (4)

2.4.3 Determination of Porosity

Eleven specimens from each sample were weighed accurately and immersed in boiling water in a large pot and boiled for 4 hours. The water level was maintained by adding more water when the water evaporated and not covering the bricks again during the boiling process. The specimens were left to cool for 12 hours and removed from the water, clean with a dry towel and weighed immediately. The differences in weight between the boiled and unboiled specimens were recorded as water porosity as percentage of the original weight.

$$\% \text{ porosity} = \frac{\text{Wet weight of sample} - \text{Dry weight of sample}}{\text{Volume of sample}} \times \frac{100}{1} \quad \text{………… (5)}$$

2.4.4 Determination of Compressive Strength

Eleven specimens from each sample were crushed using Compressive Strength tester (Buehler hydraulic press). The load (force) applied before the specimens fractured were recorded. Specimens were mouunted in turn on the machine and loads were applied axially at a uniform rate until fracture took place. The maximum pressure shown by the gauge dial which were read off from the machine was taken.

Crushing Pressure (Stress) = $F/_A$…………………. (6)

Where
A = Area of Cuboid
Area of Cuboid = 2(LB + BH + LH) M^2
F = Gauge reading calibrated in (N) Newton (FORCE)

2.4.5 Determination of Refractoriness

The refractoriness of the specimens were estimated using Shuen's formula.

$$K = \frac{360 + Al_2O_3 - RO}{0.228} \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where K= Refractoriness (^0C) ,
Al_2O_3 = Alumina Content in the clay
RO= Sum of all the oxides beside SiO_2 in the clay (or materials)
360 and 0.228 are constants.

2.4.6 Pyrometric Cone Equivalent (PCE)

Eleven specimens of fired brick from each samples were given shape of standard cone sized (blunt-tipped, skew triangular pyramids with sharp edges) marked test cones. The specimen cones were stacked in the kiln with standard cones marked reference cones. They were heated in the kiln (front loading electric, J W Ratchliff, P U 131 type of kiln) at 2.5^OC/Min alongside reference cones. This process was properly monitored using the estimated result from Shuen's formula. When the test cone collapses, the pyrometric cone equivalent (PCE) is given by the number of standard cone which behaves in the closest manner. The behaviour of the testing material (specimen cones) were compared with that of reference cones. The Pyrometric Cone Equivalent (PCE) values were based on a defined standard time – temperature relationship and the same heating rate was used throughout because dissimilarity heating rates will result in variation results.

2.4.7 Spalling Count Test

Eleven specimens from each sample were subjected to thermal shock test. The specimens were heated to 900^0C in a kiln and the hot samples were then picked out of the kiln and plunge into water of room temperature one after the other. This process was repeated until half of the specimens measured by weight have cracked away due to the shock treatment. If a specimen can endure 10 cycles of such heating and cooling, it is very satisfactory.

3.0 RESULTS

3.1 Result of Chemical Analysis of Clay Minerals

Table-3.1: Result of Chemical Analysis of Clay Minerals.

Parameters	**Edda Clay**	**$Al_2O_3.2SiO_2.2H_2O$ (Nsu clay)**	**Ekebedi Clay**	**Unwana clay (Grog)**
SiO_2	58.86	46.56	58.53	52.24
Al_2O_3	27.69	35.60	28.03	27.20
Fe_2O_3	1.27	0.05	1.41	7.00
TiO_2	0.39	0.69	1.12	1.52
CaO	0.12	0.85	0.28	0.14
MgO	0.21	0.65	0.08	0.04
Na_2O	0.01	0.08	0.03	0.54
K_2O	0.08	0.70	0.03	0.54
L.O.l	10.17	10.90	8.0	10.50
Other oxides/ impurities	1.20	3.92	2.19	0.28

3.2 GRAPHICAL PRECENTATION OF RESULTS

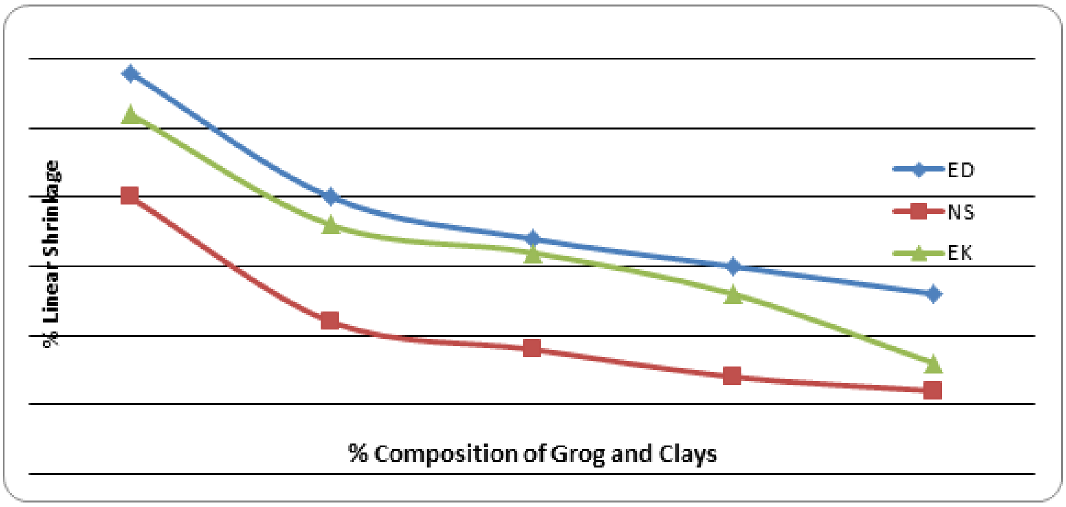

Fig-1: Effects of % Composition of Clays and Grog on shrinkage of the Refractory Bricks

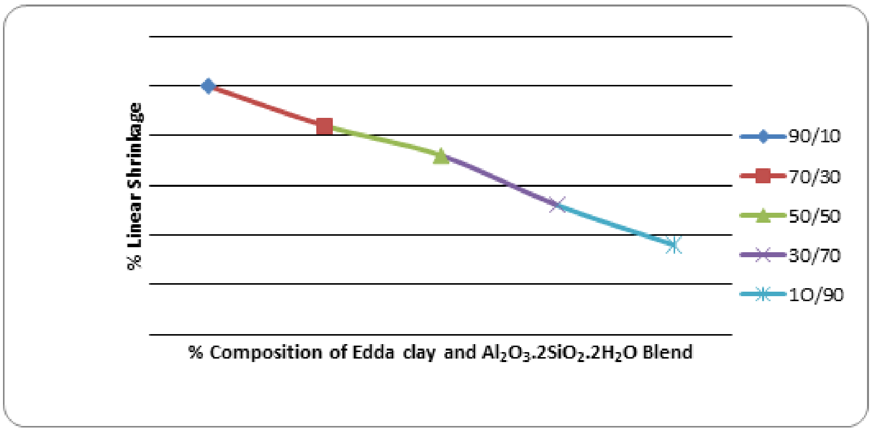

Fig-2: Effects of Percentage Composition of Edda clay and $Al_2O_3.2SiO_2.2H_2O$ Blend on shrinkage of the Refractory Bricks

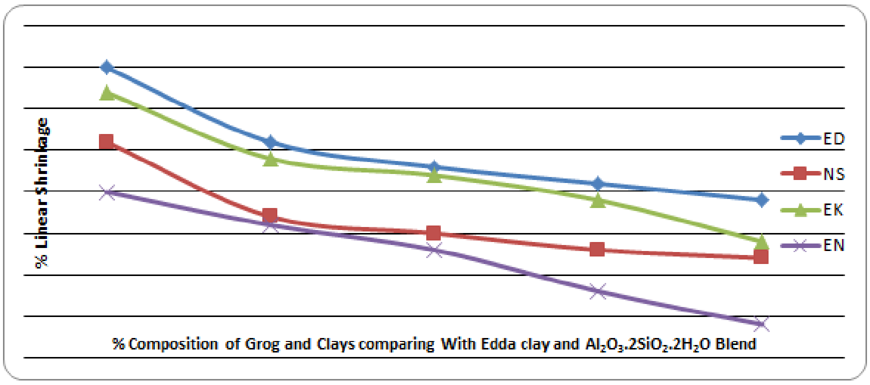

Fig-3: Effects of Percentage Composition of Clays and Grog with Edda clay and $Al_2O_3.2SiO_2.2H_2O$ Blend on shrinkage of the Refractory Bricks

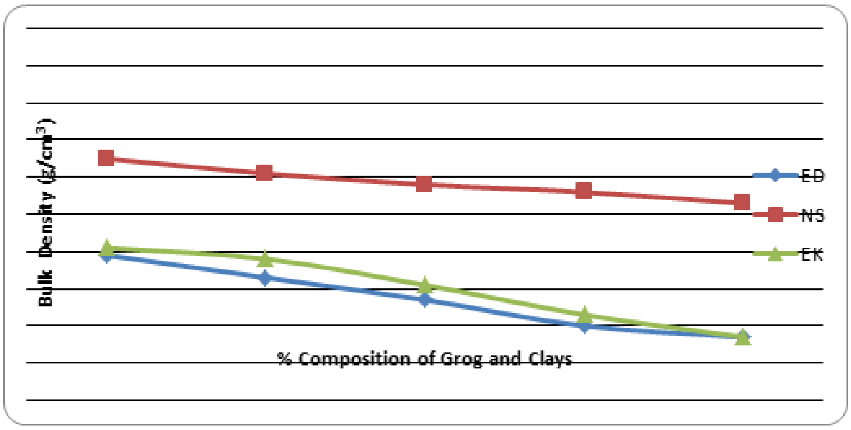

Fig-4: Effects of % Composition of Clays and Grog on Bulk Density of the Refractory Bricks

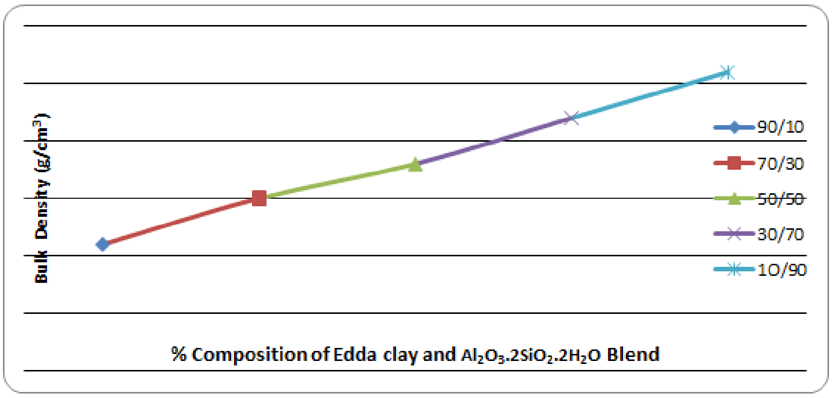

Fig-5: Effects of Percentage Composition of Edda and $Al_2O_3.2SiO_2.2H_2O$ Blend on Bulk Density of the Refractory Bricks

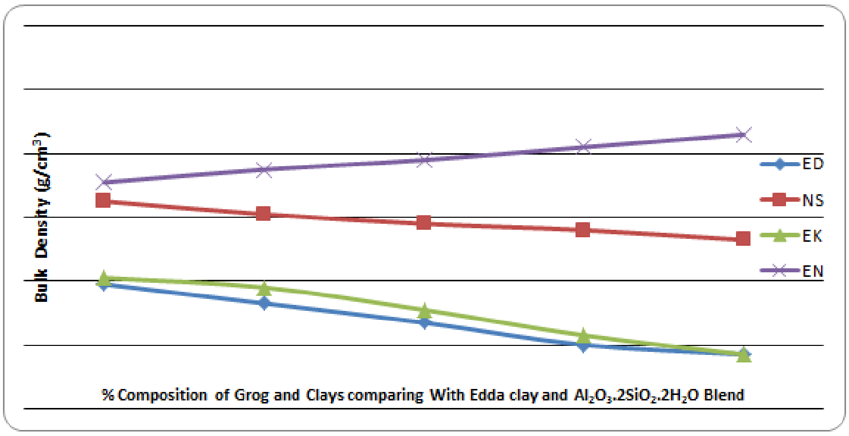

Fig-6: Effects of Percentage Composition of Clays and Grog with Edda clay and $Al_2O_3.2SiO_2.2H_2O$ blend on Bulk Density of the Refractory Bricks

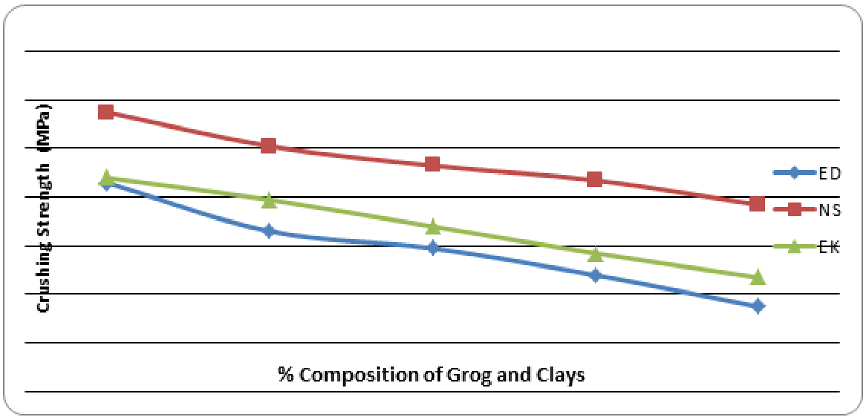

Fig-7: Effects of % Composition of Clays and Grog on Compressive Strength of the Refractory Bricks

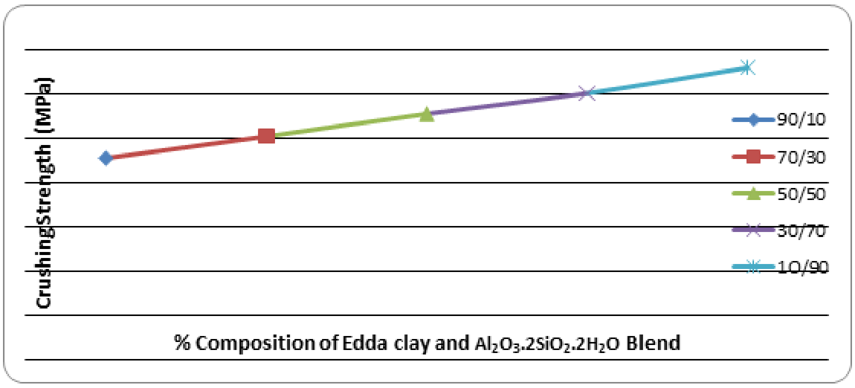

Fig-8: Effects of Percentage Composition of Edda clay and $Al_2O_3.2SiO_2.2H_2O$ Blend on Compressive Strength of the Refractory Bricks

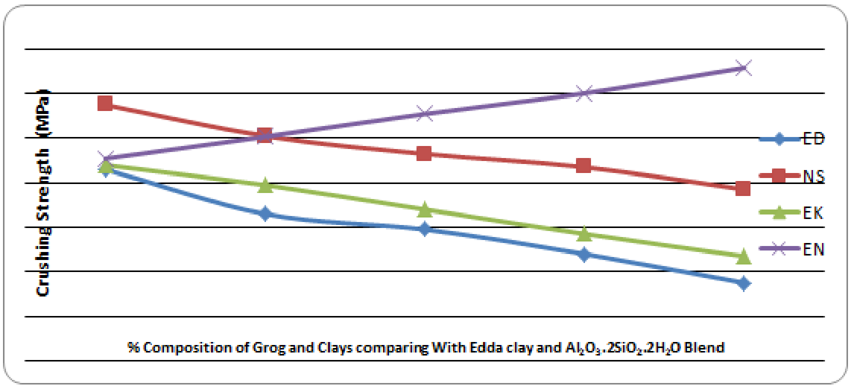

Fig-9: Effects of Percentage Composition of Clays and Grog with Edda Clay and $Al_2O_3.2SiO_2.2H_2O$ Blend on Compressive Strength of the Refractory Bricks

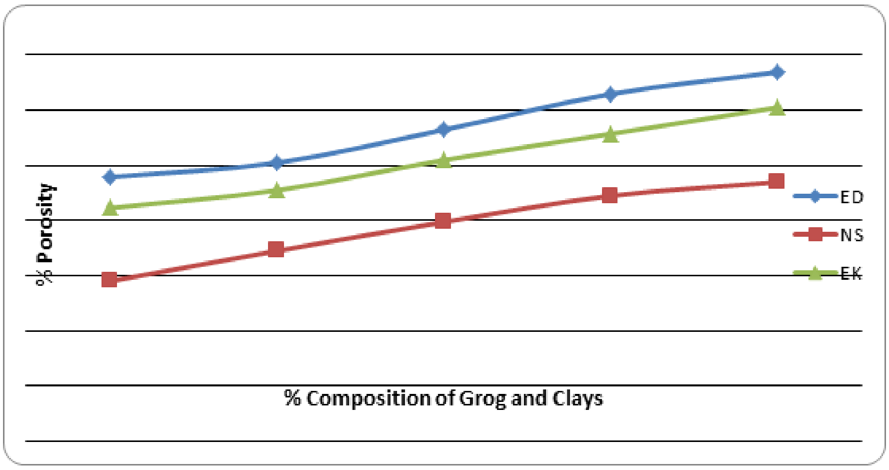

Fig-10: Effects of % Composition of Clays and Grog on Porosity of the Refractory Bricks

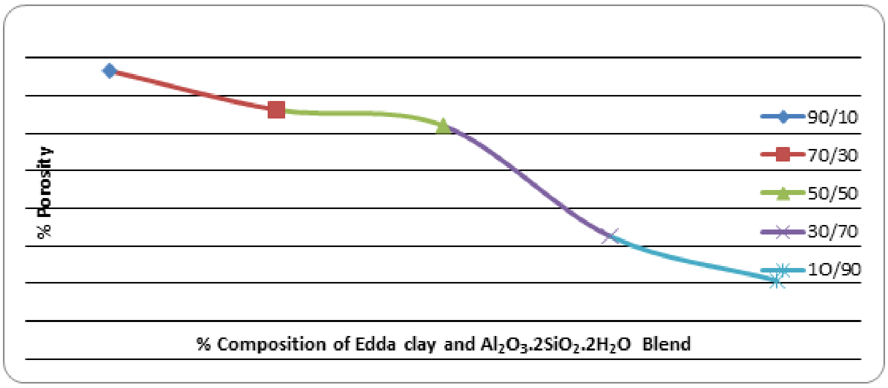

Fig-11: Effects of Percentage Composition of Edda clay and $Al_2O_3.2SiO_2.2H_2O$ Blend on Porosity of the Refractory Bricks

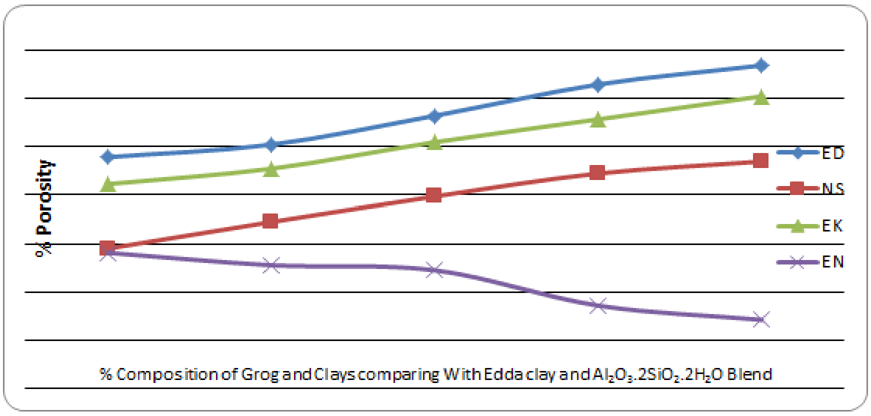

Fig-12: Effects of Percentage Composition of Clays and Grog with Edda clay and $Al_2O_3.2SiO_2.2H_2O$ Blend on Porosity of the Refractory Bricks

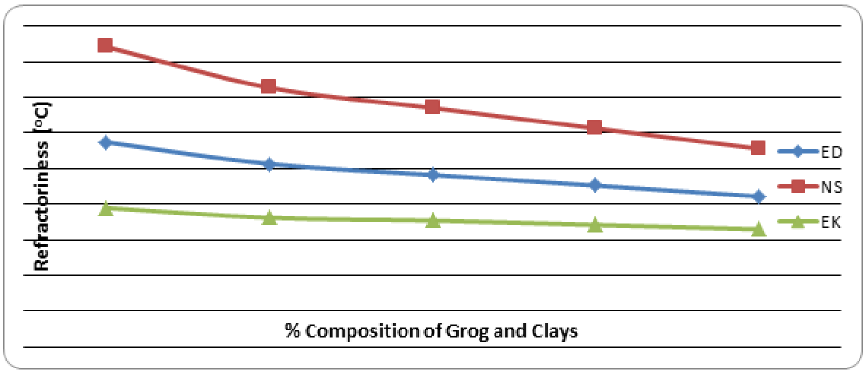

Fig-13: Effects of % Composition of Clays and Grog on Refractoriness of the Refractory Bricks

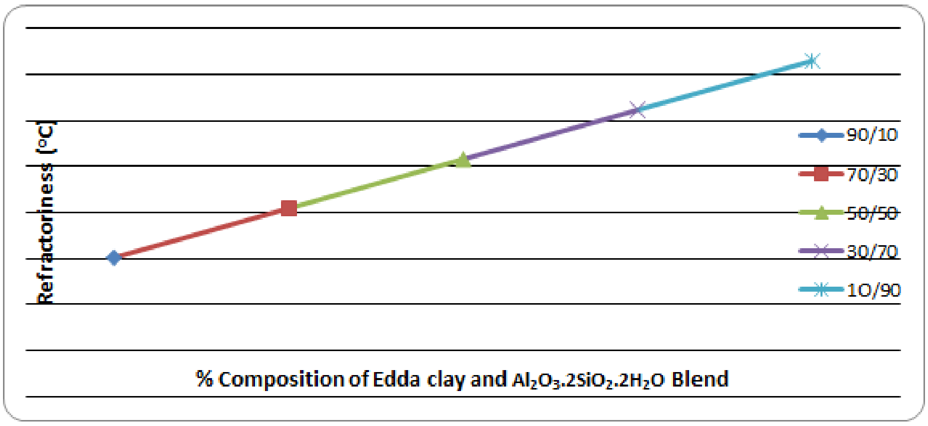

Fig-14: Effects of Percentage Composition of Edda Clay and $Al_2O_3.2SiO_2.2H_2O$ Blend on Refractoriness of the Refractory Bricks

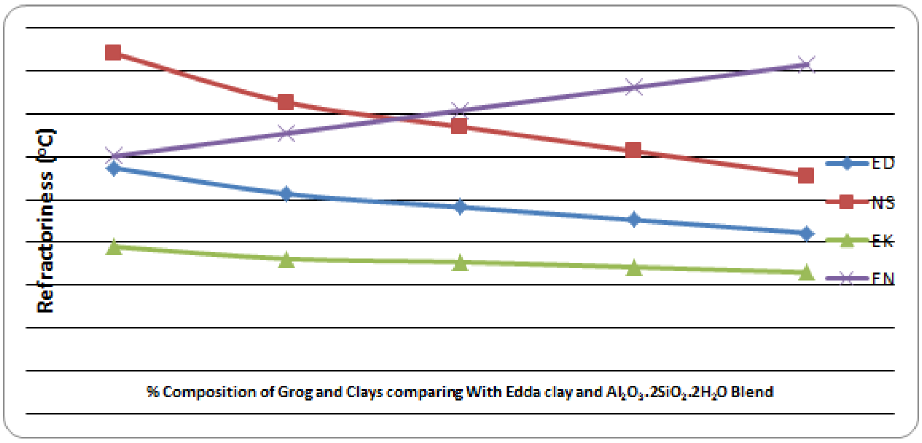

Fig-15: Effects of Percentage Composition of Clays and Grog with Edda clay and $Al_2O_3.2SiO_2.2H_2O$ Blend on Refractoriness of the Refractory Bricks

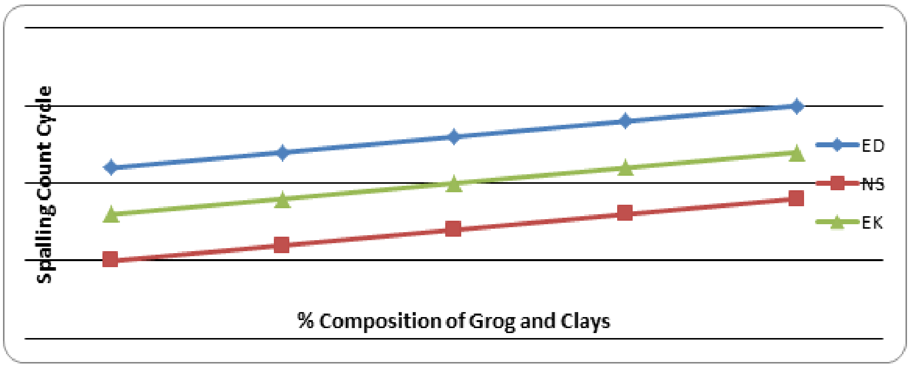

Fig-16: Effects of % Composition of Clays and Grog on Spalling Count Cycle of the Refractory Bricks

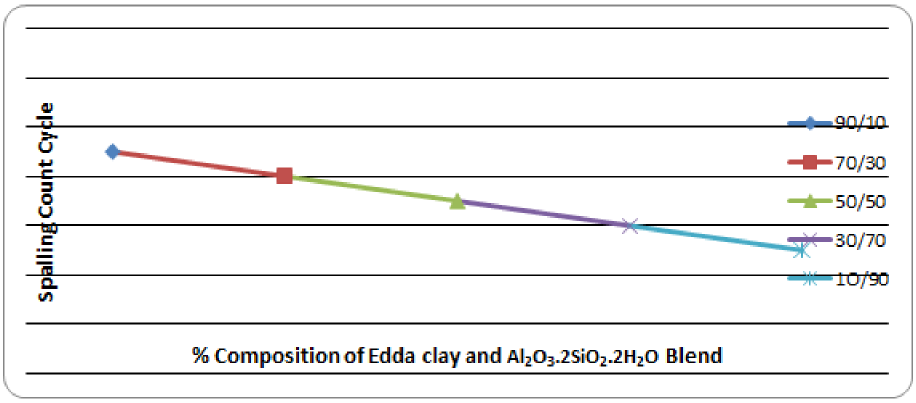

Fig-17: Effects of Percentage Composition of Edda clay and $Al_2O_3.2SiO_2.2H_2O$ Blend on Spalling Count Cycle of the Refractory Bricks

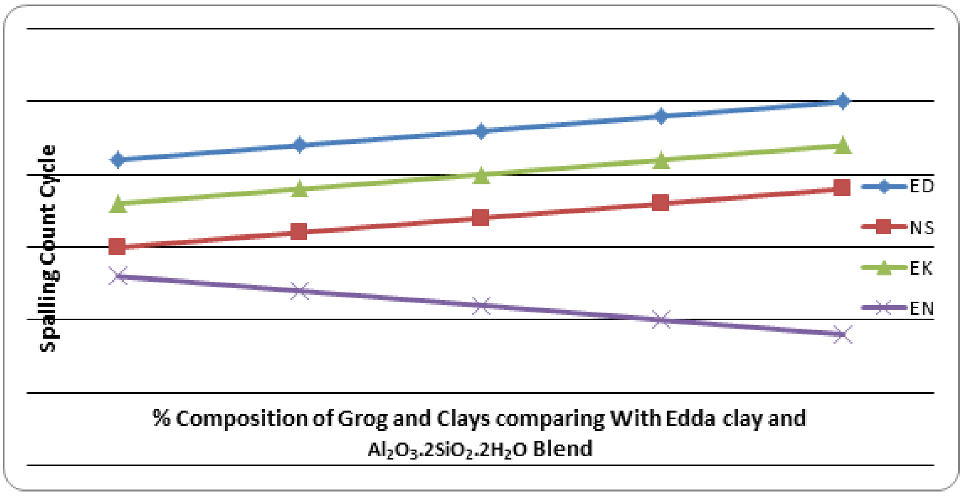

Fig-18: Effects of Percentage Composition of Clays and Grog with Edda clay and $Al_2O_3.2SiO_2.2H_2O$ Blend on Spalling Count Cycle of the Refractory Bricks

4.0 DISCUSSION

The result of chemical analysis of the raw materials as presented in table.3.1 indicated that the content of SiO_2, Al_2O_3 and Fe_2O_3 in Edda clay were 58.86% -SiO_2, 27.69% - AI_2O_3 and 1.27% - Fe_2O_3 while that of $Al_2O_3.2SiO_2.2H_2O$ (Nsu clay) had 46.56% -SiO_2, 35.60% - AI_2O_3 and 0.05% - Fe_2O_3. It was revealed that Ekebedi clay had 58.53% -SiO_2, 28.03% - AI_2O_3 and 1.41% - Fe_2O_3 while the Unwana clay used as grog had 52.24% -SiO_2, 27.20% - AI_2O_3 and 7.0% - Fe_2O_3 (Table 3.1). This shows that the % SiO_2 content of the clay minerals are within the acceptable or tolerable range of 40% and above for particular clay useful for porcelain insulator and refractory production. [6, 9]. Also, the Al_2O_3 contents are within the percentage essential for characteristic clay minerals used for refractory production. i.e it should contain 23-45% alumina [10, 11]. It was revealed that Edda clay, $Al_2O_3.2SiO_2.2H_2O$ and Ekebedi clay are kaolinitic clay deposits while grog (Unwana clay) is ball clay based on their chemical characterization. The chemical properties of a refractory are defined by the chemical analysis of the refractory grains, by the nature of the bonding and also by the capability of the refractory to resist the action of liquids when subjected to high temperatures. Also, the bonding system of the refractory plays a very important role in dictating its properties. When refractories are exposed to corrosive liquids at high operating temperatures, the degree of corrosion/erosion depends on the refractory grains and the chemical bonding system of the refractory.

The clay minerals were used with grog to compose four batches of five samples of dense refractory bricks each from all the clay minerals and their blends (ED1 – EN5) following these proportions: 100/0%, 20/80%, 30/70%, 60/40%, 50/50%, and (blends) 90/10%, 70/30%, 50/50%, 30/70% (Table .2.1). The properties of the dense bricks produced investigated after sintering at 1350^{0}C indicated that samples ED1-ED5 of bricks had % linear shrinkage ranging from 9.9% - 11.5%, samples NS1-NS5 had range of 9.2% - 10.6% while that of samples EK1-EK5 had range of 9.4% - 11.2% (Fig. 1 & 3). Also the blend samples EN1-EN5 had range of 8.4% -10% (Fig. 2 & 3). The shrinkage may be as a result of the percentage composition of the bricks, i.e the ratio of clay to grog. Also, it may occur due to the growth that accompanied the low quartz to high quartz and the high quartz to high critobalite polymorphic transformations that took place during sintering between 573°C and 1350°C. The more the brick shrinks, the less porous it is, consequently the denser it becomes [12]. The higher the percentage of grog the lower the shrinkage (Fig. 1 & 3), while in the blended samples, the higher the percentage of $Al_2O_3.2SiO_2.2H_2O$ the lower the shrinkage (Fig. 2 & 3). The result of the shrinkage fell out of the recommended value range of 7-10% for refractories as in Chester study [10, 13, 14], except ED5, NS2 – NS5, EK4 and EK5 and all blended samples (EN1- EN5) that fell within the recommended range.

The result of the bulk density revealed that the samples ED1-ED5 had bulk density ranging from 1.57g/cm^3 - 1.79g/cm^3, samples NS1-NS5 had range of1.93g/cm^3 - 2.05g/cm^3, samples EK1-EK5 had range of 1.57g/cm^3 - 1.81g/cm^3 (Fig. 4 & 6) and the blended clay samples (EN1- EN5) had range of 2.11g/cm^3 - 2.26g/cm^3 (Fig. 5 & 6). It was noticed that the higher the percentage of clays the higher the bulk density of the bricks and the higher the percentage of grog the lower the bulk density of the bricks (Fig.4 & 6). But in the blended samples, it was revealed that the higher the percentage of $Al_2O_3.2SiO_2.2H_2O$ the higher the bulk density of the bricks while the higher the percentage of Edda clay the lower the bulk density of the bricks (Fig .5 & 6). This may be due to high percentage of loss on ignition of the raw materials. The bulk density of refractory bricks fell within the recommended range of (0.8 – 2.9 g/cm^3) [15].

The result of the Compressive Strength of the brick indicated that samples ED1-ED5 of the bricks had Compressive Strength ranging from 13.5MPa - 18.6 MPa, samples NS1 – NS5 had range of 17.7MPa - 20.7MPa, samples EK1-EK5 had range of 14.7MPa - 18.8MPa (Fig. 7 & 9) while samples EN1- EN5 had range of 19.09MPa - 23.1MPa (Fig. 8 & 9). It was discovered that the higher the percentage of clays the stronger the bonding and the higher the Compressive Strength of the bricks (Fig.7 & 9). Also in the blended samples, the higher the percentage of $Al_2O_3.2SiO_2.2H_2O$ the stronger the bonding and the higher the Compressive Strength of the bricks (Fig.8 & 9). The high compressive strength value may be as a result of the growth of glassy phase which brings about the bonding strength of the dense bricks. Moreover, the existence of CaO, Na_2O and K_2O in the chemical composition (Table. 3.2) of the materials is enough to boost the process of glassy phase formation. Also, the nearer to the sintering point a material is heated, the more pronounced becomes the sintering at the temperature [12], thereby reducing porosity, increasing density and linear shrinkage with increase in Compressive Strength values of the dense bricks. All the samples of the bricks fell within the recommended ranges i.e minimum of 5MPa [6, 13, 16].

The result of the percentage porosity of the bricks shows that samples ED1-ED5 of brick had % porosity ranging 19.58% - 23.39%, samples NS1- NS5 had range of 15.80% - 19.40%, samples EK1 – EK5 had range of 18.46% - 22.11% (Fig. 10 & 12) and samples EN1 – EN5 had range of 12.84% - 15.63% (Fig. 11 &12). It was discovered that the higher the percentage of grog the higher the pores and the higher the porosity of the bricks. Also, the higher the percentage of clay the stronger the bonding system, the lesser the pores and the lower the porosity of the bricks (Fig. 10 &12). However, in the blended clay samples, It was revealed that the higher the percentage of Edda clay the higher the pores and the higher the porosity of the bricks, but the higher the percentage of $Al_2O_3.2SiO_2.2H_2O$ the lower the pores and the lower the porosity of the bricks (Fig.11 & 12). This may indicated that at higher sintering temperature, thermally activated material moved into the pores causes' decrease in porosity. The reduction in values of porosity may be due to the development of the glass phase which introduced the barrier of the large pores in the dense bricks after sintering. Furthermore, when the sintering temperature of a material reached, the more obvious becomes the density, which will bring about reduction in porosity. However, samples ED1, NS1 - NS5, EK1 & EK2 and EN1 & **EN**2 fell within the required range of (15% - 20%) porosity for dense refractory bricks [5, 17, 18] while that of ED2 – ED5, EK3 - EK5 and EN3 – EN5 that fell out of the range.

The estimated refractoriness results using shuen's formula indicated that samples ED1 – ED5 of the bricks had refractoriness of 1684.4^{0}C - 1714.8 ^{0}C, samples NS1- NS5 had range of 1711.2^{0}C - 1768.3^{0}C, samples EK1 – EK5 had range of 1666^{0}C - 1678^{0}C (Fig. 13 & 15) and samples EN1 – EN5 had range of 1720.2^{0}C - 1763^{0}C (Fig.14 & 15). It was discovered that the higher the percentage of grog the lower the refractoriness of the bricks, while the higher the percentage of clay the higher the refractoriness of the bricks (Fig.13 & 15). Also, in the blended clay samples, It was revealed that the higher the percentage of $Al_2O_3.2SiO_2.2H_2O$ the higher the refractoriness of the bricks, while the higher the percentage of Edda clay the lower the refractoriness of the bricks (Fig.14 & 15). The result of the refractoriness using Pyrometric Cone Equivalent (PCE) test investigated indicated that samples ED1 – ED5 of the bricks had refractoriness range of greater than cone 31 (<1680^{0}C) - greater than cone 32 (<1710^{0}C), samples NS1 – NS5 of the bricks had refractoriness range of greater than cone 32 (<1710^{0}C) - greater than cone 34 (<1750^{0}C), samples EK1 – EK5 of the bricks had refractoriness range of cone 30 (1665^{0}C) - cone 31 (1680^{0}C) and samples EN1 – EN5 of the bricks had refractoriness range of less than cone 33 (>1740^{0}C) - greater than cone 34 (<1750^{0}C). All the bricks met the required refractoriness for refractory bricks above cone 08 (990^{0}C) i.e minimum of 1000^{0}C [19-21]. It was clearly indicated that refractoriness test using Pyrometric Cone Equivalent (PCE) show that the brick samples possessed better refractoriness.

The result of the Spalling count test investigated indicated that samples ED1-ED5 had spalling count cycles ranging from 31 - 35, samples NS1 – NS5 had range of 25 – 29, samples EK1 – EK5 had range of 28 – 32(Fig.16 & 18) while that of EN1 – EN5 had range of 19 – 23 (Fig.17 & 18). It was revealed that the higher the percentage of grog the higher the porosity and the higher the number of cycle (Fig. 16 & 18). Also, in the blended clay samples, it was indicated that the higher the percentage of $Al_2O_3.2SiO_2.2H_2O$ the lower the porosity and the lower the number of cycle, while the higher the percentage of Edda clay the higher the porosity and the higher the number of cycle (Fig.17 & 18). The result shows that samples ED1 - ED5 and EK4 & EK5 fell above the recommended numbers of cycle while the remaining samples fell within the recommended range of (20 - 30) numbers of cycles [13, 16, 22] except EN5 that fell below it.

Nevertheless, correlation between thermal conductivity and strength exists, while other physical properties, such as abrasion, gas permeability and strength are often interconnected to the density and porosity of the refractory. Furthermore, porosity is affecting both thermal conductivity and strength. Also, as density improves, spalling resistance may turn down, it is very important to look for combinations of properties that affix to success of the product's application, such as density and permanent linear change together.

It was noticed that the higher the grog content of the dense bricks, the lower the linear shrinkage, bulk density and compressive strength while the higher the porosity, spalling count test and refractoriness of the bricks (Fig. 3, 6, 9, 12, 15 & 18). The opposite were observed when the higher the clay content of the dense bricks were considered. Also, in the blended clay samples, It was discovered that the higher the $Al_2O_3.2SiO_2.2H_2O$ content of the dense bricks, the higher the bulk density, compressive strength and refractoriness while the lower the porosity, spalling count test and shrinkage of the bricks (Fig. 3, 6, 9, 12, 15 & 18). The reversed were the cases when the higher the Edda clay content of the dense bricks were considered. However, sample EN4 of bricks produced using blended $Al_2O_3.2SiO_2.2H_2O$ and Edda clay gave the most favourable result when considering the moderate percentage linear shrinkage, higher bulk density, compressive strength and refractoriness with standard spalling count cycle. Therefore sample EN4 of bricks produced using blended $Al_2O_3.2SiO_2.2H_2O$ and Edda clay can be produce in mass for industrial production of dense refractory bricks for high temperature applications.

5.0 CONCLUSION

It was discovered that the higher the clay content of the dense bricks, the higher the shrinkage, bulk density and Compressive Strength while the lower the porosity, spalling count test and refractoriness of the bricks. Also, in the blended clay samples, It was discovered that the higher the $Al_2O_3.2SiO_2.2H_2O$ content of the dense bricks, the higher the bulk density, compressive strength and refractoriness while the lower the porosity, spalling count cycle and shrinkage of the bricks. However, sample EN4 of bricks produced using blended Edda clay and $Al_2O_3.2SiO_2.2H_2O$ gave the most encouraging result when considering the moderate percentage shrinkage, higher bulk density, compressive strength and refractoriness with standard spalling count cycle. Therefore sample EN4 of bricks produced using blended Edda clay and $Al_2O_3.2SiO_2.2H_2O$ can be produce in mass for industrial production of dense refractory bricks for high operating temperature applications.

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Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved with declaration of no conflict of interest.

REFERENCES

1. Aparna, C., & Santosh, K. (2004). Materials Science lbr Engineers. CI3S Publishers and Distributed, New Delhi, India.
2. American Society for Testing and Materials, ASTM 71. (2011). Vol. 1501.
3. Odewale, I. O., Ameh, E. M., & Amaakaven, V. T. D. (2018). Comparative analysis of insulating brick produced from locally sourced clays and combustible materials.
4. Sadik, C., Albizane, A., & El Amrani, I. E. (2013). Production of porous firebrick from mixtures of clay and recycled refractory waste with expanded perlite addition. *J. Mater. Environ. Sci*, *4*(6), 981-986.
5. Charles, A. S. (2004). Refractories Handbook, Marcel Dekker, Inc. 17 - 19.
6. Ossai, A. A. (2005). Introduction to Alumina silicate refractorics and other Refractories, 13-14, 19—21).
7. Aderiye, J. (2000). Glass and Refractory Technology. *Olu-Ade Publishers Ltd, Lagos, Nigeria*, 72-74.
8. Idu, F.I. (2015). Refractories Technology and Properties, Aku Graphic Press, Aba, Nigeria; 65 - 70.
9. Eke, H. O. (2006). *Electrical Insulator*, Nrian Publication Owerri H. O, 23 – 30.
10. Eke, H. O. (2009). Introduction to Ceramic Technology.
11. Chesti, A. R. (1986). *Refractories: Manufacture, properties and applications*. Prentice-Hall of India.
12. Odo, J. U., Nwajagu, C. O., & Nnuka, E. E. (2009). Characterization of ezebunagu clay deposit and its potential for industrial applications. *Journal Metallurgy and Materials Engineering*, *4*(2), 31-37.
13. Chukwudi, B. C., & Eng, M. (2008). Characterization and evaluation of the refractory properties of Nsu clay deposit in Imo State Nigeria. *Pacific Journal of Science and Technology*, *9*(2), 487-494.
14. Jock, A. A., Ayeni, F. A., Jongs, L. S., & Kangpe, N. S. (2013). Development of Refractory Bricks from Nigerian NAFUTA clay deposit. *International journal of materials, methods and technologies*, *1*(10), 189-195.
15. Kumar, R. (2011). *Development of Low Bulk Density Fireclay Insulation Brick* (Doctoral dissertation).
16. Chesters, J. H. (1973). Refractories--production and properties. *Iron and Steel Institute, London. 1973*, *553 p*.

17. Jonker, A., & Potgieter, J. H. (2005). Refractory properties of insulating materials from secondary cementitious materials (SCMs). In *Achieving Sustainability in Construction: Proceedings of the International Conference held at the University of Dundee, Scotland, UK on 5–6 July 2005* (pp. 177-184). Thomas Telford Publishing.
18. William, D. (2006). Fundamental Studies on Phosphate Boding Refractories. New York Prints. Lagos. *Journal of science*, *1*(1). 6.
19. Ajayi, I. A. (2002). Introduction to Refractory Technology.
20. Jonker, A. (2006). *Insulating refractory materials from* (Doctoral dissertation, Tshwane University of Technology).
21. Nyikos, F., & King, E. (1996). Refractory materials III. *Pretoria: Technikon Pretoria*, 9-11.
22. Bureau of Indian Standards (BIS). (2010). Methods of Sampling and Physical Tests for Refractory Materials, Part 3: Determination of Spalling resistance (Third Revision); 5–8. Retrieved September 19, 2015.