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ASSESSMENT OF CLAY DEPOSIT IN UZUAKOLI, ABIA STATE, NIGERIA FOR CERAMIC INDUSTRIAL APPLICATIONS

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Abstract

The use of clay minerals in industrial applications is well-documented and millions of tons are utilized yearly. Clay deposits in Nigeria are widely distributed, and understanding the properties and industrial applications of these deposits are essential for determining their profitability and suitability for different industrial purposes including the making of ceramics. This study investigated the physical, chemical and mineralogical characteristics of clay deposit in Uzuakoli community of Abia State, Nigeria, to determine its suitability for use in the ceramic industry. The materials used for this research were sourced from Uzuakoli, with two samples collected from two different areas in the clay deposit. The results of the physical analyses, such as plasticity test, linear shrinkage, apparent porosity, crushing strength, and loss on ignition, proved that the clays are suitable for use in the production of white sanitary wares, wall tiles, floor tiles, and refractory bricks. The results of the chemical analysis, using X-ray fluorescence (XRF) and X-ray diffraction (XRD) for mineralogical analysis, showed that silica is the major oxide present with content of 61.84% and 62.81% in the clay samples. Minerals kaolinite 41%; vermiculite 33%; quartz 26% were present. Kaolinitic content of 40% and 41%, and quartz content of 30% and 26% made clays suitable for refractory materials for ceramic productions. The silica-alumina composition of the clays meets the standard for ceramic applications. The Uzuakoli clays with kaolinite value of 40 and 41% meet the standard for ballclay used in ceramic productions. This study contributes to the understanding of the properties and potential applications of Uzuakoli clay which is an essential step for the exploitation of this economic mineral resource in Abia State, Nigeria.

Keywords: Industrial applications; X-ray fluorescence; X-ray diffractometer; chemical characteristics; and suitability

Introduction

Clay minerals are one of the most important industrial minerals because of the physical and chemical properties of particular clay minerals; millions of tons are utilized yearly in various applications including culture, environmental remediation and construction (Murali et al., 2018). For this reason, clay has received considerable attention especially as potential absorbents for environmental research. Many researchers around the world have beamed their search light on the phase development that occurred by sintering clay in the presence of some oxides (Awasthi et al., 2019; Khalfaoui et al., 2006; Mahesh et al., 2012).

Clays have been put into various use and in various applications especially in industries (Mahesh et al., 2012; Murali et al., 2018). The actual properties of selected clay minerals are dependent on their structure and composition and as such, the mineral composition and available phases has to be analysed before a clay sample can be put to use for a particular application (Malu et al., 2018). This calls for several examinations in order to know the particular area to apply clay and this have caused a lot of problems including the issue of discovering clay samples with the right properties for production of high quality products; and discovering the right chemical, mineralogical and physical properties for high quality ceramic products that can be applicable in other areas such as in painting, paper and medicine (Anjoran, 2011; Gaspar et al., 2022; Patrick et al., 2015). These problems necessitate this research aimed at the assessment of clay in the south eastern part of Nigeria the deposit under investigation is Uzuakoli clay.

In industrial assessment, physical properties, mineralogical and chemical composition are the parameters used in assessing the suitability on the studied clay deposit for use in various industrial specifications. X-ray techniques, qualitative and quantitative mineralogical phase analysis were frequently used for the mineralogical analysis of clay deposit that were sourced (Ademila & Adebanjo, 2017; Huff, 1990; Onyekuru et al., 2018; Salt, 1985). Chemically, most of the clays studied in several studies around Nigeria qualify as a fireclay refractory and ceramic raw materials and do not require any procedure to meet the required specifications, with the possible exception certain places like Oboro which has the lowest alumina content of 19.05% with beneficiation (Aliyu, 1995; Emefurieta et al., 1994). The mineralogical and chemical characterization of clay samples found in certain places such as Ibere, Abia state shows that they are kaolinitic and can be used as fireclay refractory raw materials for furnace and kiln lining. The chemical composition analysis showed that the clays are potential raw materials for the ceramics, paper, paints, pharmaceutical fertilizer and allied industries are beneficiated (Adeola & Olaleye, 2017; Mark, 2010).

Deposits of clay raw material are widely distributed in different parts of Nigeria (Abdulaziz et al., 2023; Iyasara et al., 2014) including around Ozuakoli, the site for this study. Large deposits of clay estimated to be 4 square kilometre is found in this area which can feed suitable ceramics industries in Nigeria for many years if found suitable, in line with the backward integration policy of the Federal Government of Nigeria (McCulloch et al., 2017; Ohimain, 2014). Also, the characterization will provide additional data on the clay materials in the South-Eastern part of the nation.

This study investigated the physico-chemical properties, clay structure, oxidized states of the element and geochemical characterization and geotechnical characterization of clay deposits found in Uzuakoli, Abia state. The mineral type of the clay was also characterized and the geochemical results were acquired and considered in line with the economic benefits in order to contribute extensively in the economic growth of Abia state through mineral resource exploitation.

Materials and Methods

The study considered the chemical, mineralogical and physical properties of clay samples obtained from Uzuakoli clay deposits in Abia State Nigeria, in South Eastern Nigeria. The materials used for this research were sourced from Uzuakoli community of Abia State, Nigeria. The area lies between Latitude, 5.633^0 and longitude 7.5667^0 and is approximately $50km^2$. The vegetation of the selected site was cleared and the overburden was removed with the use of a spade. The samples were collected by excavation using digger and spade. Two samples, A and B, were collected from different locations within the Uzuakoli deposit using systematic sampling to ensure adequate representation. The clays in the area of study are ash in colour. After the sample preparations, the methods applied for laboratory analyses of the samples were physical tests, chemical analysis using X-ray fluorescence (XRF), and mineralogical analysis using X-ray Diffraction (XRD).

Sample Preparation

The collected clay samples were air dried for four weeks and then crushed jaw crusher and ground with the edge miller machine and sieved using 30 mesh sieve. The samples were divided into two for chemical and mineralogical analyses, and physical tests. From one part of the samples, 40g each was measured out and used for the chemical and mineralogical analyses and the remaining samples were used for physical tests. The remaining sieved clay samples were then kneaded, and rolled to form small slabs, and then test pieces were produced from the slabs. The test pieces were used for linear shrinkage tests while the remaining samples were used for other physical tests which include plasticity, apparent porosity, bulk density, cold crushing strength and loss on ignition.

Physical Tests

The physical analysis of the clay samples were carried out to determine the following;

Plasticity Test: The plasticity test of the clay samples were determined by adding water to the crushed clay little by little and used to make shape rolling them on finger. The water of plasticity was determined by subtracting the initial volume (V_1) from the final volume of water (V_2) measured after drying, using the formula: $V_1 - V_2$

Linear Shrinkage Test: test pieces or bars were produced with each sample of A and B and line of 10cm were drawn on one side of the bars. The percentage total shrinkage was achieved using the formula:

$$\frac{\text{wet length - Fired length}}{\text{Wet length}} \times \frac{100}{1}$$

Apparent Porosity Test: Test bars were made from the samples. The test bars were fired in a kiln at a temperature of 1120°C. The fired samples were weighed and the weight is D. Note, when the samples were not fired they can be dried in the oven at the temperature of 105° to 110°C. After weighting the test bricks they were placed in a pot and were not allowed to touch the bottom of the pot and completely covered and were boiled for 2 hours. After boiling, were allowed to cool to room temperature and immersed in the water for 12hours before weighing. After the test bars were allowed for 12hours in the water; they were suspended with thread and weighed while in the water. The weight is S. Then the saturated weights of the test bricks were determined by bringing them out of the water and rolled on slightly moistened cotton cloth lightly to remove all drops of water from their surface. They were weigh in the air after removing the drops of water, and the weight is recorded as W.

Calculation of apparent porosity using the following formula: $\%Pa = \frac{W - D}{W - S} \times \frac{100}{1}$

Where W= Saturated weight: S = Suspended Weight
D = Dried Weight Pa = Apparent Porosity

Cold Crushing Strength: This test was carried out in the Civil Engineering Department Akanu Ibiam Federal Polytechnic Unwana using a hydraulic pressing machine. This determination was in accordance with ASTM C 133 – 97(1982).

Procedure:

For each of the clay samples, 3 bricks measuring $50mm^3$ were made using a mould. After the test cubes have been fired, their compressive strengths were tested. Each test brick was placed in turn on the compressive strength machine and load was applied axially at a uniform rate by operating the pump handle in an up and down movement until it failed that is the brick shatters. The crushing strength of each of the bricks was read off in kilonewton. Then the force was applied to crush the bricks. Before placing the bricks for crushing, the area of the faces of the bricks for application of the force were measured and multiplied by 2, for the force was applied on two faces. Area measured in mm^2. The crushing strength as pressure (P) is calculated as follows;

$$P = \frac{\text{Force (F)}}{\text{Area (A)}}$$

$$P = \frac{(F)}{(A)} N/mm^2$$

Force taken in KN is converted to Newton that is multiplying values of force measured by 1000, thus 1KN = 1000N. Values of the areas of the bricks measured were multiplied by 2. Note: Average force of the 3 bricks were taken and used.

Loss on ignition (LOI): this is a test used in organic analytical chemistry particularly in the analysis of minerals. It consists of strongly heating a sample of the material at a specific temperature allowing volatile substance to escape until its mass ceases to change.

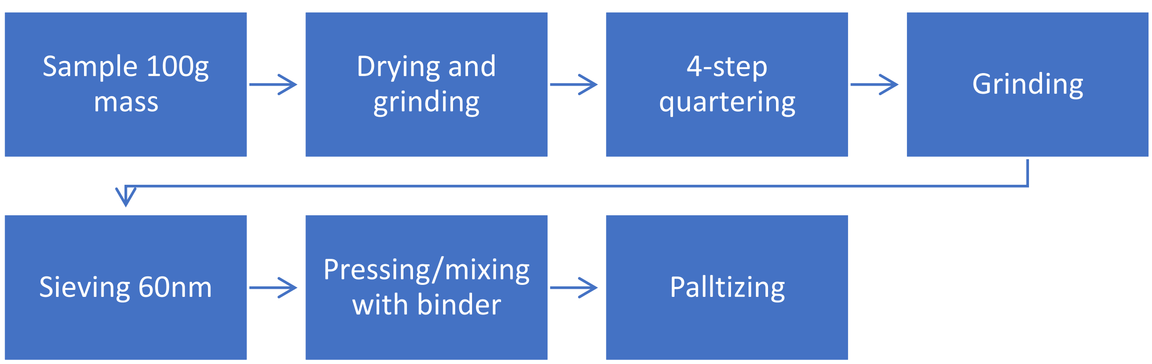
The equation is $LOI = dry\ weight - fired\ weight \times \frac{100}{1}$

Chemical Analysis

The chemical analysis was performed using X-ray fluorescence (XRF). Samples were analysed of various materials by X-ray fluorescence (XRF). XRF is often more appropriate for many geological materials where total elemental analysis is required such as rock and soils.

Procedure for XRF Analysis

Sample preparation**:** Each sample was air dried in a clean environment disaggregated and then ground sample was subdivided by quartering. Furthermore, each of the samples was ground again into finer powder in order to yield homogenous particles of each component of the heterogeneous material. Each sample was then sieved through 60nm sieve size and the retained material was re-ground again and again until there was no material retained on 60nm sieve. Sieves made of nylon and mortal with pestle made of agate were used to avoid contamination. The procedure for preparing the clay for XRF analysis is stated below.



Mineralogical Analysis

Procedure for determination of mineralogical composition of the rock sample using X-Ray Diffraction (XRD) was done with Schimadzu 6000 Model

Pulverization of Rock Sample: The samples were dried in the oven at 60^0c for 30 minutes to remove the moisture contents if any. The sample were broken into pieces using various equipment including: V12: I – diamond cutting machine, 2 – jaw crushing machine, 3- disc miller, and finally 4-vibrating cup miller. Each equipment was set between 6-8rpm (revolution per minute).Having obtained the powdered sample of particle size 100mesh (0.15micron), according to recommended standards, the sample was ready for XRD analysis.

Setting of the XRD Equipment: This is usually run (scan range) between 0^0 to 120^0 theta Bragg angle on the type of the minerals in question the running rate (SCAN SPEED) is between 2 to 10 degree per minute. The voltage recommended level is set at 30A. The auto silts (divergence, scatter and receiving) used for the various apertures control are of sizes 1.0, 1.0 and 0.3 (degree).

Bulk Analysis: Bulk sample is the powdered sample prepared, this was smeared evenly on the sample holder made of aluminium material, with the aid of smooth slide or any material with smooth surface edge. The setting was between angles 2^0 to 6^0 theta as the bulk sample scanning range. The running rate (scanning speed) was set at 6 degree per minutes. The holder was carefully placed on the loading point of the movable Gonoiometer arm that contained a clamp capable of gripping the sample firmly. Analysis commenced automatically. The pronounced Peaks or Diffractograms displayed express the minerals composition at the various angle of the degree theta.

Orient Analysis: The purpose of this analysis was to separate the Gangue and Tenor inherent in the sample. Having obtained powdered sample, about 5 log was put into a clean test tube with the aid of spatula. Distilled water was added to dissolve the sample and subsequently placed inside centrifuge machine and run the second time. This process went on for at least three to five times depending on the rate at which individual sample goes into a clear suspension. After decanting severally, about 3-5 drops of 0.6% sodium hexameta phosphate solution was added. At this point a clear suspension of clay formed above, while the over unwanted samples settled at the bottom of the test tube. dropper was used to take some quantity of the suspended clay and applied it on a clean labelled glass slides. This was allowed to dry for at least 24hrs, before ready for XRD analysis. Being an orient sample, the sample was run at scan range between 2^0and45^0 theta Bragg angles, while the scan speed was set at 6 degrees per minutes.

Generation of Raw Data

After about 10 to 15 minutes, the analysis was done and the raw data generated was collected automatically, manual basic process was followed to generate the PKK (peaks constant) of the raw data. The background correction of the PKK was set at YES value which automatically terminates errors that might have occurred during manual rearrangement of data. The PKK generated was further treated by search march menu which is necessary to relate the obtained diffractograms with the elucidated known mineral in the library.

The Machine Library: Usually used is the comprehensive USR (universal). By accepting or rejecting entry of the marched peaks the obtained peaks or diffractograms is successfully related and identified as accepted peaks, which bears the minerals names chemical symbols and the chemical names of the already known ones that correlate with the newly run data, based process and search march raw data.

Results

The result of the physical tests, chemical and mineralogical analyses, and chemical specifications for comparison were presented in the tables 1 to 4

Table 1: Physical Analysis Result of Uzuakoli Clay

PARAMETER	SAMPLE A	SAMPLE B
Apparent Porosity (%)	19.34	20.01
Bulk density (cm)	2.10	2.50
Fired shrinkage (%)	4.00	4.70
Plasticity (%)	26.00	25.97
Firing temperature	1200	1200
Fired Colour	Milky	Light Brown
Cold crushing Strength (N/mm^2)	60.16	60.34

Table 2: Chemical Analysis Result % Oxides of Uzuakoli Clay

OXIDES	SAMPLE A	SAMPLE B
SiO_2	61.84	62.81
AL_2O_3	25.50	17.12
Fe_2O_3	7.77	8.12
CaO	0.25	0.81
MgO	0.84	0.23
K_2O	0.57	1.10
NaOH	-	0.02
Ma_2O	0.01	0.02
Ti O_3	1.63	1.03
SO_3	0.01	0.54
LO1	1.30	6.73

Table 3: Mineralogical Composition of the Studied Clays

Sample location	Code	K(%)	Ch(%)	I(%)	An(%)	Q(%)	M(%)	V(%)

Sample A	UZ A	40	---	---	___	30	___	30
Sample B	UZ B	41	__	__	___	26	___	33

Table 4: Chemical Composition of the Uzuakoli Clay Samples Compared With Specification for Some Ceramics Industrial Needs

Composition (%)	**Uzuakoli clay**		**Ceramics**	**Refractory Bricks**	
	A	B			
SiO_2	61.84	62.81	48.00	67.50	51.00
AL_2O_3	25.50	17.12	37.00	26.50	25.00
Fe_2O_3	7.77	8.12	0.60	0.50	0.50
CaO	0.25	0.81	0.10	0.18	0.10
MgO	0.84	0.23	0.30	6.10	0.20
K_2O	0.57	1.10	1.60	5.60	3.50
NaOH	-	0.02	-	-	-
Na_2O	0.01	0.02	0.10	1.40	0.80
$Ti\ O_3$	1.63	1.03	0.03	-	-
SO_3	0.01	0.54	-	-	-
LOI	1.30	6.73	12.40	6.03	3.04

The sample was compared with the specification given by (Aliyu, 1995) and (Emefurieta et al., 1994).

Discussion

The clay samples are milky and light brown in colour when fired. This means they could be put to use for the production of domestic white sanitary wares, and it could also be used for the production of floor tiles and bricks (Chinweike, 2021; Mikhalev and Vlasov, 2007).In addition, the shrinkage test results of these clays show that they are good contraction clays and could be used in making of wall tiles, floor tiles, sanitary wares and table wares (Cerato and Lutenegger, 2006; Hobbs et al., 2018).

Results from the plasticity tests of the studied clay samples meet with other specification for ceramics industrial needs. These clays showed good workability and mouldability in its plastic state. The plasticity results which are 26.00% and 25.97% for samples A and B indicate that the clays become plastic when the volume of water becomes 26.0 and 25.97 respectively. The plasticity of the clay sample A is in line with sedimentary rock and showed good workability and mouldability in the plastic state as a clay body while sample B is not very plastic. Clay workability impacts in its quality, labour cost, strength and appearance (Backus, 2022). Clays with good workability and plasticity are good for tiles manufacturing (Barnes, 2018; Wienerberger, 2022). Uzuakoli clays with average apparent porosity of 19.68% meet standard for refractory bricks with range of 10-30% (Abubakar *et al.*, (2014)). The average bulk density value of 2.3g/cm^3 of the clay samples meet the standard for ceramics and refractory bricks with ranges of 2.3g/cm^3 and 2-3g/cm^3 respectively according to Omowumi, (2000) and also meet standard for refractory productions with range of 1,71-2.1g/cm^3 according to Yami, Hassan, and Umaru (2007)

The result from the chemical composition of the raw clays of this study showed that Uzuakoli clays are typical clays in which the silica content of 61.84% and 62.81% meet with the specification of clays for ceramic industrial products. The Alumina content is 25.50% and 17.12% and they meet with the specification for the production of refractory bricks. The Al_2O_3 content ranged from 25.50% - 17.12%, averaging 21.62%, has a high value suitable for glass with the range of 12-17% alumina (Abubakar *et al.*, (2014)). The relative proportion of silica to alumina (SiO_2/Al_2O_3 ratio) affects the physicochemical properties and applications of clays (Partyka et al 2015). The Fe_2O_3 content, ranging from 7.77% to 8.12% (average 7.95%), was relatively high and acts as flux to bring down the maturing temperature of a ceramic body when fired in the kiln. As iron oxides naturally occur in clays, high amounts of it can adversely impact the coloration and high temperature performance (Ekosse 2010). The chemical composition of Uzuakoli clay indicated that silica is the major oxide of the clay and is in line with the silica alumina percentage for clay that is best suited for bricks and ceramics (Alam, 2022). The Uzuakoli clays with kaolinite value of 40 and 41% meet the standard for ballclay with the specification range of 25-80% kaolinite (Galos, 2011).

Conclusion

The results of this study reveal that Uzuakoli clay has the property of high temperature which however, can be reduced by the high iron content. The clays are of light weight, and are coloured ash, and could be used for the production of sanitary wares, table wares, bricks and tiles. This work has demonstrated that clay deposits in Uzuakoli are extremely useful in the area of ceramic productions as they possess the required clay oxide percentages of silica 61.84% and 62.81% and good alumina content of 25.50% and 17.12% for the production of ceramic products such as refractory bricks. The cold crushing strength of $60.16N/mm^2$ and $60.34n/mm^2$ from the clay samples showed that the clays are suitable for construction bricks. Kaolinite content of 40% and 41%, and quartz content of 30% and 26% made clays suitable for refractory materials for ceramic productions. The Uzuakoli clays with kaolinite value of 40 and 41% meet the standard for ball clay used in ceramic productions. Despite the comprehensive assessment of the clay deposits in Uzuakoli for ceramic applications, some limitations were encountered, they include: Limited sample coverage, this is because this study analysed clay samples from selected locations within the community which may not fully represent the entire deposit's variability; Restricted laboratory analysis which is due to resource constraints as a result, only specific tests were conducted, with absence of long- term performance evaluation, as this study focused on the immediate suitability of the clays for ceramic production and there was no long-term performance tests like durability and weather resistance of fired products; Economic and industrial feasibility, that is while the study assessed properties of the clays, it did not cover the economic feasibility of large-scale mining, processing, and commercialization.

Recommendations

1. broader geological investigation, which include more extensive geological survey covering more locations within and around Uzuakoli to determine the full extent and uniformity of clay deposits in the area.

2. Long-term performance studies should be conducted to evaluate the durability and resistance of ceramic products made from Uzuakoli clays under different environmental conditions.

3. the environmental impact assessment that involves studying the potential environmental effect of clay mining and proposing sustainable extraction methods to minimize ecological disruption.

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