

Assessment of Physico-Mechanical Properties of Clay Deposits in Asa Local Government Area of Kwara State Nigeria for Industrial Applications

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Abstract

Adequate information about the properties of most available clay materials in Nigeria is necessary to enhance their industrial applications. Availability of this information will adversely reduce importation of refractory materials and its products into the country, since the mineral resources are abundantly available in the country. This study evaluated the chemical and physico-mechanical properties of some selected clay deposits across the three districts of Asa Local Government Area (LGA) of Kwara State to ascertain their suitability for refractory and other industrial applications. The results revealed that the clay samples were mainly alumina-silica based with silica and alumina concentrations of 47.30 – 58.50% and 32.75 – 34.30% respectively. The physico-mechanical properties exhibited by the clay samples included: clay content (33.80-72.20%), linear shrinkage (6.10-9.80%), moisture content (21.00-33.00%), bulk density (1.99 - 2.87 g/cm³), apparent porosity (21.00-37.00%), permeability (73-94), compressive strength (213-840 N/mm²), thermal shock resistance (+29 cycles), specific gravity (2.18-2.52) and refractoriness (>1300°C). The properties were within the required standard values which make the clays suitable for insulating materials, refractories for low-medium thermal applications and

manufacturing of ceramics. Though, Afon, Bakase and Ballah clay samples may require the addition of organic matter to enhance the clays' suitability for applications that may require a higher value of porosity and permeability and low density. Effective utilization of Asa L.G.A. clays will help to domesticate the production of refractory products and enhance the establishment of Small and Medium Scale Foundry Enterprises in Nigeria in addressing the problem of unemployment.

Keywords

Alumino-silicate, Minerals deposits, Performance, Foundry and Casting

1. Introduction

Clay is a natural fine-grained material that acquires plasticity on being mixed with a limited quantity of water (Aliyu *et al.*, 2012). From the chemical or mineralogical point of view, clay is regarded as a complex aluminosilicate compound containing attached water molecules (Aliyu *et al.*, 2012). The clay raw material used for the production of refractory fireclay, casting moulding sand which has the characteristic of making a coherent, mouldable mass and rigid when dried (Amkpa and Nur, 2016). It has been reported that clays are one of the major Nigeria minerals deposits cover with estimated proven reserves of billions of tones, and these clays deposits are scattered all over the states in the country (Sani *et al.*, 2013, Shuaib-Babata and Mudiare, 2017; Shuaib-Babata *et al.*, 2018; Shuaib-Babata and Abdulrahman, 2018).

It has been revealed through many reports that fireclay and other refractories consumed in Nigeria are sourced from abroad (Mark, 2010; Elakhame *et al.*, 2010; Shuaib-Babata *et al* 2018a; Mathew and Owøye, 2016; Olachi *et al*, 2014), despite abundant availability of many clay deposits in the country which can be used as raw materials for provision of these valuable need for her industrial development. It is established that about 38,000 – 12,000 tonnes of refractory materials presently in Nigeria are imported, which greatly and negatively affect the nation's economic (Etukudoh *et al.*, 2016). Many studies had been carried out on considering locally sourced clay material from different areas in Nigeria

for industrial uses (Sanni *et al.*, 2003; Abolarin *et al.*, 2006; Shuaib-Babata and Mudiare, 2017; Shuaib-Babata, *et al.*, 2016; Shuaib-Babata *et al.*, 2018). The results revealed that appreciable quantities of Nigerian clays from different deposits across the nation were of good quality. It was also realized that the properties of some clay samples in the country may require little improvement to be found adequately suitable for certain applications.

The material has a very high melting point in addition to its physical, chemical, mechanical and thermal properties that make it suitable for use in furnaces, kilns, reactors, and other high-temperature vessels (Abolarin *et al.*, 2006). The characteristics and chemical composition of clay deposits in Nigeria always determine its industrial utilization (Aliyu *et al.*, 2014). But Aliyu *et al.* (2012 a & b) reported that clay occurs most abundantly in nature in solids, sediments, sedimentary rocks and hydrothermal deposit where the acceptable chemical, physical and mechanical properties for refractory clay material can be found. These properties are obtained through various experimental testing of the clay samples. Clay sand control tests include moisture content test, linear shrinkage, porosity, bulk density, loss on ignition, grain fitness test, permeability test, strength test, refractoriness test, among others and mould hardness test are basic properties required for effective performance of moulding clay sand (Shuaib-Babata, 2015; Mittal and Shukla, 2003). The chemical, physical and mechanical properties are further influenced by several other factors which include particle sizes, clay raw materials, fireclay brick size, fusion temperature, firing time, cooling rate and manufacturing methods like the hand moulded or the pressure press (Amkpa and Nur, 2016).

However, to positively and permanently address Nigeria's major economic and social problems like unemployment, over-dependency on foreign goods, social unrest, among others, there is need for diversification of the country major source of income from oil and gas (Suberu *et al.*, 2015; Uzonwanne, 2015), and effective use of its available local mineral resources, such as clay sand is essential due to their immense contribution to the nation's wealth base and aids

socioeconomic development (Jack *et al.*, 2016). These materials are essential in the development and sustainability of the country industrialization; most especially small and medium scale industries were the major local needs like production and fabrication of domestic wares, spare parts. In high-temperature applications, such as production of wall and tiles, tableware, sanitary ware, electric porcelains insulator, foundry melting practices, metal extraction and power generation, refractories are known to be indispensable materials usually used in the process (Chukwudi, 2008). The need for local sourcing of clay for the production of needed refractory materials in Nigeria has been suggested (Etukudoh *et al.*, 2016). The suggestions aroused the interests of Nigerian researchers in characterizing and investigating the suitability of many clay deposits across the country for various engineering applications to address the implications of refractory importation on the country's economy. However, the abundance of the clay minerals deposits in Nigeria has not been investigated, which Asa local government area clay deposits are inclusive.

1.1 Study Area

Asa Local Government Area (L.G.A.) is one of the 16 Local Government Areas in the Kwara State of Nigeria situated in the North Central geopolitical region, endowed with many mineral resources, such as rock, with the poor presence of local small and medium scale (SME) manufacturing outfits, like a foundry. Thus, the L.G.A has the potential for abundant clay deposits since the clay have their origin in the chemical and mechanical disintegration of rocks such as granites (Aliyu *et al.*, 2012a). The L.G.A. has a population of 126,435 at 2016 census with the land scale of 1,286 km² (Kwara State Diary, 2017; Population Statistics, 2019). Figures 1(a and b) show the geographical location of Asa L.G.A. in Nigeria. The L.G.A. has no presence of any metallurgical industry.

Presently, there is no adequate and satisfactory data in the literature on Asa L.G.A. clay deposits despite the high intensity of clay deposits in the area. There is a need for industrial development of Asa L.G.A., such as metallurgical industries where clay is greatly utilized as major raw materials. However, there are possibilities of Asa L.G.A clay sand (especially those deposited from rocks) to contain important properties for industrial applications, especially refractory. As a result of this, this research intended to investigate the performance characteristics of some clay samples from selected clay deposits in Asa L.G.A.

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(a) Asa L.G. A Map (Olawepo, 2010) (b) Kwara State Map with L.G.As.(Agba, *et al.*, 2018)

Figures 1 (a,b): Maps showing location of Asa L.G.A.

2. Materials and Methods

2.1 Materials

The clay samples for this study were collected from six (6) different clay deposits across the three (3) major districts of Asa Local Government Area, Kwara State, Nigeria, using ASTM D4220/D4220M-14 guidelines. The deposits include Aboto-Oja, Afon, Alapa/Lamba, Bakase, Ballah, and Ogborodoko clay deposits.

2.2 Methods

2.2.1 Collection and preparation clay samples

The bulk clay samples were collected from the selected locations randomly from different locations (2 samples from each district) at the depth of about four (4) feet (1.2192 metres). The obtained samples were made to undergo through the processes of sorting and picking, crushing/grinding, sieving/sizing, blending, mixing and tempering at Civil Engineering Materials Laboratory, The Federal Polytechnic Ado-Ekiti. The samples were milled down using a hammer mill, soaked and washed with water for 24 hours, sieved using 75 μ , 200 μ m, and 100 μ m sieve in order to separate the debris that was collected with them and sun-dried by spreading it on a tray for 6 days to expel water in the clay. The dried clay samples were kept in desiccators for further experimental analysis.

2.2.2 Chemical composition of clay samples

The chemical compositions of the clay samples were determined using Atomic Absorption Spectrophotometer (AAS) at the Federal Institute of Research Organisation (FIIRO), Oshodi, Lagos, Nigeria.

2.2.3 Production of clay brick for experimental purpose

The tempered plastic clay samples were made to undergo ramming process using a rod to make the mixture soft to increase their plasticity and turgidity for ease moulding into the desired shape. The materials were then poured into the mould of 5.0 cm diameter and length of 5.0 cm, and thoroughly pressed (Figure 2) to remove the trapped air which may cause cracking in the moulded material. The moulded clay samples were dried in still air for two (2) days to avoid cracking as a result of shrinkage. Dried moulded clay samples were later fired in the oven (kiln) at 900°C temperature. The fired clay samples were allowed to cool and kept for further necessary laboratory tests which were required to determine the refractory properties of the clay samples. Some sets of the moulded clay were set aside as unfired moulded clay samples as shown in Figure 3.



Figure 2: Manual presser



Figure 3: Moulded Clay Samples

2.6 Determination of Physico-Mechanical Properties of the Clay Samples

Different laboratory tests were conducted on the clay samples to investigate the physico-mechanical properties of the various clay samples using ASTM and British Standard (BS) as described by Mittal and Shukla (2003) appropriately.

The properties of representative samples of each clay samples were processed and examined in Materials Laboratory of Department of Civil Engineering, The Federal Polytechnic, Ado-Ekiti using BS 1377:1975 guidelines (Mittal and Shukla, 2003) and ASTM standards test methods (ASTM 1982, ASTM 71, D422, C1100-88, C133-97, C326 and C20-00) appropriately. The details of the procedures for the test methods have been adequately discussed elsewhere (Shuaib-Babata and Mudiare, 2017; Shuaib-Babata *et al.*, 2016, 2018). The properties tested include grain size distribution, Atterberg limit/consistency of the clay (liquid limit, plastic limit, and plastic index), bulk density, clay content, moisture content, permeability, porosity, specific gravity, linear shrinkage, loss on ignition and thermal shock resistance and refractoriness.

The clay samples' plasticity index, percentage moisture content and percentage linear shrinkage was determined using relationships in equation (1), (2) and (3) appropriately

$$\text{Plastic Index, PI} = \text{Liquid Limit} - \text{Plastic Limit} \quad (1)$$

$$\% \text{ moisture content} = \frac{\text{Weight before drying} - \text{Weight after drying}}{\text{Weight before drying}} \times 100 \quad (2)$$

$$\text{Linear Shrinkage \%} = \frac{D_1 - D_2}{D_1} \times 100 \quad (\text{ASTM C326}) \quad (3)$$

Where: D_1 and D_2 was the outer diameter of the clay sample before and after sintering respectively.

Each of the sample's apparent porosity (A.P.) and bulk density was evaluated using Archimedes' method in accordance with ASTM C20 guidelines, and the value was determined using equation (4) and (5) respectively. Meanwhile, the samples' loss on ignition (LOI) was also determined using equation (6).

$$A.P. = \frac{\text{Soaked Weight (W)} - \text{Dried Weight (D)}}{\text{Soaked Weight (W)} - \text{Suspended Weight (S)}} \times 100 \quad (4)$$

$$\text{Bulk Density (g/cm}^3\text{)} = \frac{\text{Dried Weight}}{\text{Soaked weight} - \text{Density of Water}} \quad (5)$$

$$\begin{aligned} LOI &= \frac{\text{Weight of Dried Clay} - \text{Weight of Clay+Crucible}}{\text{Weight of Clay+Crucible} - \text{Weight of Crucible}} \times 100 \\ &= \frac{\text{Moisture Content}}{\text{Weight of Clay}} \times 100 \end{aligned} \quad (6)$$

The samples' compressive (crushing) strengths were determined at the Material's Laboratory, National Centre for Agricultural and Mechanization (NCAM) using a Testometric Materials Testing Machine (Model 0500-10080), Win test analysis; 100kN capacity, England made). Figures 4 - 6 show some stages of determining the clay samples' properties.



(a)



(b)



(c)

Figures 4 (a) (b) and (c): Determination of a Clay Sample Liquid Limit

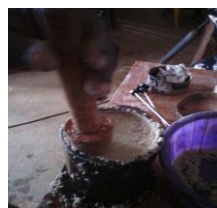
(a) A clay sample filled into the apparatus for the test (b) Two parts of the line drawn on the clay sample groove line (c) The specimens after the liquid limit test



(a)



(b)



(c)

(a) Falling head permeability apparatus (b) Mould (c) The falling head mould filled, well packed and loaded with the clay sample

Figure 5 (a,b,c): Determination of the clay samples' permeability value



Figure 6: Universal Testing Machine with a clay sample mounted being tested

3. Results and Discussion

The results of the experimental tests for characterization clay samples from different deposits in Asa L.G.A. of Kwara State are presented in Tables 1-3 and Figures 8 - 13.

3.1 The Chemical Compositions

The various elemental constituents of the clay samples are as shown in Table 1. The results revealed that the samples majorly contained silica and alumina, while other constituents, such as SiO_2 , Al_2O_3 , TiO_2 , Fe_2O_3 , CaO , MgO , Na_2O and K_2O were present in smaller concentrations. This implies that the clay samples were mainly alumina-silicate minerals based on the higher proportions of the silica and alumina in the clay samples (Hassan and Adewara, 1993; Hassan, 1990, 2005; Sanni, 2005). The other constituents in the clay as revealed in the results were expected for any clay, especially ideal kaolinite (Kirabira, 2005; Hassan, 1990,2002).

Table 1: The chemical compositions of the clay samples and some data from the literature

Clay Samples	SiO ₂	Al ₂ O ₃	TiO ₂	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	LOI
Aboto-Oja	48.26	34.30	1.34	2.31	0.31	0.71	0.41	0.31	11.67
Afon	51.83	33.51	3.20	2.5	0.27	0.72	0.39	0.21	7.1
Alapa / Lamba	49.90	34.30	0.83	2.71	0.20	0.30	0.21	0.29	11.0
Bakase	54.71	33.80	1.71	0.52	0.27	0.37	0.35	0.20	7.70
Ballah	58.50	33.90	0.69	2.67	0.23	0.3	0.12	0.27	3.1
Ogbodoro ko	47.30	32.75	3.61	0.57	0.41	0.28	0.9	2.0	12.00
Fireclay (Nnuka and Agbo, 2000)	46.00 - 62.00	25-39	-	0.40- 2.70	0.20 - 1.00	0.20 - 1.00	0.300 - 3.00	0.30 - 3.00	8.00 - 18.00
Refractory Clay (Nnuka and Agbo, 2000)	46-62	25-39	ND	0.4 2.7	0.20 - 1.00	0.2 - 1.0	ND	ND	8 – 18
Siliceous Ball Clay (Worral, 1982)	40 -60	25 – 60	-	0.25 – 4.00	-	-	-	0.00 - 0.75	0.50 - 4.00

The proportions of silica in the clay samples ranged between 47.3 and 58.5%, with sample from Ogbondoroko and Ballah having the least and highest value of silica respectively, which were within the required silica concentration for manufacture of fireclay (46.00 – 62.00%) (Nnuka and Agbo, 2000) and refractory clay (46.00 – 62.00%) (Worral, 1982). The proportions of alumina in the clay samples were between 32.75 and 34.30%, which satisfied the alumina requirements for fireclay, refractory clay/bricks and manufacture of ceramics. For refractory brick and manufacture of ceramics, 25 – 44% and greater than 26.5% alumina is respectively required (Chester, 1973). According to Gupta (2008), clay with 25 – 45% standard value range of alumina belongs to the family of alumina-silicate and semi-acid refractory. Therefore, all the clay samples belong to this family since the samples contained alumina within the standard value range. Onukwuli *et al.* (1996) also suggested that the clay with the content of SiO₂ and Al₂O₃ and low content of CaO to be kaolinite in nature. The contents of alumina affect the clay refractoriness, as the degree of refractoriness increases with alumina content (Kure, 2011). The presence of elements like Fe₂O₃, CaO, MgO, Na₂O and K₂O, which are regarded as

impurities (flux oxides) in the clay adversely affects the refractoriness and service limit of the bricks (Ochieze and Esezobor, 2018). However, the results (Table 1) show that the flux oxides in the raw clay samples were within acceptable range values (Nnuka and Agbo, 2000; Worral, 1982). The Fe_2O_3 requirements in clay for high melting clays, manufacture of ceramics and refractory bricks are 1- 9%, 0.5 – 1.2% and 0.5 – 2.4% respectively (Abubakar *et al.*, 2014). All the clay samples met Fe_2O_3 requirement for fireclay and refractory clay (Table 1). The proportion of iron in the clay samples' elemental constituents determines the thermal conductivity potential of the clay. Sanni (2005) was of the view that any fireclay for refractories application needs to contain at least 30% alumina and less than 1.8% Fe_2O_3 .

The moderate concentration of flux oxides, such as CaO , Na_2O , and K_2O , is an indication that the clay samples have the tendency for good refractoriness. The presence of alkali and other metal oxides in low concentration lowers the clay fusion temperature and accounts for relatively high refractoriness (Kure, 2011). The vitrification temperature and refractoriness of clay during firing are reduced by the action of these alkali oxides, which acts as mild fluxes (Maiti and Kumar, 1992).

The loss on ignition (LOI) on refractory bricks produced from the clay samples (3.10 - 12.00%) were within the recommended values for fireclays, 2.00 – 13.00% (Gupta, 2008). It shows that the amount of organic matter in the clay samples was low. Although, Nnuka and Agbo (2000), Worral (1982) and Grimshaw (1971) gave 8.00 – 18.00% as stipulated standards range for LOI for fireclay and refractory clay; and a value greater than 8.18% for the manufacture of ceramics. Grimshaw (1971) recommended 5.00 – 14.00% as a standard value of LOI for refractory bricks. By this analysis, clay samples from Afon (7.1%), Bakase (7.70%) and Ballah (3.10%) had LOI value lower than Nnuka and Agbo (2000), Worral (1982) and Grimshaw (1971)s' recommended LOI value for fireclay and refractory clay. This implies that the clay samples will require the addition of organic matter, such as zircon, rice husk, sawdust, among others, where the enhanced value of permeability, porosity, and low density are required.

Table 2: Summary of results of the clay properties

Clay Sample	Liquid Limit (LL) (%)	Atterberg Limit		Linear Shrinkage (%)	Specific Gravity	Refractoriness (°C)
		Plastic Limit (PL) %	Plastic Index (PI) %			
Aboto-Oja	46.0	25.2	20.8	9.8	2.52	>1300
Afon	64.3	26.9	37.4	9.3	2.49	>1300
Alapa / Lamba	54.6	20.7	33.9	8.7	2.39	>1300
Bakase	71.6	32.5	39.1	8.1	2.31	>1300
Ballah	38.6	16.7	18.9	6.1	2.18	>1300
Ogbodoroko	45.3	23.9	21.4	7.2	2.31	>1300

3.2 Physico-mechanical properties of the clay samples

3.2.1 Atterberg limit/consistency of the clay

(liquid limit, plastic limit, and plastic index),

The results of the grain size distribution (Table 2) which were obtained through sieve analysis show that the samples have liquid limit greater than 35 %, an indication that the clay samples were within medium-high plasticity clay. According to Emesiobi (2000), clays with a liquid limit between 37.0 and 77.7% are medium-high plasticity clays, which are characterized by compressibility shrinkage. Clay sample with a liquid limit above 50% is an indication of high plasticity, which may either belong to inorganic silts or organic clay with compressibility (Emesiobi, 2000). Higher liquid limit of Afon, Alapa/Lamba, and Bakase clay samples shows the samples high compressibility, an indication that the clays may belong to kaolinite or illite group, while Aboto-Oja, Ballah, and Ogbodoroko clay samples belong to medium plasticity clay. A low plasticity clay is clay with plastic index less or equal to 10% and liquid limit less or equal to 30%, as illustrated in the Casagrande chart, Figure 7 (Emesiobi, 2000).

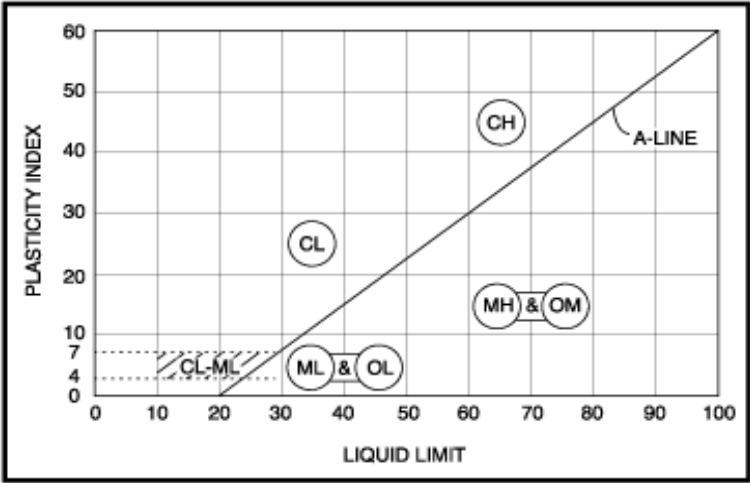


Figure 7: Casagrande Chart (Emesiobi, 2000)

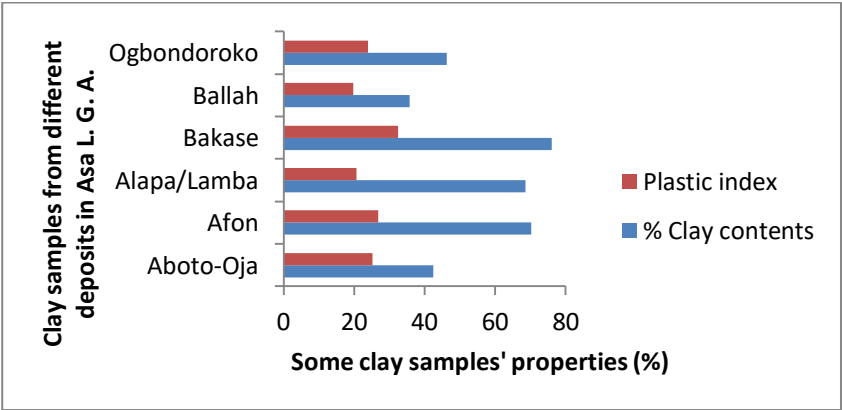


Figure 8: The clay samples' percentage of clay contents and plastic index

3.2.2 Grain size distribution / Clay content

The samples' percentage of clay contents were within 35.80 and 70.20% (Figure 4). This is another indication that the samples fall within silt-clay materials by American Association of State Highway and Transportation Officials (AASHTO) classification of soils and soil aggregates mixtures since their clay

contents were greater than 35% (Emesiobi, 2000). The plasticity of the clay samples increases as the value of the samples' clay contents increases (Figure 8).

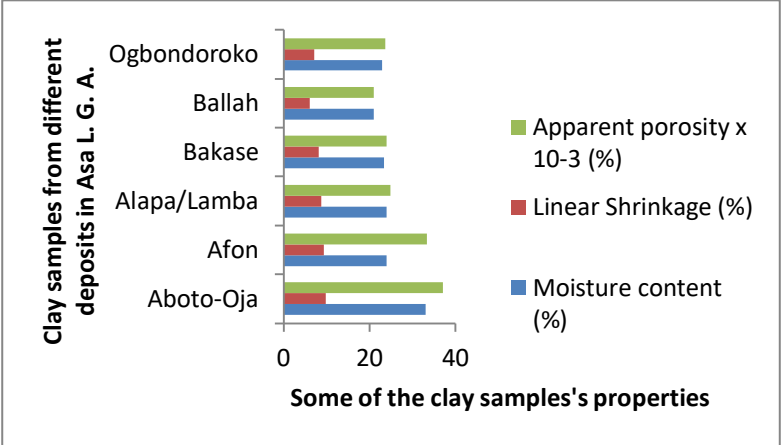


Figure 9: Relationship between the clay samples' apparent porosity, linear shrinkage, and moisture content

3.2.3 Linear shrinkage

The clay samples' percentage fired linear shrinkage values are shown in Figure 9. The samples' linear shrinkage values were between 6.1 and 9.8%. The recommended fired linear shrinkage value for refractory bricks, alumina-silicates, kaolin and fire clays is in the range of 2 – 10% (Chesti, 1986; ASTM, 1982). Recommended linear shrinkage for Insulation materials is <10% (Manukaji, 2013a). Linear shrinkage expresses the rate of volume change in the clay after firing. It is also an indicator of the firing efficiency of the clay sample. Lower shrinkage value is, therefore, more desirable (Ogbebor *et al.*, 2010). Excessive shrinkage of refractories leads to spalling, warping and cracking of the brick (Atanda, *et al.*, 2012). This affects the efficiency of furnace adversely as a result of the loss of heat which is associated with cracking of brick. From the test results of linear shrinkage, an indication of the better interlock of grains that enhances the strength of refractory in operation is revealed (Shuaib-Babata *et al.*, 2018).

Based on the results of this study, the clay samples are good materials for refractory application, especially as insulating material (since their linear shrinkage values were within the recommended range) in ascending order of Ballah (6.1%), Ogbondoroko (7.2%), Bakase (8.1%), Alapa/Lamba (8.7%), Afon (9.3%) and Aboto-Oja (9.8%). Clay with a reasonably low linear shrinkage has the tendency of good insulating characteristics (Manukaji, 2013b). The value of clay's linear shrinkage increase due to the removal of combustible materials in the clay as the temperature increases. As the temperature increases, the burning off of these combustible materials occurs which results in the creation of more space in the clay components and compression of the clay particles during sintering and vitrification. Table 2 reveals that the higher the shrinkage, the greater the clay plasticity and the easier the clay for the moulding process.

3.2.4 Moisture content

The value of the moisture in the clay samples ranged between 21.0 and 33.0% (Table 2). The level of clay samples' moisture contents reflects the value of the samples' porosity and linear shrinkage. The higher the sample's moisture content, the greater the sample's porosity and consequently the higher the linear shrinkage after firing (Table 2 and Figure 9). Clay samples with higher moisture content are likely to possess higher finer grains than the samples with low moisture content values since linear shrinkage of clay increases with moisture and consequently finer grains (Shuaib-Babata *et al*, 2018b). Appreciable values of the samples' moisture contents indicate adequate water level in the clay samples, which ensure proper mixing, simple handling and better moulding capacity into any desired shapes. The good water content in clay makes possible ease mouldability of the clay (Hassan, 1990). Clay's plasticity and strength significantly depend on the quantity of water in the clay sample (Newman, 1987).

3.2.5 Bulk density

The results of clay samples from different deposits in Asa L.G.A. are as shown in Figure 10. The density of the clay samples ranged between 1.99 and 2.87 g/cm³ in ascending order of Aboto-Oja, Afon, Alapa/Lamba, Bakase, Ogbondoroko, and Ballah. The standard range value of 1.6 – 2.0 g/cm³ is recommended for insulating refractory (Chester, 1973; Folorunsho *et al.*, 2015). For fireclay and brick lining, 1.98 – 2.05 g/cm³ and 1.7 – 2.4 g/cm³ were also

recommended as bulk density values respectively (Chesters, 1973). Hassan (2001) however recommended 1.7 – 2.1 g/cm³ for dense firebricks. This implies that all the clay samples satisfied the requirement for insulating refractory, fireclay, brick lining and dense firebricks.

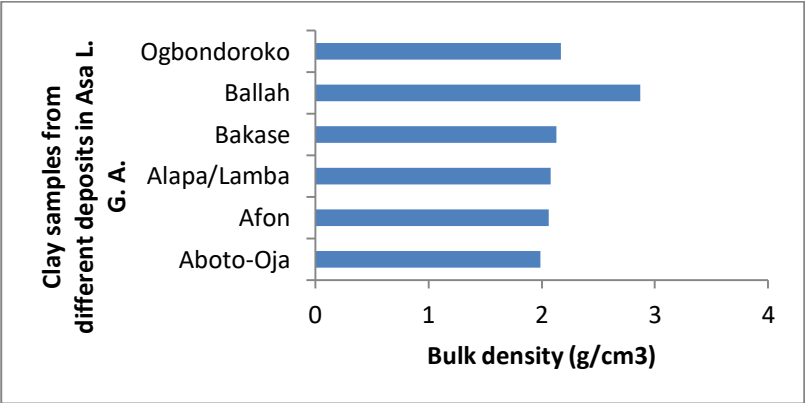


Figure 10: The clay samples’ bulk density

Table 3: Relationships between the clay samples’ strength, density, linear shrinkage and porosity

S/N	Samples	Cold crushing strength	Bulk density (g/cm3)	Linear Shrinkage (%)	Apparent porosity x 10-3 (%)
1	Aboto-Oja	108.0	1.93	9.8	37.1
2	Afon	213.0	2.06	9.3	33.3
3	Alapa/Lamba	267.7	2.08	8.7	24.8
4	Bakase	359.6	2.13	8.1	23.9
5	Ballah	840.0	2.87	6.1	21.0
6	Ogbondoroko	361.3	2.17	7.2	23.74

3.2.6 Apparent porosity

The bricks from the clay samples exhibited apparent porosity values of 21.0 to 37.0%, which were within the standard range value of 20-30% for refractory bricks (Chesti, 1986). This reveals the presence of reasonable pores in the bricks.

In the results (Figure 11 and Table 3), the clay samples with low apparent porosity had low permeability, high density and also exhibited high crushing strength. The clay samples' apparent porosity values increased with moisture content and linear shrinkage. The clay samples met the porosity requirement for insulating material / refractory bricks since the samples' apparent porosity values (21.0 to 37.0%) were within the required range (20-30%). A good insulating refractory/material must be highly porous (Manukaji 2013b). The porosity of the clay sample influences the value of moisture content in the clay. Increase in the porosity of the clay sample leads to an increase in the clay moisture content since the pores in the clay are responsible for water uptake through the clay. The closure of internal pores results in high shrinkage in the clay sample (Mark, 2010).

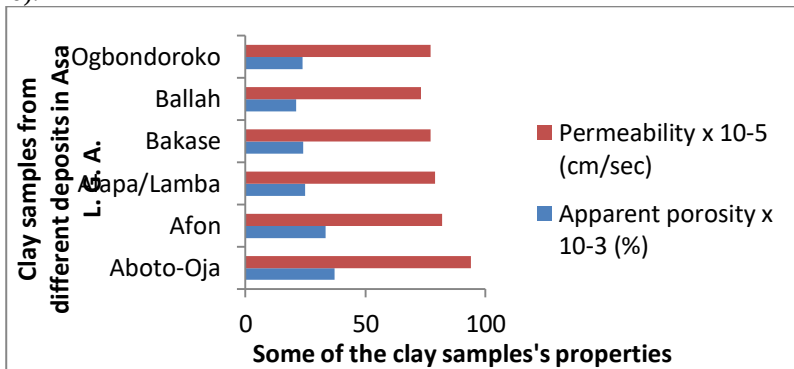


Figure 11: The clay samples' permeability and apparent porosity values

3.2.7 Permeability

The ability of the clay samples to prevent liquids and gases (fluids) from penetrating the clays wall (permeability) is shown in Figure 11. The permeability values for all the clay samples were between 73 and 94, which were within the recommended range of 25 – 90 (De Bussy, 1972 and Gupta, 2008), but ASTM (1982) recommended 82 as permeability value for fireclay. By ASTM recommendation, clay samples from Alapa/Lamba, Bakase, Ballah, and Ogbondoroko deposits would require the application of organic solvents (Brown, and Anderson, 1983) or addition of organic matters (Falih, 2017) like zircon, rice husk, sawdust, among others, to improve their permeability values.

3.2.8 Cold crushing strength

The ability of the clay samples to resist load in compression is expressed in Figure 12. The clay samples' compressive strengths were between 213 and 840

N/mm². The values were within and even beyond the recommended compressive strength of 15 – 59 MPa (N/mm²) (ASTM C133-97; Omowumi, 2001; Bam *et al.*, 2015) and 9.8 – 68.8 MPa (Krivandin and Markov (1980) for fireclay bricks. Meanwhile, Omowumi (2001) and Chester (1973) respectively recommended 150 Kg/cm² (14.71 N/mm²) and 5 MPa as the minimum suitable compressive strength for fireclay.

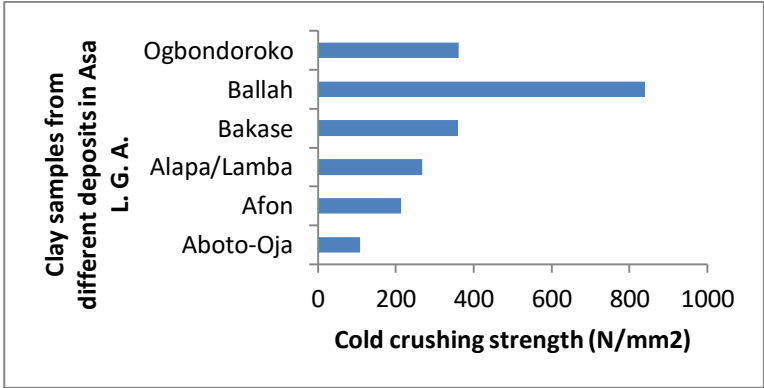


Figure 12: The clay samples’ crushing strength

The values of the clay sample’s porosity and moisture content reflect the values of the sample’s strengths. The samples’ strengths increased with the increased in the samples’ porosity and moisture contents. In the same vein, the samples’ strengths increased with a decreased in the value of the samples’ linear shrinkage (Figure 13). Clay samples that exhibited low compression strengths (Aboto-Oja, Afon, Alapa/Lamba) will be associated with low resistance to load, tension and shear stresses than the clay samples with high compressive strength (Ballah, Ogbondoroko, and Bakase) (Shuaib-Babata *et al.*, 2017). Since the clay samples’ strength values satisfied the minimum suitable compressive strength for fireclay and fireclay bricks, the clay samples had enough strength for a refractory material, which accounts for good bonding and vitrification during firing (Hassan, 1990).

Analysis of the results in Table 3 shows that the strength of clay samples increases with the samples’ bulk density or vice versa. More so, the clays’ porosity and linear shrinkage increase with the decrease in the clay samples’ bulk density value. It is an indication that the clay experience more shrinkage due to the fact that the clay samples are more compacted during firing and thus became

dense. This process resulted to increase in the clay strength. The organic materials on the clay samples were burnt away during the firing process which led to the creating of the void. More voids would be created in the clay samples with more organic materials. As such, the clay samples would be lighter than samples with less organic matter content and the bulk density value would then be lower. High bulk density impacts available water capacity in the clay, an indication of low porosity and compaction as reflected in the results (Table 2 and Figure 13). That is, the lower the clay bulk density, the lower its porosity. A higher quantity of water in clay attracts low density (Agodzo and Adama, 2003). Comparing the test results (Table 3 and Figure 13), it is reflected that higher bulk density resulted to low moisture content and higher strength due to low porosity; and low bulk density is also associated with high linear shrinkage. It is desired that clay refractories possess high bulk density because high fired-density confers high physical strength at high service temperature and high resistance to corrosion in service, slag penetration and abrasion (Shuaib-Babata, *et al.* 2018). Meanwhile, Makanju (2013b) was also of the view that clay with low bulk density (lighter body) after firing or low solid density is desirable for insulating refractory. The higher bulk density value of the clay material is an indication of higher plasticity and mouldability of the clay. This may affect the clay strength value negatively (Shuaib-Babata and Abdulrahman, 2018). In the choice of clay as refractory, coater, absorbent and filler, among others, bulk density plays significant roles (Shuaib-Babata, *et al.* 2018).

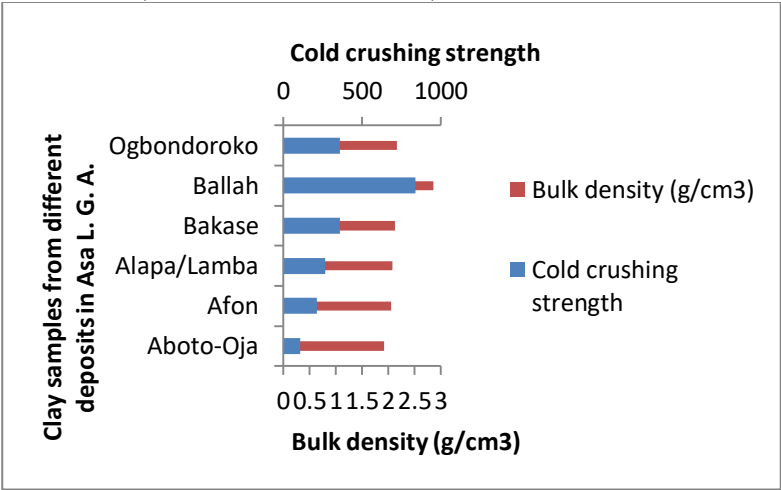


Figure 13: Relationship between the clay samples' bulk density and crushing strength

3.2.8 Refractoriness

The refractory bricks produced from the clay samples had refractoriness value greater than 1300°C. The refractory bricks produced from clay samples were able to withstand heating beyond 1300°C without any sign of failure, which implies that their sintering levels were high. It is evidence that the clay products have the ability to withstand deformation temperature at the temperature (1300°C) before fusing or bend under its own weight (Omowumi, 2001). This means that any of the clay samples can be favourably used without fear of thermal deformation of the furnace wall. This result revealed that the clay samples are of good refractoriness; as such, the clay samples satisfied the requirement as raw material for low and medium temperature duty fireclay refractories, like the lining of furnaces and other high-temperature devices that can be used for in melting of low and medium metals.

3.2.9 Thermal Shock Resistance (TSR)

The results of this test indicated that the clay samples could withstand abrupt changes in temperature since the samples survived +29 cycles without any crack. By standard, fireclay is expected to survive 20 – 30 cycles (Bam *et al.*, 2015; Omowumi, 2000; Chesters, 1973). However, Hassan (1990) classified clay TSR as excellent (>30 cycles), good (25 – 30 cycles), fair (12 – 20 cycles), acceptable (10 – 15 cycles) and very poor (<10 cycles). By this classification, the clay samples' thermal resistance shock values were therefore within the "good class" of TSR, as the clay samples survived the number of cycles within the standard range, a good characteristic showing the clay suitability for production of fire-brick for thermal applications.

4. Conclusion

The following conclusions were drawn from the experimental results on the clay samples from Asa L.G.A.: The clay samples in Asa L.G.A. were major of alumina-silica minerals; hence they belong to alumina-silica group of clay. The quantity of silica (47.30 – 58.50 %) and alumina (32.75 – 34.30 %) with a moderate concentration of flux oxides in the clay samples were adequate and good for refractories, fire-brick, and manufacture of ceramic requirements, especially for low-medium thermal applications.

The clay samples were characterized to be compressibility shrinkage clays, being within medium-high plasticity clay, which was suitable as potential raw materials for fireclay refractory in furnace and kiln lining, manufacture of ceramics, paper, and in other industries. Afon, Bakase and Ballah clay samples

may require the addition of organic matters to enhance their permeability and reduce their density for applications that required higher porosity, permeability, and low density. The clay samples' physico-mechanical properties, such as plasticity, moisture content, crushing strength, linear shrinkage, bulk density, permeability, porosity, clay contents thermal shock resistance and refractoriness were reasonable and within the standard values of refractory properties. This is an indication that Asa clays were suitable as raw materials for refractory applications, such as in the production of fireclay, production of ceramics, as insulating materials, refractory, coater, absorbent and filler. Thus, the clay materials serve as suitable raw materials of acceptable standards to domesticate production of refractory products and for foundry applications.

The clays either in raw conditions or at a higher temperature could be used successfully as suitable materials in replacement of imported clays in refractory applications, like in casting and melting of the low and medium temperature of metals, in earthenwares and chalk production, and as ceramic raw materials, among others.

Effective utilization of Asa L.G.A. clay samples will help in the establishment of small and medium scale firms in Kwara State in particular and Nigeria in general. This will also assist to strengthen the nation's economy and aid the diversification of Nigeria economy from over-dependence on oil and gas.

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