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Evaluation of Chemical and Physico-Mechanical Properties of some Nigeria Natural Clays Samples for Foundry Applications

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Abstract— Studies have shown that Nigerian clays have not been fully utilized for foundry applications, either as refractories or even bonding clays, and are still being imported into the country. There is need to effectively exploit and adequately utilize the available natural resources to improve Nigeria economic activities, most especially during the present economic recession. Samples of clays were obtained from Auchi, Dada-Okelele (Ilorin), Kaba, Maraba-Rido, Mokwa and New-Bussa in Nigeria. The samples' physico-mechanical properties were examined for its suitability for foundry/refractory applications. The results of the chemical analysis revealed that the samples belong to Alumino-Silicate refractories. The samples exhibited 35.3-96.2%, 17.1-28.7%, 1.72-2.34 g/cm^3, 2.2-10.1%, 73-86 and >1300°C as values for percentage clay contents, apparent porosity, bulk density, permeability, linear shrinkage and refractoriness respectively. These values were within the standard range values of >35%, 22-30%, 17-2.4%, 2.0-10.1% and 25-90 required as percentage clay contents, apparent porosity, bulk density, permeability and linear shrinkage values respectively, for refractory clays/brick lining or alumina-silicates, kaolin and fireclays. Hence, the clays could suitably replace imported clays / ceramics in refractory applications, such as in production of earthen wares, chalk; as insulating refractories for casting and melting of low and medium temperature iron and steel. Appropriate utilization of these clays for local foundry applications will assist in addressing the problem of inadequate job, and over dependence on foreign goods.
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Keywords— Alumino-Silicate, Clay, Foundry, Moisture and Refractoriness

1 INTRODUCTION

The shift for alternative source of income apart from oil and gas is the call of the day in Nigeria at all levels. There is also quest for local materials that can substitute (if not total elimination) the importation of materials, such as refractory products, iron and steel, agricultural products, among others as result of the economic situation in the country. Studies have shown that majority of available natural resources in Nigeria, most especially clay, have not been receiving sufficient attention (Aaron & Ishmael, 2015; Musa 2013). In addition to silica sand, clay is a known principal moulding material used in for all types casting whether ferrous or non-ferrous (Atanda et al., 2012a). With proofs that Nigeria clay meets current American Petroleum Institute (A.P.I.) standard by beneficiation and proven reserves of more than four (4) billion metric tonnes of bentonite, Nigerian local sodium bentonite are neglected (Okologume & Akinwumi, 2016). The materials are still imported for use in Nigerian oil industries.

In Nigeria, many industries, especially metallurgical industries depend on external sources for supply of clay with required foundry properties (Aliyu, 1996). Nigeria imported about 27 million metric tonnes of refractory materials in 1987, according to (Obadinma, 2003). The demand for refractories for different high temperature processes and building in Nigeria is enormous as result of rapid involvement of Nigerian industries in high temperature processes (Borode, et al., 2000). Delta Steel Company can consume N1.4 million worth of fire clay (Alumino silicate) materials annually in the steel melt shop, and Ajaokuta Steel Complex at full capacity will require 36,000 tonnes of refractory bricks annually, worth of N5,034 billion Naira annually (Sullayman & Ahmed, 2003).

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Nigeria depends greatly on importation of refractory materials to cater for its domestic and industrial needs. Bulk of the clay consumed in Nigeria is imported from United States of America, United Kingdom and Japan (Iwuanyanwu, 1990). Lack of adequate information on their properties is a contributing factor. About 27 million metric tonnes of refractory materials were imported to Nigeria in 1987 (Obadinma, 2003). Considering the present situations (rise in population, demand for industries revolution, and inflation rates) in the country, the importation rate will definitely be in multiple tonnes. Sullayman & Ahmed (2003) also revealed from their study that export earning of Nigeria in clay/refractory within 1996-2011 stood only $394,000.00, while Italy in 1997 alone exported $3,442,653,000.00 worth of clay/refractory products and related materials.

It is a common practice that materials, such as clay, are sourced for suitability through consideration for specific and general properties for design and construction purposes (Shuaib-Babata & Tanimowo, 2016). To realize effective usage of materials, an engineer needs to fully understand the various properties of materials. The reason for this is that practically all useful properties of materials are strongly dependent on international standards (Craig et al., 1973).The information on materials' characteristics could be reliably obtained from physical and mechanical tests, which will be useful in characterizing the materials and subsequently aid their applications optimally and appropriately.

There is need to effectively exploit and adequately utilize the available natural resources like clay, to improve Nigeria economic activities, most especially during the present economic recession that require shifting attention from over dependency on oil and gas as main economic source through adequate knowledge of their properties. This study therefore examined the

Chemical and Physico-Mechanical Properties of some Nigeria natural clays samples to enhance the adequate utilization of the local clays especially for foundry applications

2 Materials and Methods

2.1 Materials

The clay samples were collected randomly from six (6) different deposits from some clay deposits in Nigeria, namely: Auchi, Dada – Okelele (Ilorin), Kaba, Maraba-Rido, Mokwa and New Bussa

2.2 Methods

2.2.1 Preparation of Samples

The samples collected were air-dried, crushed, grinded and sieved through 75µ, 200µm and 600 µm sieves at the Federal Polytechnic Ado-Ekiti Civil Engineering Materials Laboratory where the refractory analysis were carried out. The specimens for various experiments were rolled and pressed, dried and kept in a crucible in a plastic form before different parameters were determined.

2.2.2 Brick Production

Parts of the plastic clay samples were moulded into block form with rectangular bricks of dimensions 5 x 5 x 2 cm using hydraulic press. The bricks were dried in hot air oven and fired and used to determine the refractory properties of the clay samples.

2.2.3 Determination of Chemical and Physico-Mechanical Properties of Clay Samples

Representative samples of the selected clay materials were analysed to determine their chemical constituents using Atomic Absorption Spectrophotometer (AAS) in line with the recommendation of Chesti (1986) that x-ray fluorescence (XRF) or Atomic Absorption Spectrophotometer (AAS) can be used for that purpose.

The Physico-mechanical properties of the clay samples (such as grain size distribution liquid limit, plastic limit, plasticity index, hydrometer analysis, loss on ignition, moisture content, permeability, compression crushing strength, thermal shock resistance, refractoriness value) were also examined in line with British Standards (BS 1377:1975) recommendations as described by Mittal and Shukla (2003) and ASTM standard test methods for plasticity, drying shrinkage, firing shrinkage, apparent porosity, water absorption, apparent specific gravity and bulk density (ASTM. 1989) appropriately. The details of the procedures have been adequately discussed elsewhere (Shuaib-Babata and Mudiare, 2017). Plates I and II show clay samples during the process of liquid limit determination and crumbled specimens after plastic limit test respectively

Plate I: Clay sample during Liquid Limit test

Plate II: The crumbled specimens after plastic limit test

3 Results and Discussion

3.1 Chemical Composition

The results of the clay samples' chemical analysis, which is an essential step to establish the nature of minerals (Newman, 1987), are presented in Table 1. The chemical analysis results show that about 80% of the clay materials were characterized by eight elements, while the remaining was attributed to water, trace elements and organic matter. The results also reflect slight variability of average in the values of silica (SiO_2) and alumina (Al_2O_3) contents, which constitute about 70% major constituents of the clays. Therefore, the clays belong to alumino-silicate group.

SiO_2 and Al_2O_3 in the clay samples were fairly stable ranging from 45.58% to 76.70%, and 18.01% to 34.40% respectively. The silica and alumina values were within acceptable range for clay types (ASTM, 1982; Omowumi, 2000; Kirabira, 2005). This class of clay sample can be used as fireclay refractory raw materials for furnace and kiln lining; and as suitable potential raw material for ceramics, paper, paints and other industries. The iron oxide concentration ranges from 0.37 to 1.66 %. The elemental compositions of clay samples in Table 1 are in agreement with Sanni (2005) that any fireclay to be used in refractories should have at least 30% Alumina (Al_2O_3) and less than 1.8% Iron (III) oxide (Fe_2O_3). This means that the clay samples were suitable as refractories chemically.

The values of flux oxides in the raw clay samples also varies, which can be attributed to contamination from the impurities available at the various locations where each of the clay samples were obtained. The slight blackish colouration in the clay samples can be due to the presence of carbonaceous (organic) matter (like vegetable). Other fluxing agents (impurities) in the clay such as CaO, MgO, K_2O and Na_2O, were within the acceptable ranges. Kirabira (2005) is of the view that impurities, such as CaO, MgO, Na_2O, $CaSO_4$, $CaCO_3$, MnO_2, P_2O_5, Fe_2O_3 and TiO_2 in an ideal kaolinite should be in small quantities. High content of SiO_2 and Al_2O_3 and low content of CaO present on clay suggested the clay to be kaolinite in nature (Onukwudi et al., 1996).

Table 1: Chemical Composition of the Clay Samples

CLAY SAMPLES	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	Na_2O	K_2O	L.O.I
Kaba	76.70	18.01	-	0.88	1.01	0.18	0.46	1.06	1.70
Auchi	57.00	27.10	1.10	1.40	0.20	0.70	0.10	2.00	10.21
Dada – Okelele (Ilorin)	45.58	34.40	0.87	0.61	0.07	0.08	0.04	0.20	17.77
Mokwa	62.26	28.96	0.06	0.37	0.31	0.27	0.24	2.33	5.2
New Bussa	56.71	26.73	-	1.29	2.30	2.07	0.90	-	10.0
Maraba-Rido	46.84	33.89	1.32	1.66	1.34	0.07	0.38	0.36	13.89

Table 2: The Refractory Properties of the Clay Samples

Clay Sample	Atterberg Limit										
	Liquid Limit (LL) %	Plastic Limit (PL) %	Plastic Index (PI) %	Linear Shrinkage (%)	Particle Distribution (% Clay Contents)	Apparent Porosity (%)X10-3	Bulk Density (g/Cm^3)	Permeability (X 10^{-5} cmsec^{-1})	Cold Crushing Strength (N/mm^2)	Moisture Content	Refractoriness (^{0}C)
Kaba	56.7	21.1	35.7	6.0	64.40	22.72	1.93	81	441.0	22.2	>1300
Auchi	53.1	19.5	33.6	5.1	45.70	18.52	2.10	82	563.0	21.0	>1300
Dada – Okelele (Ilorin)	77.7	25.1	52.6	10.1	96.20	28.70	1.72	73	368.5	27.3	>1300
Mokwa	66.1	27.3	38.8	8.8	77.00	23.30	1.86	83	433.0	23.0	>1300
New Bussa	37.0	17.9	19.1	2.2	35.30	17.10	2.34	86	592.0	20.0	>1300
Maraba-Rido	64.1	24.3	39.8	9.0	69.60	25.00	1.78	81	391.3	23.2	>1300

3.2 Refractory Properties

The refractory properties of the clay samples such as the grain size distribution, clay contents, moisture content, permeability, porosity, bulk density strength and refractoriness are presented in Table 2.

3.2.1 Analysis of the Distribution of Grain Size

Through sieve analysis of the clay samples, it is also shown that all the studied clays possessed liquid limit greater than 35% as presented in Table 2. This analysis reveals that the clay samples belong to high plasticity clay. According to the plasticity chart (Figure 1), liquid limit of a clay sample above 50 % is an indication that the clay is of high plasticity and therefore belongs to either inorganic silts or organic clay with compressibility. Medium to high plasticity clay usually possess liquid limit between 37 - 77.7% with compressibility shrinkage characteristics (Emesiobi, 2000). The higher liquid limit value of the clay indicates high compressibility of the clay. Also, high plasticity of the clay samples is an indication that the clays may belong to kaolinite or illite group (Shuaib-Babata, et al., 2016).

3.2.2 Plasticity (Percentage Of Clay Content)

The experimental results in Table 2 show that the samples' clay contents were in the range of 35.3 to 96.2%. It indicates that all the clay samples contained clay proportion above 35%. New- Bussa clay sample out of all the clay samples had the least plasticity with liquid limit of 37.0% and plastic index of 19.1%, while Dada-Okelele (Ilorin) clay sample exhibited the highest plasticity (liquid limit of 77.7% and plastic index of 52.6%). Other samples recorded moderate plasticity. Medium to high plasticity of the clay samples is an indication that the clays might belong to kaolinite or illite group (Shuaib-Babata, et al., 2016). Reduction in the value of plastic index reflects increased in the values of permeability and decreased in compressibility (Table 2). However, clay samples with low plasticity would possess low clay contents. According to Cansagrande chart (Figure 1), clay with Plastic Index less than or equal to 10% and liquid limit less than or equal to 30% is of low plasticity (Emesiobi, 2000). Illustration of the relationship between plastic index, plasticity, compressibility and Liquid limit is shown Figure 1.

3.3.3 Apparent Porosity

The Apparent porosity of the clay samples were within the range of 17.1 – 28.7%, in which some samples fall within the standard values of 22 – 30% for fired bricks (Chesters, 1975) and 10 -30% for refractory clays (Chester, 1973). It is an indication that the clay samples were likely to be refractory clay materials of good life span, when use in operation. Low percentage of apparent porosity enhances the trapping of gases in the clay materials which has adverse effect on refractory material life (Gupta, 2008). The higher the value of porosity of clay material the higher the material insulating properties (Shuaib-Babata & Mudiare, 2017).

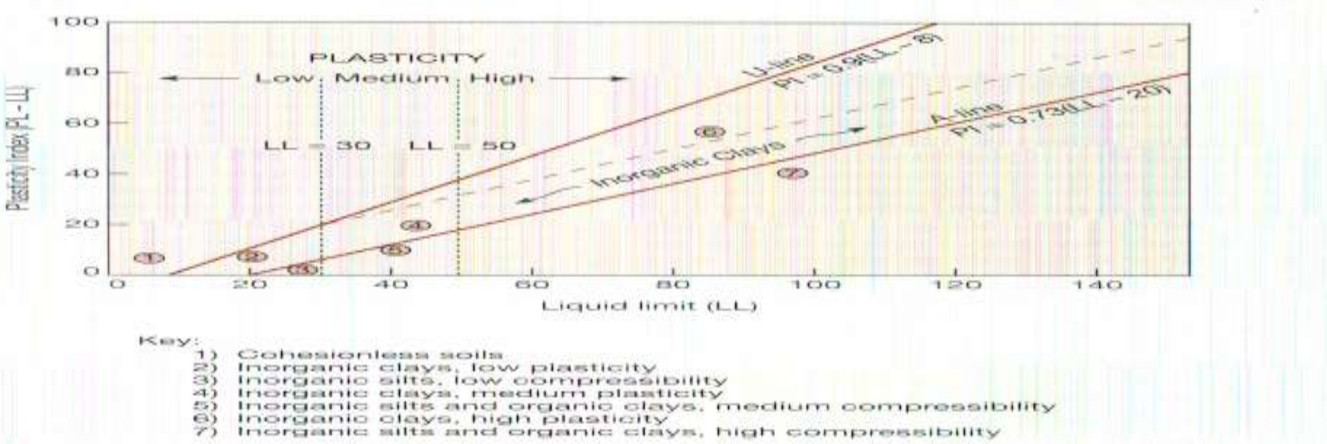

Fig. 1: Plasticity chart (Emesiobi, 2000)

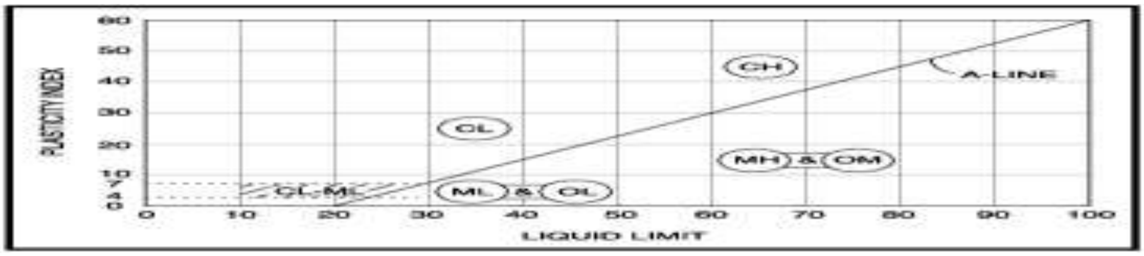

Fig. 2: Cansagrande chart (Emesiobi, 2000)

3.3.4 Bulk Density

From Table 2, the clay samples' bulk density values were within the range of 1.72 - 2.34g/cm3. The clay samples possessed bulk density in ascending order of Dada-Okelele (1.72 g/cm3), Maraba-Rido (1.78 g/cm3), Mokwa (1.85 g/cm3), Kaba (1.93 g/cm3), Auchi (2.10 g/cm3) and lastly New Bussa (2.34 g/cm3). Chesters (1973) gave 1.98 – 2.05 g/cm3 and 1.7 – 2.4 g/cm3 as bulk density values for fireclay and brick lining respectively. The samples' bulk density values were within the recommended values for refractory materials to be used for brick lining. Meanwhile, the clay samples' bulk density values are also within the recommended values for fire clays, except New Bussa clay with value (2.34 g/cm3) above the recommended values. Interestingly, New Bussa bulk density was found to be suitable as refractory materials going by bulk density recommended values for refractory materials (2.2 – 2.8g/cm3) given by Babatola, et al. (2014). Higher bulk density value in a clay material is an indication of higher plasticity and mouldability, but may adversely affect the clay strength (Shuaib- Babata, et. al., 2016). The bulk density of clay plays significant role in its economic value when fired as a refractory, filler, coater, and absorbent among others. It is desired that clay refractories possess high bulk density, due to the fact that high fired-density usually confers high physical strength at high service temperature and high resistance to corrosion in service, slag penetration, and abrasion (Shuaib-Babata et al., 2016). Thus, the clay samples have desirable values of bulk density for standard refractory materials and fireclay.

3.3.5 Cold Crushing Strength

The clay samples exhibited cold crushing strength (CCS) values between 368.5 and 592.0 N/mm2. New-Bussa clay sample had the highest CCS (592 N/mm2), while Dada-Okelele (Ilorin) clay sample has the lowest CCS (368.5 N/mm2) as shown in Table 2. The higher New-Bussa clay sample crushing strength value is a reflection of its higher bulk density. Clay samples with low crushing strength usually have low resistance to load, tension and shear stresses than the clay samples with high crushing strength (Shuaib-Babata & Mudiare, 2017). However the crushing strengths for all the clay samples considered in this study were high enough for a refractory material, which accounts for good bonding and vitrification during firing (Akinbode, 1996).

3.3.6 Linear Shrinkage

The clay samples' linear shrinkage values were between 2.2 and 10.1% (Table 2). New-Bussa clay sample had the least value of 2.2%, while Dada-Okelele (Ilorin) sample had the highest value of 10.1%. It is an indication of good efficiency of firing since the values fell within the recommended linear shrinkage value (2.0 – 10.1%) for alumina-silicates, kaolin and fire clays (ASTM, 1982). The result shows indication of better interlock of grains that enhances strength of refractory in operation. Too much shrinkage of refractories usually leads to spalling, warping and cracking of the brick (Atanda, et al., 2012b). Loss of heat in furnace is associated with cracking of brick. Clay samples obtained from Dada-Okelele with value of 10.0% is likely to possess higher finer grains and moisture content than other clay samples, while clay sample from New-Bussa (with value of 2.2 %) likely to possess the least finer grains and moisture content, since linear shrinkage of clay increases with moisture content and consequently finer grains (Shuaib-Babata, 2015). This trend is apparently shown in the results in Table 2.

3.3.7 Permeability

The permeability clay samples; numbers were within 73 – 86, which fell within the acceptable values of 25 – 90 for fireclay (Gupta, 2008; De Bussy, 1972). This is an indication that the clay materials will be suitable as insulating refractories.

3.3.8 Refractoriness

Each of the clay samples had refractoriness greater than 1300oC. It implies that the clay samples had the ability to use without fear of thermal deformation of the furnace wall up to temperature of 1300oC, since refractoriness is the ability of clay material to withstand the deformation temperature at temperature before fussing or bend under its own weight (Omowumi, 2001). The samples did not show any sign of failure at temperature of 1300oC. This is a sign that the sintering levels of the sample were high; dues they have good qualities of refractoriness. The samples can therefore be used for lining of furnaces and other high temperature devices for melting low and medium temperature metals.

3.3.9 Thermal Shock Resistance (TRS)

The clay samples survived 30 cycles without any crack. The results of TRS show that the clay samples could withstand abrupt changes in temperature.

3.3.10 Moisture Content (MC)

The results of the samples' moisture contents reveal that the values are within 20-27.3%. New Bussa clay sample had the lowest percentage of moisture content of 20%, while Dada-Okelele (Ilorin) clay sample had highest value of 27.3%. The moisture content of the samples increased with apparent porosity and linear shrinkage. This increment reduced the clay sample bulk density and consequently the strength. For instance, Dada-Okelele (Ilorin) clay sample with 27.3% MC also has 28.7% and 10.1% apparent porosity and linear shrinkage respectively. While, New Bussa clay sample with 20% MC equally had 17.1 and 2.2% apparent porosity and linear shrinkage respectively. Appreciable values of moisture in the clay samples indicate that the clay samples contains water adequate for proper mixing, ensures simple handling and better moulding capacity into any desire shapes. This agrees with Hassan (1990)'s view that good water contents make ease mouldability of the clay possible.

4 Conclusion

Through experimental results, the following conclusions were drawn. The chemical characterization of the clay samples revealed that the clay samples were Siliceous in nature as result of higher percentage of silica (46.84-76.7%) in the clays. The clay samples are also within the Alumino-Silicate class of refractories due to high proportion of Aluminum Oxide (18.0-34.4%). This class of clay sample can be used as fire fireclay refractory raw materials for furnace and kiln lining; and as suitable potential raw material for ceramics, paper, paints and other industries.

The clay samples were dense and well porous, which made them to be suitable for improved thermal insulation influences in many applications, such as in pyrolysis plant where linings are not exposed to fumes and vapour. The studied clay materials exhibited better refractory properties of acceptable international standards, such as clay contents, linear shrinkage, slag resistance, crushing strength thermal shock resistance and refractoriness. Thus the clay samples either in their raw conditions or at higher temperature are suitable as medium melting and fireclay refractory and ceramic raw materials of acceptable standards.

Comparison analysis of experimental results obtained (the clay samples' properties) with the properties of standard/commercial clays, it is revealed that the studied clays could suitably replace imported clays / ceramics in refractory applications, such as in production of earthen wares, chalk; as insulating refractories for casting and melting of low and medium temperature iron and steel. Appropriate utilization of Nigerian clays will assist in addressing the problem of inadequate job, and over dependence on foreign goods.

5 Recommendations

This study recommends the need to adequately utilize available local clay materials for local production of ceramic wares and other refractory products instead of relying on imported ceramic products, to boost the lean economic of the country, Nigeria. The government and individuals need to focus on establishment of small and middle scale refractory firms within the identified clay deposits (environments) to enhance local; capacity building, reduce unemployment rate in Nigeria and possibly rates of crimes among the youths

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