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Comparative Assessment of Properties of Laterite and Clay of Otukpo in Benue State for Suitability in Making Bricks and Geopolymer Cement for A Green Environment

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ABSTRACT

As the cost of living is gradually becoming burdensome not only in the continent of Africa involving developing countries like Nigeria, but also in other continents of the world involving developed nations, efforts have been geared in recent years towards adequate utilization of cheap and readily available natural resources like laterites and clays as efficient substitutes and composites building materials for provision of affordable houses for the citizenry while maintaining eco-friendly green environment. Notably, governments at different levels have been saddled now more than ever with the responsibility of providing affordable housing to citizens due to the soaring cost of building materials. Thus, in this study, a comparative assessment of the suitability of properties of laterite and clay soils in Otukpo Local Government Area of Benue State has been carried out. The results of physicochemical properties obtained were: particle size (mm) 1.66 (laterite)/0.006 (clay); pH = 6.68 (laterite)/ 6.15 (clay); geotechnical properties (specific gravity = 2.87(laterite) /3.80 (clay); moisture content = 29.6% (laterite) /50.6% (clay); bulk density (g/ml) = 1.10 (laterite) /1.80 (clay); plasticity indices (Ip) = 25.32% (laterite)/36.85% (clay); liquidity limits (WL%) = 38.97 (laterite) /59.70 (clay) and thermal properties (M.T ^{o}C = 55- 630 (laterite)/40-660 (clay), thermal conductivity = 34.98 $kgms^{-2}\theta^{-1}$ (laterite)/ 107.8 (clay); resistivity (Ωm) = 0.0358 (laterite/0.0186 (clay). These results show that clay has light particles while laterite has heavy particles, and both have plastic behaviour and other excellent properties that guarantee them as suitable materials for making quality bricks for sustainable, eco-friendly green environments.

KEYWORDS: Citizenry, House, Building, Material, Green Environment, Eco-friendly.

1. INTRODUCTION

Before the advent of cement for molding blocks for building houses, man had primitively exploited clay and laterite soils for a long time for building local huts to provide shelter for himself and his family. Currently, not only in Nigeria, but in the whole of the African continent, laterite- and clay-based materials are emerging and sustaining as the new generation of building materials [1]. Unfortunately, now more than ever, the cost of purchasing bags of cement for molding blocks for building houses is quite exorbitant and burdensome. Consequently, houses, especially in rural areas, are no longer affordable to the common man due to the high cost of rent. Additionally, sand, as a highly demanding ingredient for concrete making, is regrettably costly even with its availability [2]. It is unarguably expected that the construction sector of the economy of most developing countries is currently facing a huge demand for sand due to the drastic growth of infrastructural development in the areas of roads, houses, and industrial constructions [3]. With this situation of high cost of materials for making concrete and blocks, it has become pressing necessary to utilize cheap and available alternatives or substitute materials for sand and cement for making bricks for building houses. Particularly, the prominent role that laterite and clay soils have continued to play in promoting the production of cheap bricks for the building of houses has led to a rising concern for their effective and maximum utilization. Essentially, laterite soils are rich in silica, and they are locally available material of low cost, and one of the major advantages is that they can be replaced with fine aggregate in concrete making [2].

Nevertheless, at present and in the past few decades, there has been a remarkable increase in the use of laterite soils as raw materials in various construction applications for enhancing social and ecological values, and a significant number of studies and reviews have explored the unique properties of laterite soils in various building products and road components [3]. Laterite soils are generally used as an alternative raw material for the production of fired and unfired bricks. Since the late 1970s, laterite soils have been used in place of stones as a base layer for low-volume roads with bituminous-surfaced asphalt or tar [1], and since then, they have been widely used to mold bricks, build roads, as aquifers in water supply, water treatment, manufacture of geo-polymeric products, etc. Being highly rich in iron content in addition to high content of corroded kaolinite of amorphous nature, laterite soils are equally used as precursor materials for making geopolymers through alkaline activation, thereby making it a

green, eco-friendly, and sustainable binder used in controlling the emission of CO_2 from the cement industry [4, 5].

On the other hand, considering clays as naturally occurring expansive soils, clay soils are abundantly found in various regions across the globe, including Nigeria in Africa [7], and the science of clay has been the interest of all kinds of people from different scientific backgrounds. However, clay in general consists of particles that are the smallest in the soil, with sizes less than 0.02 mm or less than 0.005 millimeter and the particles usually possess a net negative charge, and therefore can attract positive ions (cations), hold them, and then release them to the soil water when its cations have been lost through leaching or plant uptake [8, 9]. Perhaps for building, construction, and engineering purposes, clays have, in addition to the above-identified properties, mechanical and geotechnical properties. [10]. Additionally, it must however be pointed out that the most commonly occurring clay minerals are kaolinite, illite and montmorillonite, plus allophane and halloysite, which occur in active volcanic terrains and these minerals are not predominantly equidimensional, however, they may occur basically in flat plated, warped plated, tubular and in chain forms, giving the required characteristic properties of clays [11].

Essentially, there is a need to be aware that, in terms of applications, no other known earth material has so wide an importance or such extensive applications or uses as clays do. Clays and laterites commonly used in the manufacture of pottery and bricks must be made of fine grains and equally be sufficiently plastic to be molded when wet, and in addition, they must retain their shape when dried and sinter together to form a hard, coherent mass without losing their original shape when heated to a sufficient temperature [12]. On the strength of available extant evidence in terms of engineering significance, clay soil may cause regrettable damage to constructed structures in which it is used to form their foundation because of its inherent potential to react proportionately to changes in moisture regime and temperature [13, 14]. Equally worth mentioning is the fact that the uplift or elevated pressure due to a change in volume of clay often leads to structural foundation failure, with a resultant damage to the upper floors of a constructed building [13, 14].

Meanwhile, considering the fluctuating properties of clays, it is always essential for the characteristic properties of particular clay and laterite soils to be identified accurately before their utilization for any construction activities [13, 14], and that is therefore the primary focus of this study. Despite the extensive applications of laterites and clays, the abundant nature of the resources in Otukpo Local Government in Benue State, Nigeria, and the fact that the materials have been in used for long in the area, there is hardly any available reports in the literature on the suitability of properties of Otukpo laterites and clays for utilization for bricks production, except that very recently, Idongesit *et al*. [4], have reported the assessment of the mineralogical and elemental compositions of the clays of Otukpo, Benue State, Nigeria as potential raw materials for manufacturing of bricks, refractories and geopolymers. Therefore, this work was conducted to investigate the properties of lateritic and clay soils from three different sites in Otukpo Local Government Area of Benue State, Nigeria as potential raw materials for effective utilization for production of bricks, cements, and other building and construction materials and the findings achieved in the course of this study will be detailed below and we hope that the results of this investigation will also provide a valuable source of information about the laterite and clay resources of Otukpo for their effective utilization for value chain development for national and international recognition and utilization as good and efficient raw materials for production of bricks, cements, and other building and construction materials.

2. MATERIALS AND METHODS

2.1 Sample Collection

The 5.0 kg examples of lateritic soils and clay soils, respectively, were separately taken using a hand trowel at 1.0-meter depth from three different locations in Otukpo metropolis in sterilized polyethene bags and were transported to the point of analysis (Figure 1).

(a)  (b)  (c)  (d) 

Figures 1a & b: Plates of Image of Laterites, and **c & d** are Plates of Clays Used
Sample Preparation

Up to 5.0 kg portions of each dry clay sample were sieved before they were ground using a jaw (10300TPH concrete crusher, China) and roller crushers (2PG series, 350 x 350Jpeq, Japan). The samples were then riffled to obtain representative samples by using a Jones Riffler equipment and then followed by homogenization, and thereafter, each sample was divided into three equal portions and stored for analysis [4].

2.2 Determination of Physicochemical Parameters

2.2.1 Temperature Measurement

The temperature of the clay samples was taken in situ, at the point of collection of each sample. The temperature of each clay sample was taken in degrees Celsius but was converted to Kelvin using the relationship: $T\,^{o}C = (273 + T\,^{o}C)\,K$ [4] ……………………… (Equ. 1)

2.2.2 pH Tests

In each case, 100 g of the laterite and clay samples was dissolved in distilled de-ionized water, and the resulting solution was first tested with litmus papers and then with a Digital pH meter (Lab Tech Model, USA), at a standard temperature of 298 K [4].

2.2.3 Electrical Conductivity Measurement

A sensitive electrical conductivity measuring meter, DDS meter (DDS 307), with the instrumental degree of accuracy of 0.001 and measuring range of 0.000$\mu S/cm$ to 199.90 $\mu S/c$m, was used to measure the electrical conductivity of the laterite and clay samples [4].

2.2.4 Particle Size Measurement

In each case, the laterite and clay particle sizes were determined using the sieve analysis method. Each of the laterite and clay samples was freed from debris, and stones were sieved using a mesh of known hole size between 0.02 - 70 µm, as reported in Idongesit *et al*. [4]. Hydrometer analysis was further employed to confirm the results obtained.

2.2.5 Thermal Properties Tests

Again, in each case, 100 g of homogenized composite form of the laterite and clay samples were subjected to a thermogravimetric test using a muffle electric furnace. Each sample was heated in the muffle electric furnace (SX-5-12; PC:22070222/2000 °C), and the weight loss behaviour of each sample was carefully monitored at various temperatures [4].

2.2.6 Specific Gravity Measurement

The measurement specific gravity of the samples was performed using a relative density glass bottle (50 ml/20 °C) to determine the ratio of the density of each sample compared to the density of pure water (ρl = 1000 kg/m^3), and the results were further confirmed using Archimedes' principle methodology [4].

2.2.7 Hardness Tests

Hardness tests were performed using indentation tests, and the results were further confirmed using scratch tests (Mohs) as described in [15, 16].

2.3 Mineralogical and Chemical Analysis

The XRF analysis was done with 100 g of fine powder of laterite and clay samples, respectively, where each sample was mixed with a binding aid and pressed to produce homogeneous sample pellets, and thereafter the samples were subjected to XRF analysis using a Thermo Fisher Scientific Machine (Ma 01876, USA; XL3-98293) model. Also, in each case, 100g of powdered laterite and clay samples were analyzed for structural arrangement of particles in the clay using Scanning Electron Microscope (Thermo Fisher Scientific, SEM, XL3-98293, USA) and for optical mineralogical properties [4, 17].

2.4 Analysis of Geotechnical Properties

2.4.1 Determination of Resistivity

The values of resistivity, as the ratio of resistance and cross-sectional area to the length of a material or resistivity (ρ), are often calculated as the product of resistance (R) and the cross-sectional area (A) divided by the length (l) of the material ($\rho = RA/l$). In this work, the resistivity of the samples was calculated as resistivity (ρ) = $1/\sigma$, where σ stands for the conductivity of the samples [1].

2.4.2 Determination of Activity

Activity used as an index property to determine the swelling potential of soils was determined using this relationship: A = PI/C, where PI = Plasticity Index and C = % of laterite or clay–size fraction, by weight [15].

2.4.3 Determination of Activity of the Laterites and Clays

The activity (A) of the soil samples was obtained by dividing the plasticity index (PI) by the percent of clay-sized particles (less than 2 µm) present [15, 16].

2.4.4 Determination of Dry Unit Weight

Dry unit weights of the samples were determined using the formula as described by [15, 16]

Dry unit weight, γ_d (kN/m^3) = $\frac{\text{Weight of dry soil}}{\text{Volume of soil}}$; ....(Equ. 2)

2.4.5 Determination of Bulk and Wet Density

This formula was used: Bulk or wet density ρ_b (Mg/m^3) = $\frac{\text{Mass of wet soil}}{\text{Total volume of soil}}$; ...... (Equ. 3) [15].

2.4.6 Shear Strength Tests

Both in-situ and laboratory testing were performed to determine the shear strength of the samples. While the cone penetration test (CPT) technique was adopted for in-situ tests, direct shear box tests were employed for laboratory tests as described by [15, 16].

2.4.7 Plastic Limit (PL) Tests

The brittle or plastic behaviour of the samples was tested using the method described in [15], and a 3.0 mm diameter rod was used to gauge the thickness of the thread during the test, and the plastic limit test was defined by the ASTM standard test method [15, 16]

2.4.8 The Liquid Limit Tests

The test method for measuring the liquid limit used in this work was the fall cone test where the measurements were based on the penetration into the soil of a standardized cone of specific mass instead of Casagrande method because the results of the method are often considered to be a more consistent as the method often minimizes the possibility of human variations of results [15, 16]

2.4.9 Shrinkage Limit Tests

The tests to determine the shrinkage limit (SL) of the laterite and clay samples were performed to determine the water content at which further loss of moisture will not result in any more volume reduction in each of the samples, as described by [15, 16].

2.4.10 Determination of Moisture Content (%)

This formula was used: Moisture content w (%) = $\frac{\text{Mass of water in soil}}{\text{Mass of dry soil}}$ x 100; ....(Equ. 4) [16].

2.4.11 Determination of Liquidity Index

The liquidity index (LI) is often used for scaling the natural water content of a soil sample to the limits. In this work, it was calculated as a ratio of the difference between natural water content, plastic limit, and plasticity index: LI = (W-PL)/(LL-PL); where W is the natural water content [15, 16], PL is the plastic limit, and LL is the liquid limit.

2.4.12 Measurement of Unconfined Compressive Strength (UCS)

Unconfined compressive strength (UCS) measurements were made using an electronic servocontrolled MTS stiff testing machine with a capacity of 220 kips [15, 16]. The values were measured following the procedures given in ASTM D2938, with the length-to-diameter ratio of 2, by using NX-size core samples, and three UCS determinations were used to achieve statistical significance of the results [15, 16].

3. RESULTS AND DISCUSSION

3.1 Physicochemical Characteristics of Laterites and Clays

Table 1: Mean of Physicochemical Properties of Laterite and Clays

Property	Laterite	Clay
Temperature (^oC)	49.6±0.010	55.0±0.001
Conductivity (mS/cm)	2.15 x 10^2 ± 0.01	2.13 x 10^2±0.01
Pore volume (mL g^{-1})	0.34±0.001	0.32± 0.001
Specific surface area (m2/g ^{1})	150.9±0.002	158.20±0.005
pH	6.68±0.010	6.15±0.002
Particle size (mm)	1.66±0.001	0.006±0.001
Hardness (Mohr)	2.54±0.001	2.61±0.001
Specific gravity	2.87±0.005	3.80±0.002
Refractive index	0.99±0.001	1.55±0.001
Colour	Reddish brown	Grey

Idongesit *et al.* [4] and [17]

The results of the physico-chemical properties of the laterites and clays (Table 1) show that the laterites have moderately high conductivity, small pore volumes of 0.34±0.001, and high specific surface area 150.9±0.002. Comparatively, the clays have a higher specific surface area of 158.20±0.005, specific gravity of 3.80±0.002, refractive index of 1.55±0.001, and hardness of 2.61±0.001, than the laterites, but possess a lower pH of 6.15±0.002, particle size of 1.60±0.001, and pore volume 0.32± 0.001. In general, it is crystal clear and necessary to understand, in first instance that both the laterites pH (6.68±0.010) and the clays are slightly acidic (pH = 6.15±0.002), and the results are somewhat higher than the result of 5.59 achieved by [18] and 4.86, reported by [19], but lower than 6.7 reported in [20]. The specific gravity of 2.87±0.005 for laterites and 3.80±0.002 for clays obtained in this study is also higher than the previously reported value of 2.74 by [18], 2.75 by [19], and 2.61 acquired by [20] for laterites. The relatively higher specific gravity (2.87/3.80) obtained in this work may be attributed to low organic content and high percentage of fine particles (Figure 2a & b) of the soils used in the current study. Nevertheless, the pH and the specific gravity values obtained in the current study for both laterites and clays (6.68/6.15) and (2.87/3.80) are in the range of previously obtained results elsewhere for lateritic soils [18] and for clays [16].

3.2 Mineralogical/Chemical and Elemental Characteristics

Mineralogical and elemental compositions of lateritic soils and clays determine the type of clay minerals present in their soil disposal, and in addition to their geotechnical/mechanical properties. The results of mineralogical and elemental composition of the investigated laterite and clay soils are shown in Tables 2 and 3, respectively.

Table 2: Mineralogical Composition of Laterite and Clay

Mineral Composition	Percentage Composition (%)	
	Laterite	**Clay**
Al_2O_3	26.95	19.74
SiO_2	9.29	9.72
Fe_2O_3	7.49	6.39
MgO	3.06	2.02
CaO	2.79	2.80
TiO_2	2.35	1.12
$CaCO_3$	2.11	---
K_2O	1.61	0.201
Na_2O	0.169	0.067
LOI	5.99	14.62

LOI: Loss of Ignition During Heating at the Temperature of 1000 °C [4, 17]

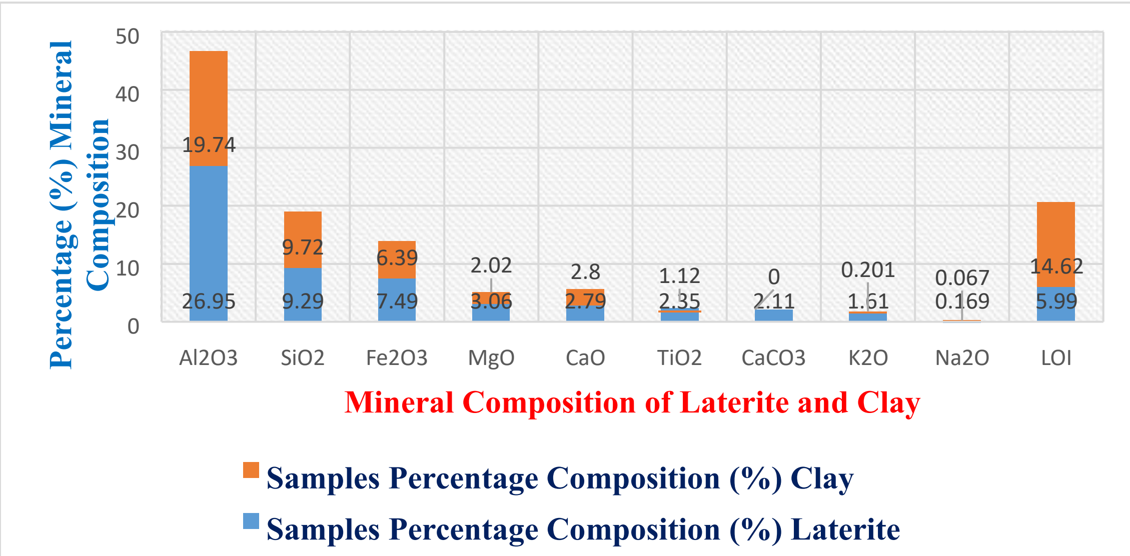


Figure 2: Chart of Percentage Mineral Compositions of Laterite and Clay Samples

The results of the mineralogical and elemental compositions of the laterites and clays investigated (Table 2) showed that the laterite contains approximately 1:3 silica-alumina ratio (SiO_2: Al_2O_3 = 1:3) and therefore it is high alumina-based laterite that is composed of kaolinite and illite minerals and the results obtained in this study are close to the results reported by [4, 21], while the clays also have high alumina to silica ratio of 2:1, hence, the clays are high kaolinite since high kaolinite clays have been reported to have alumina-to-silica ratio of 1:1 [4, 22, 23], and it contains also illite and may also contains small amount of montmorillonite which determines the swelling and the shrinkage of clays [4, 22]. The laterites and clays are enriched with major minerals such as alumina (Al_2O_3), silica (SiO_2), hematite (Fe_2O_3), magnesia (MgO), lime (CaO), and titania (TiO_2) with their percentage compositions as shown in Figure 2. The presence of calcium carbonate ($CaCO_3$) accounts for the major mineralogical difference between the laterites and the clays. Additionally, the specific surface area in the range of (5-20 m^2/g) is often attributed to kaolinite and (80-120 m^2/g) is for illite and the specific surface area of the studied laterite is (150.9±0.002) and that of clay is (158.20±0.005), it can be urged that the laterites and clays are rich in kaolinite and illite minerals (5-120 m^2/g) with small montmorillonite mineral. Interestingly, the results of mineralogical compositions obtained in this study are consistent with previously researched work reported by [4, 21, 22, 23].

Table 3: Elemental Composition of Laterite and Clay Samples

Elemental Composition	**Laterite**		**Clay**	
	% composition	**± Error**	**% Composition**	± Error
Al	14.62	± 0.089	----	----
Bal	81.246	± 0.002	95.719	± 0.023
Fe	8.932	±0.236	2.468	±0.055
Ti	0.174	±0.010	0.588	±0.012
Ca	0.060	±0.007	0.169	±0.008
Zr	0.059	±0.002	0.021	±0.001
Nb	0.004	±0.001	0.004	±0.001
Sr	0.003	±0.001	0.011	±0.001
Mo	0.001	±0.001	-----	-----
K	0.001	±0.001	0.973	±0.020
Na	0.001	±0.001	---	----
Cr	----	----	0.013	±0.001
V	----	----	0.015	±0.001
Rb	----	----	0.008	±0.001
Bi	----	----	0.010	±0.005

Idongesit et al. [4] and [17]

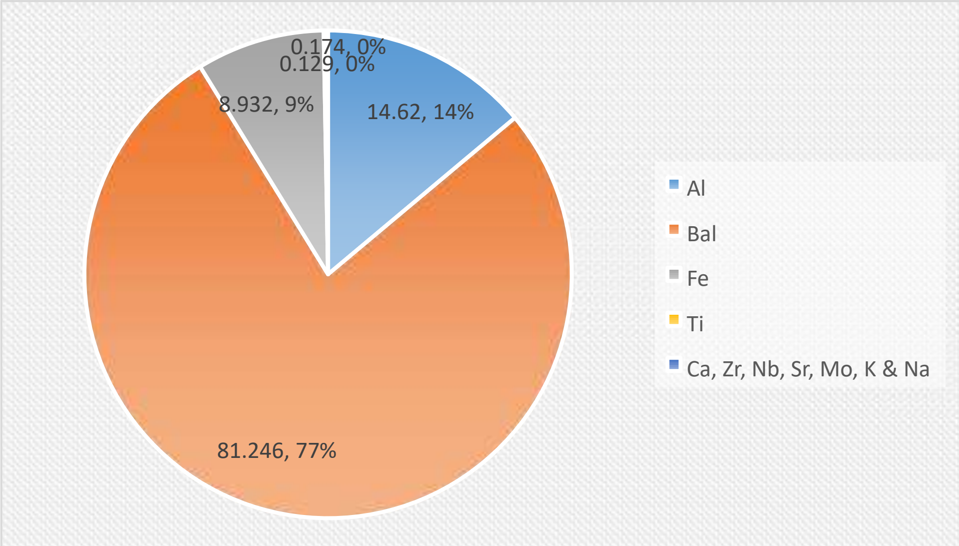


Figure 3: Chart of Percentage Elemental Composition of Laterite Samples

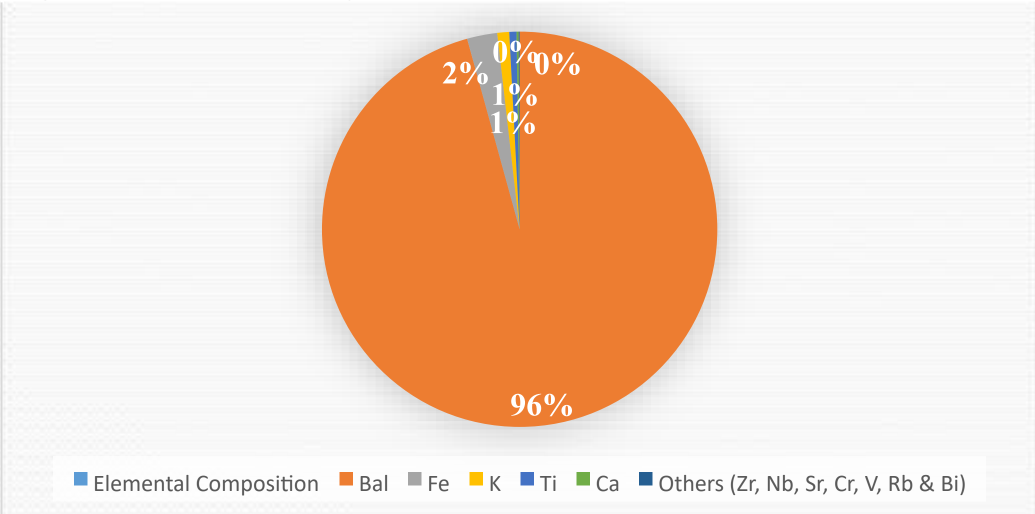


Figure 4: Chart of Percentage Elemental Composition of Clay Sample.

The XRF results (Table 3) show that the laterites and the clays of Otukpo in zone C of Benue State, Nigeria, used in this study contain significant percentages (81.246 %) and (95.719 %) of boron aluminide (Bal) as further presented in Figures 3 and 4 respectively. This alloy has no known historical report in the literature of its natural occurrence in mineral resources. However, the presence of Bal in the laterites and clays seems to add value to the samples as boron aluminide is an alloy of high demand in the aerospace industry. Meanwhile, further studies are required for the extraction of the alloy. In addition, the laterites also contain a significant amount of aluminum and iron. In contrast, the absence of aluminum in the clays may be attributed to the high percentage of Bal due to the bonding between aluminum and boron to form the alloy. Typically, the laterites and clays contain the prerequisite elements, Al, Fe, Ti, Ca, K, Zr, etc., and the results obtained are consistent with the results reported by [4, 16, 20, 21, 22]. Generally speaking, the presence of the elements makes the laterites and the clays suitable raw materials for the production of bricks and other building materials, as reported by [4].

Property	Laterite	Clay
Liquidity limits (W_L in %)	38.97±0.001	59.70±0.005
Plasticity limits (Wp in %)	20.44±0.02	29.93±0.010
Uniformity coefficient (Cu)	2.55±0.001	2.58±0.001
Coefficient of curvature (Cc)	4.375±0.005	4.570 ±0.01
Consistency	1.79±0.002	1.59±0.001
Plasticity indices (PI in %)	25.32±0.010	36.85±0.002

Hydraulic conductivity m/s	1.0×10^{-9}±0.01	1.0×10^{-8}±0.01
Sand equivalent (ES in %)	15.03±0.001	17.15±0.001
Moisture content (%)	29.60±0.002	50.60±0.001
Maximum dry density	1.41±0.001	3.02±0.002
Bulk density (g/cm^3)	1.10±0.005	1.80±0.001
Shear strength (KN/m^2)	24.89±0.001	29.95±0.01
Shrinkage Index	9.65±0.002	20.10±0.001
Dry unit weights (kg/cm^2)	1.32±0.001	1.59±0.005
Clay content %	28.90±0.05	68±0.002
Activity	0.98	1.09
Unconfined compressive strength (kPa)	249.80	78.90

The results of geotechnical properties of the laterites and clays (Table 4) show that the clay samples have high liquidity limit of 59.70±0.005, while the laterites (38.97±0.001) have medium and that is in agreement with the reports of Murali et al. [24], which reported that soils with high liquid content falls within the range of 40-60 % (W_L), and 30-40 % for medium. Also, the laterite samples have a medium plasticity limit of 20.44±0.02, while the clays have a high plasticity limit that falls within 20 -55 %, in agreement with the results reported by [24]. Furthermore, the shrinkage index of the laterites (9.651±0.002) is low, indicating a low degree of expansion (< 15), while that of the clay is 20.10±0.00, indicating also a medium degree of expansion in line with the (15-30) medium range reported by [24]. The results in Table 4 also showed that the moisture content of the laterites is 29.60 %, which is slightly higher than the 28 % reported by [18], 16-25 % reported in [25] and 10.1-20.6 % reported in [26], while that of the clay is 50.60 % and is higher than 16.9-33 % reported by [25]. Additionally, the plasticity indices of the laterites (25.32 %) are within the range of 13.5-26.5, reported by [27], and 8-24.1 % in [25], and that of the clays (36.85 %) is within the range of (23-45 %) reported in [27]. Furthermore, the unconfined compressive strength of the laterites (249.80 kPa) obtained is within the range of 71-375 reported by [26], and that of the clays (78.90 %), which is higher than 71.5 kPa reported in [28], and lower than 41.70 kPa reported in [29].

Meanwhile, from most research reports, the compressive strength of laterites or clays decreases as the plasticity index increases, and high plastic laterite and clay soils have stronger binding pressures, which may lead to an increase in the soil's shear strength [27, 29]. Also, it has been recognized that laterites and clays with high calcium carbonate content ($CaCO_3$) have lower plasticity indices and significantly higher shear strengths. That accounts for why the laterites used in this study had more unconfined compressive strength than the clays. For applications of laterites and clays, the determination of shear strength is often very critical to ensure that the produced structures of intention, like bricks, are secured against shear failure and excessive settlement [21]. The result also shows that the laterites have an activity of 0.98, while the clays have 1.09, which is higher than 0.5 reported for kaolinite clays by [27]. The laterites and clays used in this study are normal in terms of their activity rating (i.e., 0.75 -1.25, range for normal) [18, 24, 28], assuming that in each case, the plasticity index is approximately equal to the laterite or clay fraction (A = 1).

Table 5: Thermal Properties of Laterite and Clay Samples

Property	Laterite	Clay
Melting temperature (^oC)	55- 630	40-660
Thermal conductivity (kgms$^{-2}\Theta^{-1}$)	34.98	107.8
Resistivity (Ωm)	0.0358	0.0186
Thermal Temperature Range	49.6- 840 °C	55- 1320

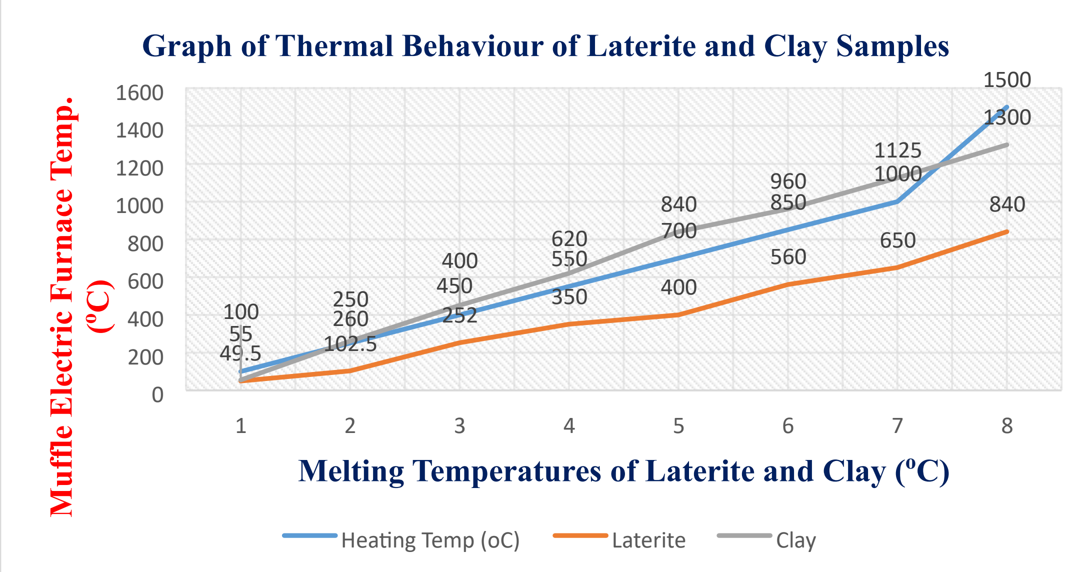
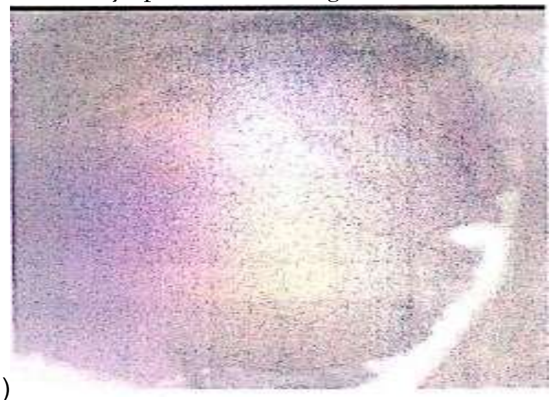


Figure 5: Graph of Thermogravimetric Analysis of Laterite and Clay Showing Their Thermal Behaviour

The results of electrical and thermal conductivity obtained (Table 5) revealed that the laterite soils have very low thermal conductivity of 3.498 x 10^1 kgms^{-2}ϴ$^{-1}$ and resistivity of 3.58 x 10 ^{2} Ωm, while 1.078 x 10^2 kgms^{-2}ϴ$^{-1}$ and 1.86 x 10 ^{2} Ωm were obtained for the clay samples. The resistivity values obtained in this study were much lower than the 340-5,500 reported by Mari [30]. Nevertheless, the low resistivity recorded in the present work could be attributed to the high temperatures of the laterites (49.6±0.010 ^{o}C) and clays (55.0±0.010 ^{o}C), since severe increases in resistivity often occur as the soil temperature decreases and past even the freezing point, or resistivity of soil samples often decreases with increase in the soil temperature [29]. However, the thermal conductivities according to Table 5 reveal that the laterite samples have the lowest thermal conductivity, while the clay samples have the highest as shown in Figure 5. In general, the low conductivity values obtained in our results indicate that both the laterites and the clays will be good heat-insulating materials for housing projects because of their low thermal conductivity, while the clay materials may conduct heat at a higher rate; however, their absorbent power may take a longer period to reach the steady state [1].

3.3 Microstructural and Optical Characterization

In addition to the mineralogical and elemental compositions, the microstructure of laterites and clays influences their geotechnical properties. Thus, the results of the scanning electron microscopic (SEM) analysis carried out to verify the microstructure of the samples showed that in both the laterite and clay soil, the particles are grain-like [19], and packed in wedge-like inter-aggregate pores. The soil particles' grains are connected face to face, edge to edge, and face to edge shapes with each other, as seen in Figure 6a & b [18]. Hence, the obtained microstructure can be considered matrix microstructure, in which the particles are connected irregularly to each other and the aggregation of the soil particles forms a rough surface, resulting in a well-interlocking arrangement between soil aggregates. The obtained microstructure results in this work are consistent with previously researched reports [4, 18, 23].


(a)


(b)

Figures 6a: The Result of SEM Image of Laterite [17] and (b) The Result of SEM Image of Clay Adapted from [4] (10k magnification): Thermo Fisher Scientific, MA 01876 USA.

4. CONCLUSION

The studies were conducted on the various properties of the studied laterites and clays based on the new features of instrumental research methodologies and statistical calculations. The results of this study showed that both the laterites and clays contain kaolinite ($Al_2Si_2O_5(OH)_4$) mineral, alumina (Al_2O_3), silica (SiO_2), hematite (Fe_2O_3), magnesia (MgO), lime (CaO) and titania (TiO_2) among other minerals and elements, Al, Fe, Ti, Ca, K, Zr, etc. with good geotechnical properties. Since it has been repeated averred that the geotechnical/mechanical and thermal characteristics of laterite and clay soils varied considerably with climate, parent rock and formation process and the raw materials also possess inherent limitations [3, 24, 27], it is often expedient to verify and validate whether laterites and clays have the inherent prerequisite minerals, chemicals and properties like high thermal strength that would make them able to withstand stresses, pressures, high and low temperatures (temperature fluctuation) that they will be exposed to from the materials that they are intended to be used for. Because, early detection of inherent weaknesses of lateritic and clayey soils can be adequately addressed through supplementary provisions and limiting of their uses to what they are suitable for and based on that the determination of inherent properties of laterites and clays such as the shear strength has been a priority issue for engineers and mathematicians for more than 250 years as pressure due to volume change often experienced by soils especially clay can cause serious damage to concrete foundation, or failure and floor slabs as well as the rooms and upper building above them [24]. Therefore, it is usually essential to identify the characteristics of the soils before they are used for any construction activities to be carried out [23]. Overall, we have found experimentally through their properties that the laterites and clays have low thermal conductivity, high resistivity, good shear and compressive strength, high plasticity with moderate water content, high porosity, good shrinkage index, among other properties, and therefore, they have medium expansion and cracking potential in addition to their sufficient prerequisite mineral and elemental compositions. Hence, they are suitable raw materials for making cold and fired bricks, geopolymers, ceramics, and even tiles. We therefore call on the Federal Government of Nigeria, Benue State Government, Otukpo Local Government, industries, individual manufacturers and foreign investors to take advantage of this information to explore the possible maximum exploitation of the natural abundance laterite and clay raw materials of the area for economic benefit of Nigeria by joining countries like USA and become one of the exporters of laterites and clays for production of adsorbent, fillers, drain and roofing tiles, ceramics, organic pet litters, polymers, silica gel, sewer pipe etc.

CONFLICT OF INTERESTS

The authors declare no conflict of interests.

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