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Characterization of Asaba Clay for Production of Porcelain Insulator

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Abstract: The study highlights the potential of Asaba clay for producing high-quality ceramic wares by examining the physicochemical characteristics of clay mineral using advanced analytical techniques such as X-ray fluorescence (XRF), X-ray diffraction (XRD), scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), and atomic absorption spectrophotometry (AAS). Results obtained reveal that the sample was kaolinite with SiO_2 (43.63%), Al_2O_3 (16.65%), and Fe_2O_3 (4.87%) as the most predominant elements. The identified minerals include Quartz (SiO_2), Orthoclase ($KAlSi_2O_3$), Kaolinite (Al_2O_3•$2SiO_2$•$2H_2O$), and Albite ($NaAlSi_2O_3$). Wavenumbers ranges from 3697.51913 - 685.83016, while the high intensities of the hydroxyl-related peaks at 3421.70 cm^{-1}, 3622.97 cm^{-1}, and 3697.52 cm^{-1} suggest that Asaba clay has properties similar to kaolinitic. Elemental composition indicates that the elements (Co, Cr, Cu, Fe, Mn, Ni, Pb, Cd, Zn and Ca) are in acceptable concentration levels. The study therefore revealed that the clay from Asaba has kaolinite characteristics, is environmentally safe and is therefore suitable for porcelain insulator production.

Keywords: Asaba Clay, SEM, XRD, XRF, Porcelain Insulator.

I. Introduction

Clay is one of the most ancient mineral substances used by mankind. It is a widely dispersed, plentiful mineral resource with substantial industrial significance for a wide range of applications. It is one of the most important minerals in the world, both in terms of value and annual production. The term Clay can be described as a naturally occurring material composed of layered structures of fine-grained minerals which exhibit the property of plasticity at appropriate water content but becomes permanently hard when fired (Ombaka, 2016). Clay is used in many modern industrial processes, such as paper making, cement production, and chemical filtering. Majority of the world's population live or work in buildings made with clay, often baked into brick, as an essential part of its load-bearing structure. Clay minerals are natural materials mainly composed of hydrated aluminium silicates, generally referred to as phyllosilicates with particle size of less than 2 µm (Di, Chun-Hui, Chun-Xiang, Dong-Shen and Wei-Hua, 2010). They have varying chemical composition depending on both the physical and chemical changes in the environment where clay deposits are found (Salawudeen, *et al*., 2010). The nature of clay and its composition determines, not only its quality and commercial value but also, to a large extent, its engineering behaviour (Onyeobi *et al*., 2013). Among the characteristics of clays that influence their industrial performance are clay mineral composition, physical properties such as particle size distribution, porosity, structure and geologic history (Barry, *et al.*, 2022). Natural clay minerals contain impurities and are not homogenous, which cause their use to be difficult for technological applications (Di, *et al*., *2010*). Therefore, in order to improve their properties, it is necessary to prepare mixtures (Azzouz, *et al.*, 2011*;* Olasupo and Omotoyinbo, 2009) or to enhance them with the use of additives (Kocserha and Gömze, 2010).

Porcelain insulators are high quality products with excellent technical properties, and are being commercialized worldwide. Ceramics have a huge range of applications in modern society and it is expected that the demand for ceramics will be more highly increased in the near future. It is hoped that exploiting the available underutilized ceramic resources in the country for the purpose of producing insulators and refractories such as porcelain electrical insulators and crucibles would reduce the cost spent on the importation of foreign-made ones into the country, encourage the development of local industries that would replicate its production in mass and provide job for the teeming unemployed Nigerian youths, thereby sustaining the economy.

It is in this light therefore that this research is channeled towards characterization of Asaba clay for the production of electrical porcelain insulator.

II. Methodolgy

a. Sample collection and preparation

The clay sample used in this study was firstly excavated from its deposit which was crushed and then deleterious materials removed followed by sun drying for one day, ground and then soaked in water for three days to slake. The sample was mixed with water and sieved. The filtrate was allowed to settle and decanted after two days. The remaining material was dried and milled into powdered form, thereafter, sieved to a uniform particle size of 0.425mm.

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b. Characterization of the clay sample

The sample was analyzed using Atomic Absorption spectrophotometer (AAS) (Buck Scientific Model 210 VGP, Made in the United States of America)., Fourier Transform Infra-Red spectrophotometer (FTIR) with model (Cary 3500 by Agilent Technologies Inc USA)., scanning electron microscope, SEM model 840.A11, X-ray fluorescence with a Magi X-pro model XRF spectrometer, Made in China. and X-ray diffraction with PANalytical X'Pert Pro powder diffractometer as well as physical production of sample.

c. Production methods of the Porcelain Insulators

The local porcelain insulators were produced through various stages which include;

i. The compounding of the body
ii. Deflloculation and slip casting
iii. Atmospheric and electrical drying
iv. Firing

i. Compounding of the body for production of porcelain insulator

The weighed materials were poured in a basin and mixed with water with continuous stirring of the mixture with an electric stirrer to ensure homogeneity. Then, the mixture was poured on a Plaster of Paris slab mould to absorb the excess water leaving the body in a plastic stage.

ii. Deflloculation of the slip for casting

The plastic clay body was wedged and weighed in a weighing balance to know the weight of the material. The mixed body was dissolved with a little water and sodium silicate (Na_2SiO_2) which is a deflloculant, was added to it to reduce the power of suspension, making the body to flow. After, adding the sodium silicate, the mixed body was stirred continuously with electric stirrer until a slip was formed.

iii. Slip casting

The porcelain insulator plaster of Paris mould was bound with a rubber band and the slip was stirred with an electrical stirrer so as to make the materials in the slip to be in a uniform state. Later, the slip was poured into the mould. The slip in the mould was kept topped, as it reduces when the plaster of Paris mould absorbs water from the slip. After about 4 hours, the article produced was removed from the mould.

iv. **Atmospheric drying of the electrical porcelain insulators**

The porcelain insulators formed was allowed to undergo atmospheric drying i.e. to remove the water content which the mould could not absorb. This process took as much as seven days. The insulators are then parked in an electrical dryer and set to a temperature of about 150^0C, so as to remove the moisture content that could not be absorbed by the atmosphere. This process also took up to five hours.

v. **Firing of the Porcelain Insulators**

The porcelain insulators underwent firing in the kiln. When clay bodies are fired in the kiln, they lose moisture, organic matter, sulphur and carbon (IV) oxide. When the temperature in the kiln rises, some of the clay particles fuse together, destroying the original clay structure and binding the mass together.

The porcelains were fettled to remove the outlines of the mould that appeared on them. Afterwards, they were packed into the kiln using a bath and were fired to a temperature of 800 ^OC, so as to remove the chemically combined water from the porcelain insulators and before they were glazed

III. Results And Discussion

a. Chemical composition of Asaba clay sample

The results of the chemical composition tests showing the main components of the clay sample are as shown in Table 1

Table 1: XRF Analysis of Asaba clay

Mineral	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**MgO**	**TiO_2**	**K_2O**	**SrO**	**Sb_2O_3**	**BaO**
Concentration	43.63	16.65	4.87	2.1	1.03	1.58	0.69	0.53	0.53

The chemical composition of Asaba clay, as revealed by X-ray fluorescence (XRF) analysis, shows that the primary constituents are SiO_2 (43.63%), Al_2O_3 (16.65%), and Fe_2O_3 (4.87%), alongside smaller amounts of MgO, TiO_2, K_2O, SrO**,** Sb_2O_3, and BaO**.**

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The SiO_2 content is a key indicator of clay's suitability for ceramic applications, contributing to the material's strength and thermal stability. Asaba clay contains 43.63% SiO_2, which is slightly lower than the values reported for other Nigerian clays such as Ikorodu clay, which contains approximately 48.6% SiO_2, and Ifon clay, which has around 51.2% SiO_2 (Ijalana and Aderemi, 2014; Ogbebor and Dada, 2020). This low value of SiO_2 could be attributed to the nature and composition of the soil of Asaba. Although the SiO_2 content in Asaba clay is lower, it remains within acceptable limits for ceramic production.

The Al_2O_3 content in Asaba clay is 16.65%, which plays a critical role in improving the clay's refractory properties, mechanical strength, and resistance to thermal shock. This value is comparable to that found in Ukpor clay (Chukwudi et al., 2014), which has 17.2% Al_2O_3, and is only slightly lower than the typical range for high-quality ceramic clays such as China clay, which contains 18-20% Al_2O_3 (Chukwudi et al., 2014). Given these similarities, Asaba clay's Al_2O_3 content supports its potential use in producing heat-resistant ceramic products such as crucibles and porcelain insulators.

The Fe_2O_3 content in Asaba clay is relatively high at 4.87%, which could impact the color and strength of the ceramics. While the MgO content in Asaba clay is lower than in some commercial ceramic clays, which range between 3-5%, it is still adequate to contribute positively to the thermal shock resistance and durability of the final product (Bamg boye et al., 2019). Additionally, the TiO_2 content, at 1.03%, is in line with typical values found in other clays, such as Igbokoda clay, which contains around 1.2% TiO_2 (Chukwudi et al., 2014). This level of TiO_2 will help improve the opacity and brightness of the ceramics, supporting the creation of durable, visually appealing products. The K_2O content of Asaba clay is 1.58%, which serves as a fluxing agent, lowering the melting point during firing and aiding in the bonding of clay particles. This concentration is comparable to that found in many high-quality ceramic clays, where the K_2O typically ranges from 1.5% to 2.5% (Yaya et al., 2019). The minor constituents such as SrO (0.69%), Sb_2O_3 (0.53%), and BaO (0.53%) are present in smaller amounts. These elements could influence specific properties, such as grain structure, color, and chemical resistance, though their overall effect on the clay's performance as a ceramic material is likely minimal.

b. Elemental analysis of Asaba clay (AAS)

The elemental composition of Asaba clay as analyzed using Atomic Absorption Spectrophotometer is shown in Table 2.

Table 2: Elemental analysis of Asaba clay (AAS)

Element	**Co**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**	**Cd**	**Zn**	**Ca**
Concentration(ppm)	0.066	0.469	0.529	14.102	0.785	0.161	0.94	0.004	0.078	0.87

The trace element composition of Asaba clay, as revealed by the results, shows the presence of various elements in parts per million (ppm). Each of these elements can influence the properties of the clay, particularly in terms of its mechanical strength, durability, and potential environmental implications when used in ceramic production. The trace element composition of Asaba clay shows similarities to other Nigerian clays in terms of Cr, Co, Cu, Mn, Ni, and Zn levels, which are within typical ranges for clays used in ceramic production (Ademola and Olatunji, 2013; Yaya et al., 2019). The higher Fe content in Asaba clay is consistent with clays known to produce darker ceramics, while the low levels of Pb and Cd are reassuring for safety and environmental concerns. The presence of Ca suggests that the clay will exhibit good vitrification properties during firing, enhancing the overall quality of the ceramics produced.

c. Fourier Transform Infrared Spectroscopy Result of Asaba clay

Fourier Transform Infrared (FTIR) spectroscopy was employed to identify the functional groups present in Asaba clay based on the specific absorption peaks. The wave numbers, intensities of the observed peaks and their corresponding functional groups are presented in Table 3 and provide insights into the clay's molecular structure and potential behavior during the ceramic production process.

Table 3: FTIR Result of Asaba clay

Peak Number	**Wave Number (cm^{-1})**	**Intensity**	**Functional Group**
1	3697.51913	86.81736	O-H
2	3622.97238	84.17324	O-H
3	3421.69613	89.7971	O-H
4	1632.57397	93.42346	H-O-H
5	998.92654	26.18758	Si-O
6	909.47043	36.18951	Fe-O
7	775.28627	62.71166	Al-O
8	685.83016	59.47613	Si-O-Si

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The FTIR results of Asaba clay are consistent with those of other clays used in ceramic production. Similar peaks for Si-O and Al-O vibrations have been reported in studies of clays from other regions, indicating the presence of quartz and alumina as major constituents (Ademola and Olatunji, 2013; Chukwudi et al., 2014). The high intensities of the hydroxyl-related peaks at 3421.70 cm^{-1}, 3622.97 cm^{-1}, and 3697.52 cm^{-1} suggest that Asaba clay has properties similar to kaolinitic clays, which are commonly used in ceramic production for their workability and plasticity.

d. Scanning Electron Microscopy Analysis of Asaba clay at varying magnifications

SEM is used to the show the surface morphology and particle size of the clay. The scanning electron microscope result of the clay is shown in figure 1.

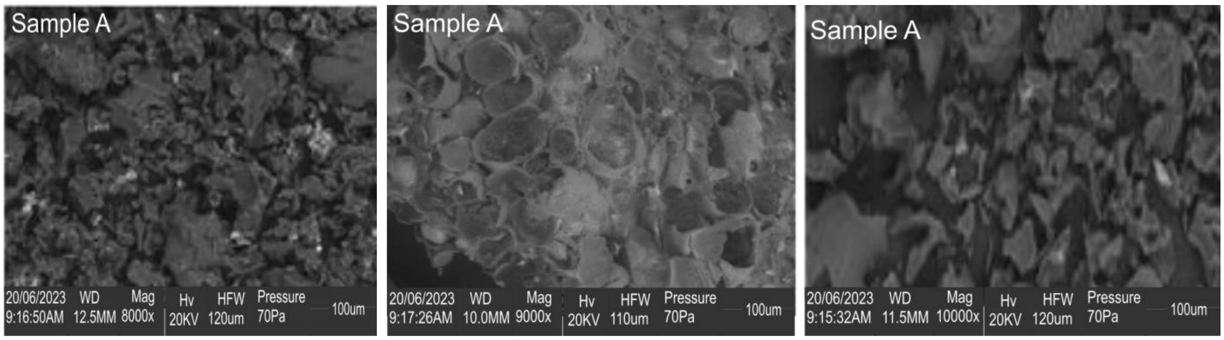

Figure 1: Particle size distribution (SEM) of Asaba clay at 8000x, 9000x and 10,000x magnifications respectively

At 8000x magnification, the SEM image reveals a fairly uniform particle distribution with irregularly shaped particles. The clay particles appear to be aggregated, which is typical for kaolinitic clays. The average particle size is in the range of 1-3 µm, with a few larger agglomerates observed. These small particle sizes are advantageous in ceramic production because finer particles enhance the plasticity and workability of the clay, making it easier to mould and shape during the production of ceramic wares (Adefila & El-Yakub, 2018).

At 9000x magnification, the particles are more defined, and individual grain boundaries become more apparent. The particle size remains in the same general range of 1-3 µm, but the presence of some more distinct flakes and elongated particles is evident. These flake-like structures are indicative of kaolinite clay minerals, which are known for their platy morphology. The SEM image also shows increased agglomeration compared to the 8000x magnification, suggesting strong inter-particle forces, which could contribute to the clay's plasticity (Ademola & Olatunji, 2013).

At 10,000x magnification, the image shows a more detailed view of the clay particles, with even finer grain structures visible. The particles appear well-packed, with an average size still within the 1-3 µm range, though with more pronounced porosity and roughness on the particle surfaces. The increased roughness may indicate areas for moisture retention, which would affect the drying and firing process of the clay. However, this porosity can also contribute to the high thermal shock resistance of the ceramic products derived from Asaba clay, as it allows for better stress distribution under thermal cycling (Ijalana and Aderemi, 2014).

The SEM analysis of Asaba clay shows that it possesses similar morphological characteristics to other clays used in ceramic production. Studies on kaolinitic clays from different regions also report flake-like particles with sizes in the 1-5 µm range, which is considered ideal for high-quality ceramic wares (Adefila and El-Yakub, 2018; Ademola and Olatunji, 2013). The observed particle size distribution are in line with what has been reported for clays with good thermal resistance and plasticity, suggesting that Asaba clay is suitable for similar industrial applications.

e. X-ray Diffraction Analysis Result of Asaba clay

XRD is used to the show the mineral compositions of the clay. The result of the XRD is shown in Table 5.

Table 5: Mineralogical analysis of Asaba clay

Phase Name	**Formula**	**Figure of Merit**
Quatz	SiO_2	0.705
Orthoclase	$KAlSi_3O_8$	1.596
Kaolinite	$Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$	2.964
Albite	$NaAlSi_3O_8$	2.863

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The mineralogical composition of Asaba clay shown by the identified phases along with their corresponding formulas and figures of merit (FoM) are presented in Table 4.4. The identified minerals include Quartz (SiO_2), Orthoclase ($KAlSi_2O_3$), Kaolinite (Al_2O_3•$2SiO_2$•$2H_2O$), and Albite ($NaAlSi_2O_3$). The figure of merit (FoM) values indicates the quality of the match between the observed diffraction pattern and standard reference patterns for each mineral phase.

The mineralogical composition of Asaba clay is similar to other kaolinitic clays used in the ceramic industry. Quartz, kaolinite, and feldspars (orthoclase and albite) are common minerals in clays used for the production of ceramics such as porcelain, tiles, and refractory wares. For example, studies on kaolinitic clays from the South-Eastern regions of Nigeria have also identified quartz and kaolinite as the primary phases, with feldspar minerals contributing to the material's fluxing and vitrification properties (Anuma et al., 2021; Iseoluwa & Dada, 2018).

IV. Conclusion

Clay mineral has become increasingly relevant for industrial application due to its environmentally friendly properties, low cost, and relative abundance and its deposits are ubiquitous in Asaba, Oshimili, South LGA of Delta State. In comparison to other studies, the chemical composition of Asaba clay aligns with the requirements for producing electrical porcelain insulators.

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