Bida Clay: A Source of Raw Material for Engineering Applications

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Abstract:- Clay from Bida was investigated and characterized using XRF, XRD, SEM and physico-mechanical methods. The XRF analysis shows high value of 69.58% SiO_2, 23.15% Al_2O_3, and 2.93% Fe_2O_3, with low amount of other oxides like CaO, K_2O and Na_2O. The clay deposit from the XRD results was found to be kaolinitic with refractoriness of 1250^{0}C and a good 12 cycles of thermal shock resistance were observed. The physico-mechanical characteristics of the clay studied were found to improve as the firing temperature increased. This was attributed to decrease in porosities and increase in compaction of the samples. The mechanical properties values of cold crushing strength (CCS) of 202.41kgF/cm^2 was attained and meet the requirements for production of tiles, refractory lining of heat treatment furnaces and kilns. The chemical properties from XRF results were found to be within the standard requirements for application in ceramic and refractory applications.

***Keywords*:-** *Bida; clay; kaolin; physico-mechanical; XRD; XRF.*

I. INTRODUCTION

Clays are used for a wide variety of engineering applications. The main reason for the utilization of a certain clay mineral in one area of application is because of their chemical and physical properties that are dependent on their structure and composition [6]. This explains their usage in sanitary-wares, electrical porcelain, high quality tableware, glazes or tiles.

In general, clay minerals are important industrial minerals that are used in for producing many ceramics products and with each product requiring clay with appropriate and specific properties. Millions of tonnes are used annually in several applications [3]. These uses include uses as refractory materials for ovens, furnaces and lining kilns in the process industries, construction, agriculture and geology [2; 18; 22].

Clay deposits (from Ndia - akum, Taraba State) were characterized for industrial application by [15] using physicochemical, XRF and TGA methods. The TGA results indicated loss of some weight on heating and high temperature thermal stability of the clay with improved physical properties such as shrinkage, bulk density and plasticity.

Kaolin clay from Ejigbo (Lagos) was studied by [18], who found that it has high crystallinity and orderly-arranged structures that can serve as a basis for supporting nanoparticles with hydroxyl groups that act as anchoring active regions catalytic substrates. The clay was also found to have a large surface area, excellent form, and strong thermal stability. In addition, [1] investigated the characterisation and micro-structural aspects of the ceramics use of Mgbom clay around Afikpo (Ebonyi State). The clay was found to have the three primary minerals quartz, kaolinite and haematite; however, the clay's burned behavior revealed that it was unsuitable for uses such as electrical insulation, thermal insulation, refractory and porcelain.

Numerous experts have looked into a few of the clays that can be found in Nigeria. In order to assess the viability of various clay samples from various deposits, [21], [1], [11], [4] and [9] determined the chemical and mineralogical nature and characteristics of the samples, such as bulk density, thermal stability, cold crushing strength and porosity. They discovered favorable characteristics that can compete with worldwide standards and satisfy the criteria for use as refractory material or ceramic raw materials.

The estimated two billion metric tons of kaolin reserves in Nigeria have drawn interest from both domestic and international companies due to their wide range of uses and their distinctive characteristics [18]. Yet there is continuous imports of various items used in daily life to drilling fluids; porcelain; vehicles; ceramic industry, to produce household wares like plates, cups, flower vases, electrical sockets (insulators), toilet seats, bath tubs, refractory bricks; but has enough raw materials for the production of these tools widely available across the country all of which is most urgently needed. The clay deposits in these places should be thoroughly characterized, beneficiated, and processed in order to determine the overall ore grade and to exploit and determine the markets for the items in the nation.

The Nigerian government is concentrating its attention to development of solid mineral sector as a result of lingering oil crises around the world. Large deposits of these clays are present within Niger state and are yet to be exploited. Therefore, the aim of this study is to characterize and study the physico-mechanical properties of clay from Bida with a view to predict the engineering characteristics and evaluate its potentials economically, for the nation's technological and industrial development.

II. MATERIALS AND METHODS

The clay materials used in this research was sourced from Patishin, 3 to 4 km along Bida-Minna road, Bida - Niger State (Nigeria). The raw samples were randomly collected from different points at a depth of 2m to cover a good depth of the entire site. The clay was placed in a dry clean polythene. For five days, the raw samples were sun-dried and pulverized and sieved to 0.15 microns, to ensure the elimination of debris and coarse materials.

The clay was characterized to determine its chemical properties to ascertain its properties for ceramics and industrial applications using XRF, XRD and scanning electron microscope (SEM). A 2kg weight of the clay was mixed with water to achieve moldability for production of test specimen. The samples for mechanical properties (modulus of rupture, cold crushing strength) and physical properties (porosity, linear shrinkage, water absorption) tests were processed and subjected to heating (sintering) at temperatures of 1250^0C, 1150^0C, 1050^0C and 950^0C under an hour soaking time [16, 22 and 17]. The required tests were all completed in accordance with ASTM standards [8].

III. RESULTS AND DISCUSSIONS

A. Chemical Analysis

The chemical analysis results of the clay samples from the study location indicates high value of SiO_2 of 69.58%, 23.15% Al_2O_3 and Fe_2O_3 of 2.93 %. Low value of CaO, Na_2O, K_2O and lost on Ignition (LOI) was also observed in the studied clay (Table 2).

The abundance of K-feldspar (orthoclase and microcline) is indicated by the substantially greater alkalis K_2O/Na_2O ratio (3.13) in the sample. The felsic nature of this clay is shown in the lower concentrations of P_2O_5, CaO and MnO. This composition is comparable to Mgbom [1] and Kutigi deposits [5]. This deposit contains high silica composition of approximately 70% with little to moderate alumina component which is comparable to results of [18] from Ejigbo in Lagos state, and hence suitable for use in zeolite and ceramics application.

There is the availability of oxides in the clay, which play important role in the industrial applications of clays especially kaolin and it also helps to stepdown the melting temperature of quartz and control glass viscosity. High $SiO_2$and Al_2O_3 indicate that it could be useful in the production of ceramics and refractories [14]. Its high silica concentration also makes it a useful raw material for the production of zeolite, amorphous silica alumina, tiles, and bricks. The Fe_2O_3 content makes it unsuitable for use in tiles, pottery and sanitary-wares. The opacity and lightness of the clay makes it useful for paints and coating in plastic [1]. The content of the studied clay compared with industrial engineering specifications makes the clay deposit an important mineral (raw material) for the production of ceramics and refractory bricks.

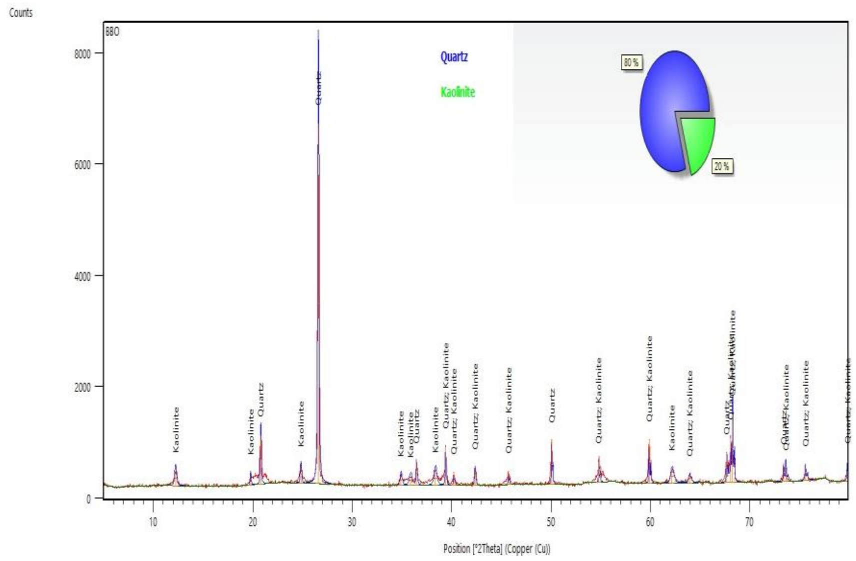
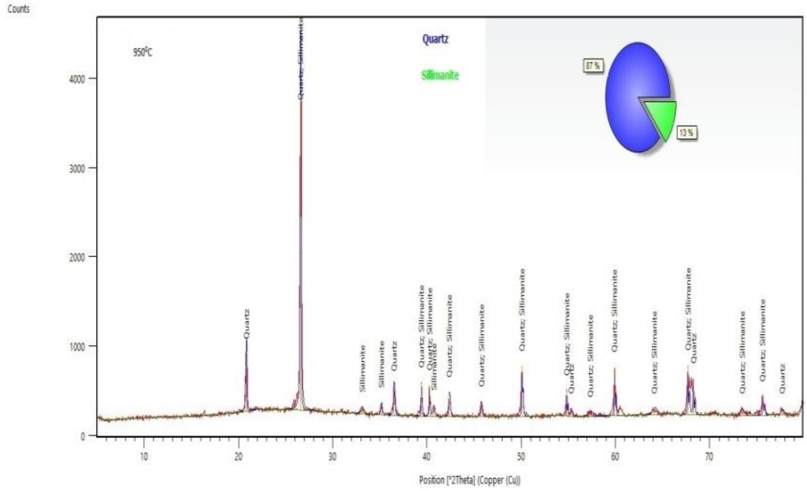


Fig. 1: XRD Spectrum of raw clay

The x-ray diffraction (XRD) result is shown in Figure 1. The mineralogy of the raw clay is composed of kaolinite $\{Al_2Si_2O_2(OH)_4\}$ and quartz. This confirms the studied clay to be kaolinitic in nature.



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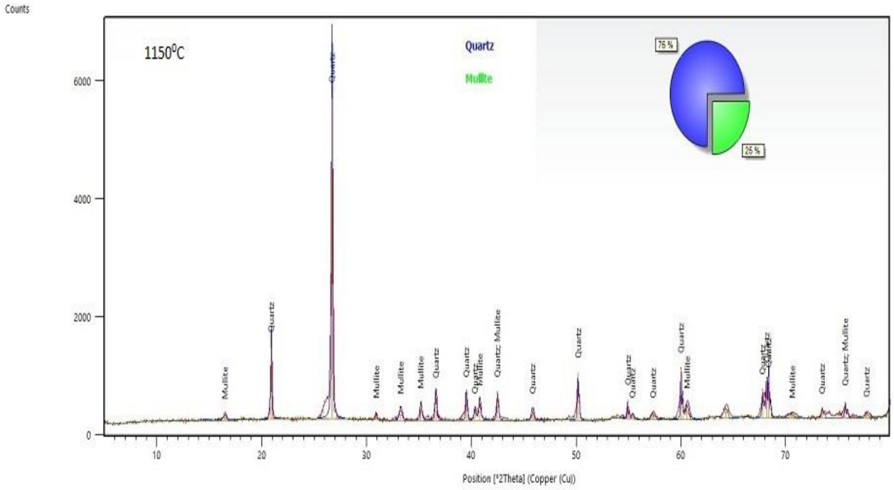

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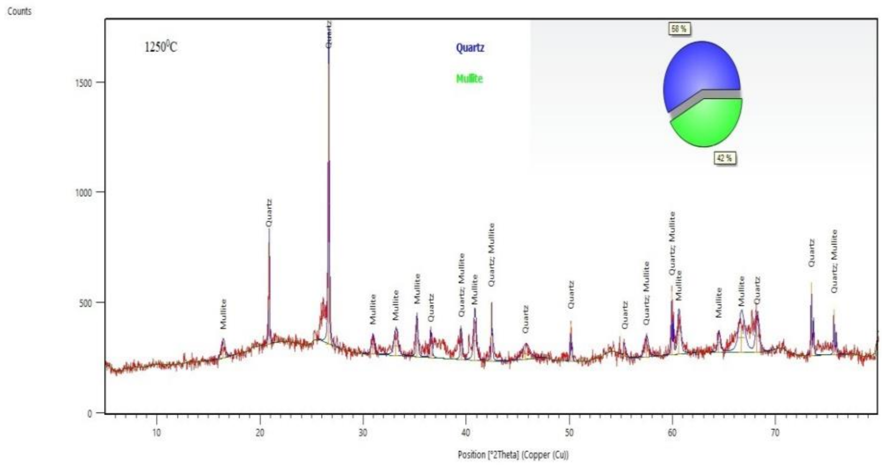

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Fig. 2: XRD Spectrum of Sintered Clay at (a) 950^0C (b) 1150^0C and (c) 1250^0C

Table 1: Thermal shock resistance (cycle) and refractoriness of the clay

Thermal shock resistance	Refractoriness/P.C.E. Cone value
12	1250^0C /cone 8

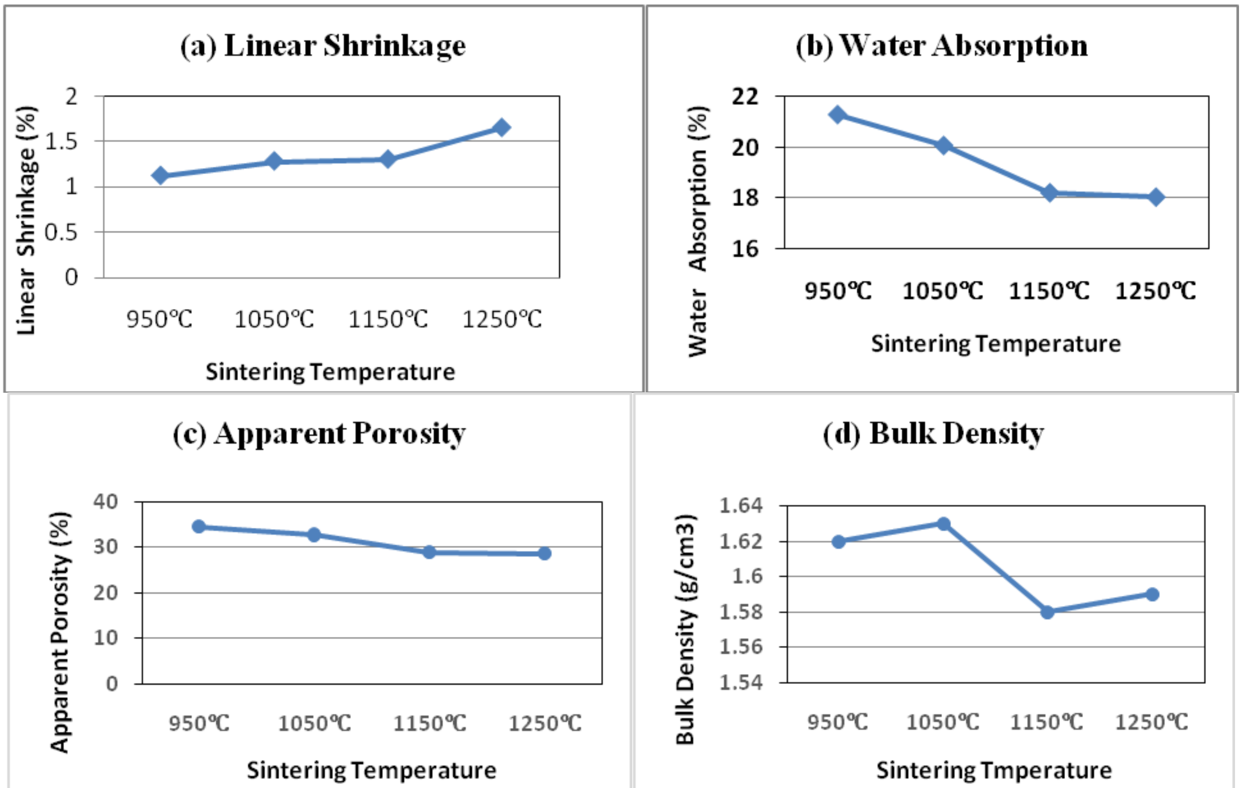
Table 2: Chemical composition of studied clay in comparison with some standard industrial application clays [1 ; 10; 11; 14]

Percentage chemical composition												
Material	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	LOI	Total
Bida clay	69.58	23.15	2.93	0.03	2.76	0.35	0.08	0.25	0.49	0.11	0.26	99.99
Refractory	51.0-70.0	25.0-44.0	0.5-2.4	-	-	0.1-2.0	-	-	-	-	-	-
Glass	80.0-95.0	12.0-17.0	2.0-3.0	-	-	4.0-5.0	-	-	-	-	-	-
Paper	45.0-45.8	33.5-36.1	0.3-0.6	-	-	0.03-0.6	-	-	-	-	-	-
Paint	45.3-47.9	37.9-38.4	13.4-13.7	-	-	0.03-0.6	-	-	-	-	-	-

LOI: Lost on Ignition

Table 3: Physico-Mechanical Properties of the Clay compared with ISO standards [3; 7; 12; 13; 20]

Property	**950^0C**	**1050^0C**	**1150^0C**	**1250^0C**	**Ceramics**	**Refractory**	**Fireclay**
Bulk Density (g/cm^3)	1.62	1.63	1.58	1.59	≥1.85	≥1.80	≥1.85
Apparent Density (g/cm^3)	2.22	2.23	2.42	2.47	≤2.2	-	≤2.2
Water Absorption (%)	21.29	20.08	18.23	18.06	-	-	-
Apparent Porosity (%)	34.46	32.73	28.83	28.67	10 – 30	10 – 30	20 - 30
Linear Shrinkage (%)	1.12	1.28	1.30	1.65	≤10	≤7	≤8
CCS (KgF/cm^2)	89.12	131.85	175.70	202.41	15.30	14.68	15.30
M.O.R (KgF/cm^2)	5.41	8.46	10.30	14.48	-	-	-
Elastic Modulus (KgF/cm^2)	438.07	676.07	492.01	139.60	-	-	-



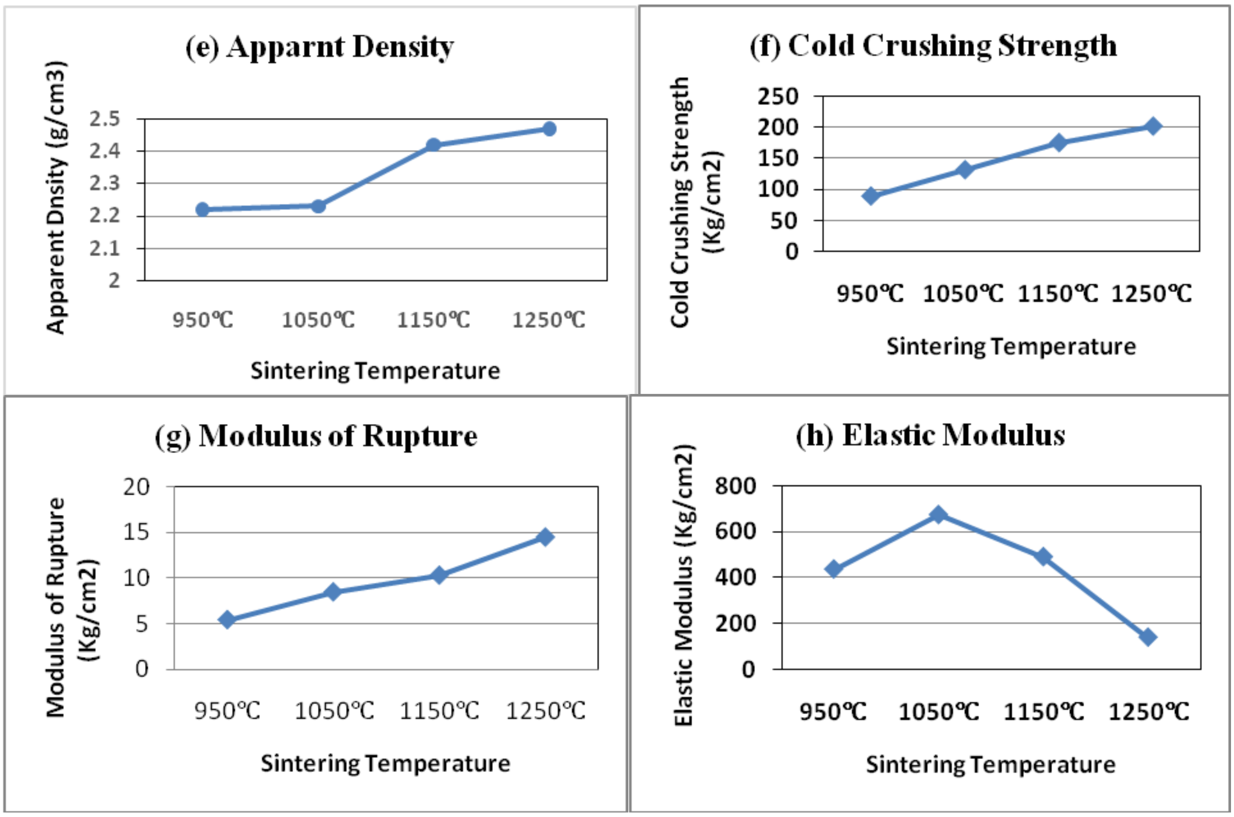
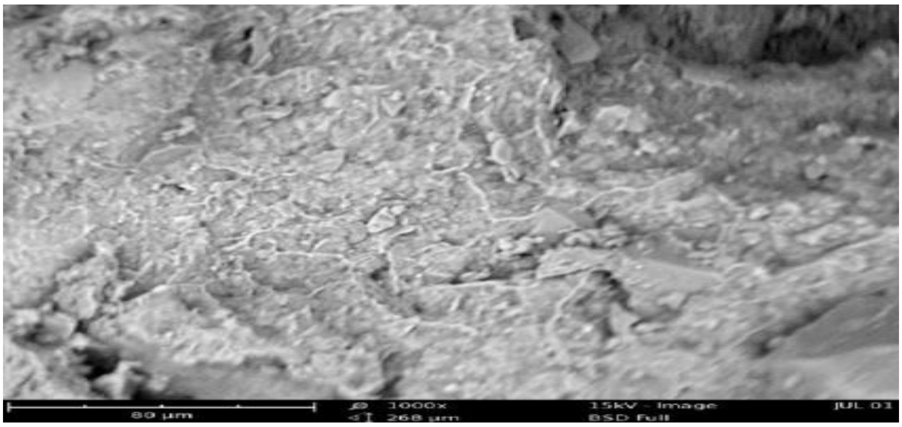


Fig. 3: Effect of sintering temperature on the physico-mechanical properties of Bida clay



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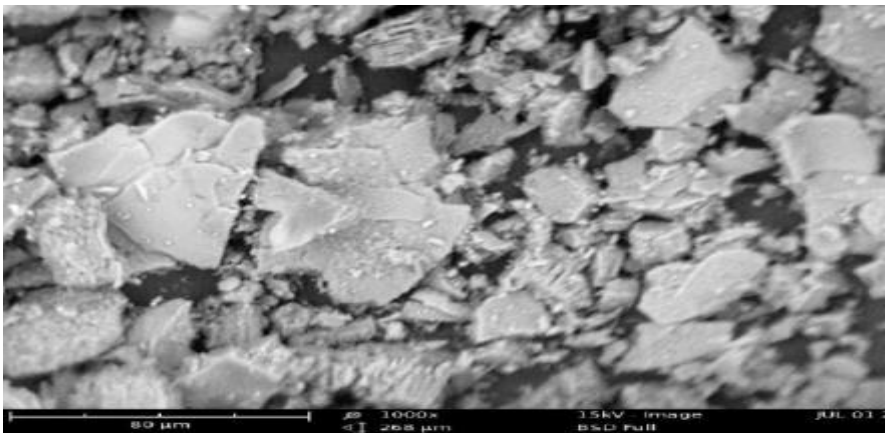

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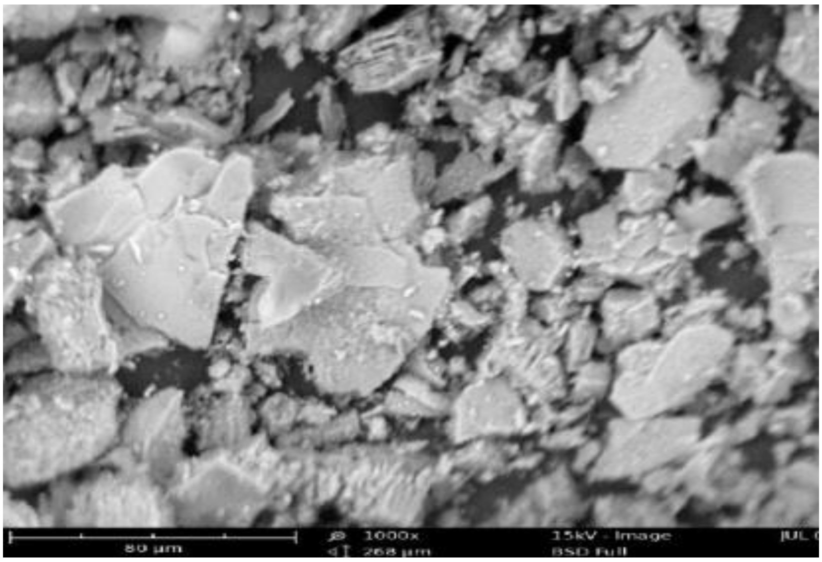

(c)
Fig. 4: SEM Photomicrograph of Sintered Samples at: (a) 950^{0}C, (b) 1150^{0}C and (c) 1250^{0}C

When fired, the clay was observed to undergo phase transformation from the original phases of the virgin raw kaolin. As the temperature is increased towards 1250^{0}C, there is change in phase transformation to quartz- sillimanite phase up to 1050^{0}C and from quartz-sillimanite phase to quartz-mullite phases at 1150^{0}C and 1250^{0}C respectively, as can be seen from the XRD patterns of various samples. Figure 2 shows the XRD results of sintered clay at different temperatures. The SEM photomicrograph of Figures 4 showed flakes of mullite observed in quartz-glassy phase, as observed in a similar manner by [6].

B. *Refractoriness and Thermal Shock Resistance*

In case of refractoriness, it shows that the experimented clay has moderate refractoriness and can withstand temperatures of 1250^{0}C which makes it useful for applications in low temperature areas. Examples are low temperature ovens, microwave and kilns, compared to others that have useful application in heat treatment furnace for annealing and ladles [13]. The clay investigated did not meet the standard requirement for refractory materials in terms of thermal shock resistance and refractoriness. However, it has 12 cycles of thermal shock resistance as seen in Table 1, which are below the required cycles for standard refractories [12].

C. *Physico-mechanical Properties*

The mechanical and physical properties of the deposit under investigation were determined using the equations below:

$$\text{Linear shrinkage} = \frac{Ld - Lf}{Ld} \times 100 \quad (1)$$

$$\text{Water absorption} = \frac{W - D}{D} \times 100 \quad (2)$$

$$\text{Apparent porosity} = \frac{W - D}{W - S} \times 100 \quad (3)$$

$$\text{Bulk density} = \frac{W\rho}{W - S} \times 100 \quad (4)$$

$$\text{Apparent density} = \frac{D\rho}{D - S} \times 100 \quad (5)$$

$$\text{Cold crushing strength (C.C.S)} = \frac{\text{Applied load (F)}}{\text{Cross sectional area (A)}} \quad (6)$$

$$\text{Modulus of Rupture (M.O.R)} = \frac{3FL}{2bd^2} \quad (7)$$

$$\text{Elastic Modulus} = \frac{FL^3}{4bd^3D} \quad (8)$$

Where, W = Saturated weight, D= dry weight, S = suspended weight, Ld= Dry length, Lf = Fired length, p = Density of water = 1g/cm^3, F= yielding/breaking load, L= distance between supports or gauge length, d= height/depth, b= breadth, D= deflection and C.C.S= Cold Crushing Strength.

The water absorption rate of sintered clay samples reduces with sintering temperature increase from 21.29% to 18.06% at 950^{0}C and 1250^{0}C respectively. Also, the porosity of sintered clay indicates that there is a general reduction in the porosities of clay as the temperature increases. These conditions could be associated with the reduction in pore spaces and increase in densification within the ceramic body within the investigated temperature range as reported by [19].

The porosity values of 34.46% at 950^{0}C and 28.67% at 1250^{0}C were comparable to ISO standards of 10 to 30% for ceramics and refractory applications as seen in Table 3 and Figure 4 respectively. The linear shrinkage values peaked at 1.65% compared to ≤7 and ≤10 for refractory and ceramics respectively, just as the bulk density increased as the temperature increased to a peak value of 1.59g/cm^3 as compared to ISO standard value of ≤1.8.

In terms of mechanical properties, the cold crushing strength of the clay tested was observed to improve with the sintering temperature increment, this leads to an increase in densification and reduction in porosities, making the samples more rigid. A cold crushing strength of 89 KgF/cm^2 and 202kgF/cm^2 were obtained at 950^{0}C and 1250^{0}C respectively.

The modulus of rupture (MOR) was observed to increase from 5.41 to 14.48 KgF/cm^2 as the temperature increased and elastic modulus was found to increase from 438 to 676 KgF/cm^2 and then decreased to 139.6 KgF/cm^2 at 1250^{0}C. This was comparable to those obtained in Baruten clay deposits [22] as shown in Table 3 and Figure 3 respectively. This behavior of mechanical properties could be attributed to increased densification due to the decrease in porosity, pore spaces and formation of glassy-phase in the matrix. The effect of sintering temperature on the physico-mechanical properties of the clay are as observed in Figures 3.

IV. CONCLUSION

The clay deposit was observed to be kaolinitic and stable thermally with refractoriness at 1250^{0}C and possesses a 12 cycles of thermal shock resistance of. The clay was found to have good physical properties and cold crushing strength values of 202.41kgF/cm^2 which meets the requirements for production of tiles, refractory lining of heat treatment furnaces and kilns. The chemical properties were found also to be within the standard requirements for application in ceramic and refractory applications.

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