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Mineralogical, geochemical and physical properties assessment of clay deposits in Umuoke Obowo Southeastern Nigeria for industrial applications

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Abstract

This study assessed the suitability of clay deposits from Umuoke, Obowo in southeastern Nigeria as local raw materials for industrial applications. Ten samples were collected from different mining pits across the locality. X-ray fluorescence, X-ray diffraction and physical property tests characterized the clays based on geochemical composition, mineralogy and key attributes. The clays showed high silica (56.41%) and alumina (32.82%) contents typical of aluminosilicate clays. Iron oxide levels were moderately elevated (3.34% Fe_2O_3). Clay minerals kaolinite (18.9-37.0%) and illite (0.5-4.15%) occurred predominantly alongside non-clay minerals like quartz, feldspars and metal oxides. The clays exhibited high plasticity (avg. plasticity index 26.61%) enabling easy moulding and shaping. Porosity averaged 21.33% appropriate for refractories. Firing shrinkage (6.5-19.2%) and density (1.54-1.76 g/cm^3) were in acceptable ranges. Strength post-firing reached the 15 N/mm^2 minimum standard. Estimated refractoriness was 1680.22°C. Overall, the Umuoke clays demonstrate favourable chemistry, mineralogy and physical properties for refractories and structural ceramics applications pending some processing adjustments. Locally exploiting these deposits can promote import substitution, rural industrialization and sustainable development in Nigeria. Further pilot testing can optimize formulations and processes for targeted ceramic products. Comprehensive nationwide clay deposit prospecting is also recommended. The clays are suitable for refractory bricks, ceramic tableware, architectural ceramics, wall tiles, pottery items.

Keywords: Geochemical composition; Mineralogy; X-ray fluorescence; X-ray diffraction.

1. Introduction

Nigeria possesses vast, yet largely untapped, clay deposits with potential economic benefits (1). These industrial clay resources could significantly boost Nigeria's economy and reduce import dependency if properly assessed and utilized by local industries (2). Despite the government's historical focus on exploiting these resources, issues surrounding the perceived unsuitability of available deposits have impeded progress (3,4). To address this, further survey and characterization of Nigerian clay deposits are urgently needed to determine their properties and industrial applicability. The hindrance to beneficiation and application of Nigerian clays arises from misconceptions about their mineralogical, chemical, and physical characteristics (3,4). Despite past research demonstrating successful uses of local clays, exploitation remains below potential due to persistent perception issues. Consequently, a comprehensive survey and characterization of the diverse clay deposits across Nigeria are crucial for accurate assessment of their properties and industrial suitability.

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Proper evaluation of mineralogical, chemical, and physical attributes is essential as clay utilization feasibility depends on these qualities for intended applications (5,6). Clay minerals play a significant role in determining the properties and industrial value of deposits (7). Kaolinitic clays are valuable for ceramics manufacturing and various industries due to their desirable properties (8). On the other hand, smectite and illite clays find applications in pharmaceuticals, cosmetics, oil drilling, wastewater treatment, and industrial processes (9). Assessing Nigerian clay typology and attributes is critical for scientific and socioeconomic perspectives to understand their composition-property-function relationships and potential economic contributions.

Imo state in Nigeria's southeast region harbors underexplored clay deposits in Umuoke Obowo Local Government Area with potential industrial uses (10). Despite a lack of prior documentation on the mineralogy, chemistry, and physical properties of these deposits, the study aims to fill this knowledge gap. The potential industrial applications of Umuoke Obowo clays, if found suitable, could contribute to import substitution, rural industrialization, and employment. The study proposes a methodology using modern analytical techniques like X-ray diffraction (XRD) and X-ray fluorescence (XRF) for evaluating obscure Nigerian clay deposits against technical specifications. If Umuoke Obowo deposits, including kaolinite and ball clays, are substantiated as suitable sources through rigorous characterization, they could reduce Nigeria's dependence on foreign kaolin and ceramic imports, providing a model approach for mapping and utilizing the country's clay reserves during economic uncertainty.

1.1. Geological Setting

The study area contains sediments of the Benin and Ogwashi-Asaba formations, southeast Nigeria (11). The Benin formation outcrops in Avutu Obowo, comprising cross-bedded sands and clays, up to 2100m thick, dipping southwest. The underlying Ogwashi-Asaba formation spans the Oligocene-Miocene with blue clays, shales, silts and sands containing lignite seams. It dips northeast with 450-900m thickness (12).

Ten clay samples were collected 4-10m deep in Umuoke after removing overburden (11). The Umuoke area specifically has clay-sandstone interbeds, white to brown in color. Sampling sites spanned 5°33'30.61′′N to 5°34'53.02′′N and 7°22'32.87′′E to 7°23'24.80′′E based on GPS. The lithology matches previous Oligocene-Miocene descriptions, likely representing Anambra basin sedimentation.

2. Materials and methods

2.1. Materials

The materials utilized during fieldwork and sampling included topographic maps, a Brunton compass, clinometer, hammer, spade, measuring tape, sample bags, digital camera and GPS device. For sample preparation, a jaw crusher, sieve, grinding equipment and sealing bags were used. The laboratory equipment for chemical and mineralogical characterization included an X-Ray Fluorescence Spectrometer (XRF), X-Ray Diffractometer (XRD), sample mill, pressing equipment and oven. Materials needed for the physical testing comprised plasticity cans, grooving tools, kiln, electronic balance, stove and a hydraulic press.

2.2. Study Area

The study area encompasses clay exposures in existing sand mining pits across the Umuoke locality, Obowo LGA in Imo State, southeastern Nigeria. Ten sampling points were selected from latitudes 5°33'30.61''N to 5°34'53.02''N and longitudes 7°22'32.87''E to 7°23'24.80''E. Fig. 4 shows the distribution of sampling sites within Umuoke.

2.3. Field Sampling

Clay samples were collected from depths of 4-10m across designated mining pits after removing the overburden layer. The reddish-brown overburden comprises lateritic soil, hardened sandstone and/or loose sand. At each pit, the clay unit appeared as white, light grey or brown massive bedrock, occasionally alternating with friable sandstones. The fine-grained, smooth clay sediments were extracted using picks and hammers based on accessibility.

2.4. Sample Preparation

The clay samples were air-dried for two weeks, then mechanically crushed using a jaw crusher and ground into fine powder below 150 microns grain size. About 40 grams of the powdered subset was stored in sealed bags and transported to the laboratory for chemical and mineralogical analyses. The remaining bulk sample was retained for physical testing. Prior to each new sample, the crusher was thoroughly cleaned to avoid cross-contamination.

2.5. Chemical Analysis

The major oxide composition of the clay fraction was quantified using X-Ray Fluorescence (XRF) Spectrometry. XRF tested major oxide composition. Samples milled below 150 microns. 30-40g powder in sample cups. XRF operated 35-40kV. Diffraction spectra collected. Peaks matched to database oxide wt % output.

2.6. Mineralogical Analysis

The bulk mineralogy of powdered clay specimens was determined using XRD at the National Steel and Raw Materials Exploration Agency. XRD determined mineralogy. Samples milled below 0.15 microns. XRD parameters: 2-60° 2theta, 6°/min, 40V, 30A. Smearing on holders, automated analysis and background noise removal Matching were attached to database to accept mineral fractions output.

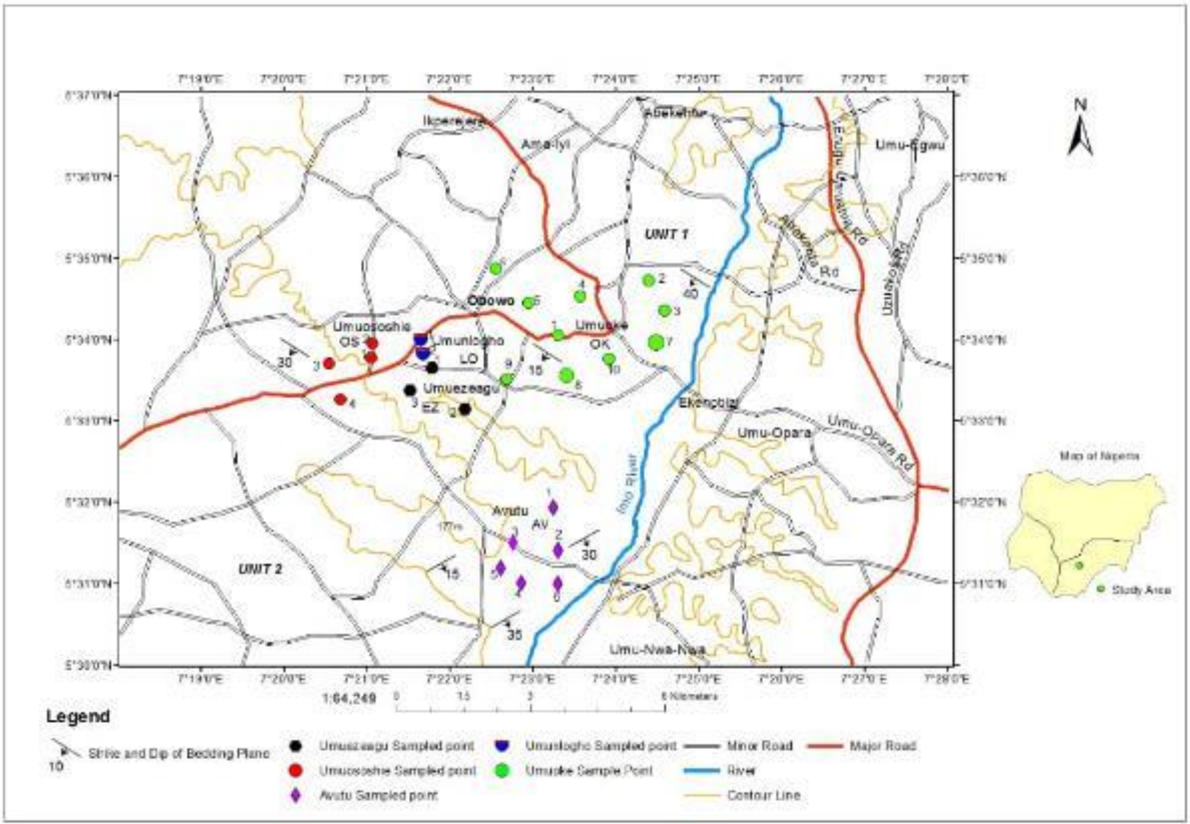

Figure 1 Sample Location Map of the Studied Umuoke Obowo Area

2.7. Physical Testing

A range of tests were undertaken to evaluate the practical performance characteristics and industrial applicability of the Umuoke clay deposits as summarized below. Tests evaluated practical performances were liquid limit, plastic limits and plasticity index per ASTM D4318. Firing shrinkage of molded bars was determined per ASTM C326. Apparent porosity, water absorption, bulk density, and apparent specific gravity were evaluated per ASTM C20. Compressive strength of cubic specimens were determined while the refractoriness prediction was determined using chemical oxide content.

Results compiled, averaged, compared to standards to assess suitability and favorable applications.

3. Results

3.1. Chemical Analysis

The chemical analysis of the Umuoke clay samples was conducted using X-ray fluorescence (XRF) spectroscopy to determine the oxide compositions. The Umuoke clays were found to be predominantly composed of silica (SiO_2) and alumina (Al_2O_3), with average concentrations of 56.41% and 32.82%, respectively (Table 1). These elevated SiO_2 and Al_2O_3 levels classify the Umuoke deposits as hydrated alumino-silicates (13,14).

Additionally, notable levels of iron oxide (Fe_1O_3) averaging 3.46% were detected across the Umuoke samples. The presence of Fe_2O_3 is likely attributable to the effects of superficial oxidation and contamination by Fe-rich solutions percolating from the overlying ferruginous sandstone and laterite. Meanwhile, concentrations of other major oxides, including TiO_2, CaO, MgO, Na_2O and K_2O were relatively minor, altogether constituting less than 5% of the average composition. The loss on ignition (LOI) values was consistently below 3%, indicating minimal organic matter in the clays.

Table 1 Chemical Analysis (Concentration in % Wt Oxides) for Umuoke (Ok) Clays

SP										
Code	Ok1	OK 2	OK 3	OK 4	OK 5	OK 6	OK 7	OK 8	OK 9	OK10
SiO_2	54.69	55.28	55.11	59.07	57.46	55.39	53.98	58.35	59.04	55.69
V_2O_5	0.31	0.33	0.3	0.25	0.31	0.32	0.53	0.24	0.24	0.48
Cr_2O_3	0.05	0.08	0.08	0.08	0.05	0.08	0.12	0.05	0.05	0.13
MnO	0.03	0.04	0.04	0.03	0.03	0.04	0.07	0.03	0.03	0.07
Fe_2O_3	3.61	2.77	3.07	2.2	2.74	3.03	4.78	4.09	3.18	3.97
Co_3O_4	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Nb_2O_3	0.02	0.03	0.03	0.02	0.02	0.03	0.06	0.02	0.03	0.06
P_2O_5	-	-	0.03	-	0.06	-	0.17	-	0.02	0.09
SO_3	0.16	0.44	0.33	0.54	0.47	0.17	0.68	0.34	0.3	0.22
CaO	0.05	0.13	0.06	0.07	0.11	0.02	0.16	0.07	0.09	0.1
Al_2O_3	35.23	34.39	34.37	32.29	33.18	34.64	30.97	31.39	31.16	30.6
ZnO	0.01	0.01	0.01	0.01	-	0.01	0.01	0.01	-	0.01
TiO_2	4.35	5.08	4.89	3.88	4.09	4.82	6.36	4.16	4.6	6.54
K_2O	0.3	0.24	0.36	0.23	0.26	0.23	0.18	0.1	0.11	0.15
Na_2O	0.21	0.68	0.52	0.06	0.38	0.11	0.06	0.08	0.04	0.41
LOI	2.42	3.42	3.08	2.06	3.14	2.49	3.28	2.16	2.66	2.36

3.2. Mineralogical Composition

The table below shows the results of the mineralogical analysis. X-ray diffraction analyses demonstrate the Umuoke clays to be mineralogically dominated by quartz (SiO_2) and kaolinite ($Al_2Si_2O_5(OH)_4$), which on average constitute over 80% of the deposit (Table 2, Figure 2). Quartz levels range between 44.9-65.9%, while kaolinite varies from 18.9-37.0% across the samples. Meanwhile, minor accessory phases identified include orthoclase feldspar, illite, hematite, albite, muscovite, chlorite, and anatase. Among the accessory minerals, hematite is the most abundant, reflecting the elevated Fe_2O_3 levels noted previously. Overall, the mineralogical uniformity mirrors the observed geochemical consistency, further confirming the geological homogeneity of the Umuoke clays.

Table 2 Mineralogical Composition of the Studied Clays for Umuoke (OK)

Sample location	Code	K(%)	Qz(%)	Or(%)	An(%)	Ch(%)	I(%)	Mu(%)	He(%)	Al(%)
Sample 1	OK 1	36.1	47.0	11.3	16.0	13.0	0.9	6.8	---	---
Sample 2	OK 2	31.0	56.0	5.8	---	1.8	0.5	3.6	1.54	---
Sample 3	OK 3	27.0	53.0	1.0	---	4.0	---	1.0	---	7.2
Sample 4	OK 4	31.0	57.0	1.0	---	4.0	---	1.0	---	5.0
Sample 5	OK 5	37.0	55.0	3.2	---	---	1.3	2.3	0.9	---
Sample 6	OK 6	28.0	58.0	0.35	---	---	1.6	6.1	1.4	4.9
Sample 7	OK 7	30.6	44.9	7.8	---	---	4.15	4.69	1.97	6.0
Sample 8	OK 8	20.0	55.0	8.1	---	---	3.9	5.0	2.2	6.3
Sample 9	OK 9	37.0	50.0	-	---	1.5	---	11.1	---	0.4
Sample 10	OK 10	18.9	65.9	3.44	---	---	4.10	6.40	0.56	0.76

K = Kaolinite, Or = Orthoclase An = Anatase; Ch = Chlorite Qz = Quartz; He = Hematite; I = illite Mu = Muscovite, Al = Albite

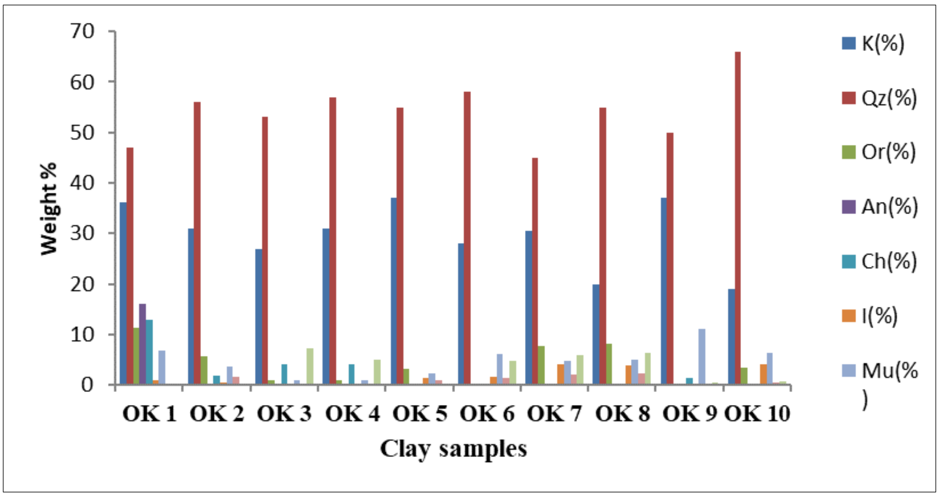

Figure 2 Clay Mineral Occurrences in the Samples in Umuoke(OK)

3.3. Plasticity

Atterberg limit tests conducted on the Umuoke samples reveal liquid limits ranging from 33.0-88.0%, plasticity limits of 10.3-47.7%, and plasticity index values between 17.4-43.5% (Table 3). Based on the Casagrande plasticity chart, the majority of Umuoke clays classify as intermediate to highly plastic inorganic clays. Exceptions include sample OK3 which plots below the A-line as a silty clay, while OK1 falls on the boundary between intermediate and low plasticity zones.

Table 3 Results of the Atterberg Limit of Umuoke (Ok) Clay

Sample code	Liquid limit	Plastic limit (PL %)	Plastic index (PI %)
OK1	33.0	10.3	28.7
OK2	44.3	25.5	18.8
OK3	60.1	42.7	17.4
OK4	69.2	25.9	43.5
OK5	47.3	28.4	18.9

OK6	42.0	21.4	20.6
OK7	45.0	13.9	31.1
OK8	88.0	47.7	40.3
OK9	49.5	31.0	18.5
OK10	39.8	11.5	28.3
Average	**51.82**	**25.83**	**26.61**

3.4. Physical Properties

Physical testing reveals the Umuoke clays to possess average apparent porosity, water absorption capacity, bulk density and apparent specific gravity values of 21.33%, 13.65%, 1.67 g/cm^3 and 2.18, respectively (Table 4, Figure 3). Porosity ranges from 12.96-28.33% across samples, while water absorption varies between 10.16-16.38%. Higher porosity promotes greater water absorption, as exemplified by sample OK2.

Table 4 Result of Apparent Porosity, Water of Absorption, Bulk Density, and Apparent Specific Gravity of Umuoke(OK) Clay

Sample Location	Apparent porosity (%)	Water of absorption (%)	Bulk density (g/cm3)	Apparent specific gravity
OK 1	12.96	10.16	1.67	2.01
OK 2	28.33	16.38	1.73	2.41
OK 3	18.39	10.48	1.76	2.15
OK 4	24.25	14.36	1.67	2.20
OK 5	12.98	14.5	1.63	2.13
OK 6	26.24	14.99	1.75	2.57
OK 7	26.76	16.3	1.64	2.24
OK 8	19.43	12.62	1.54	1.91
OK 9	19.33	11.99	1.61	2.00
OK 10	24.64	14.75	1.67	2.22
Average	21.33	13.65	1.67	2.18

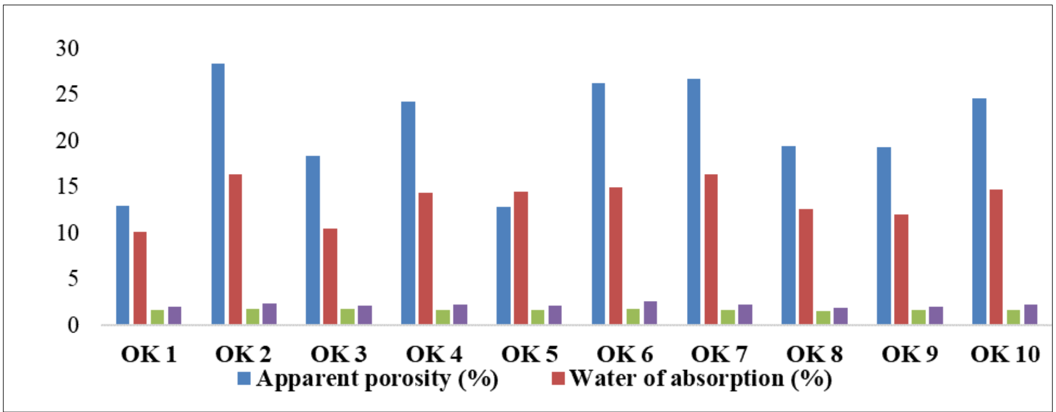

Figure 3 Chart of the Bulk Density, Water of Absorption, Apparent Porosity, Apparent Specific Gravity of Umuoke(OK) Clay

3.5. Firing Shrinkage

Analysis of drying and firing shrinkages reveals total linear shrinkage values for Umuoke clays between 6.5-15.0% (Table 5, Figure 4). On average, clays contracted by 5.16% during oven-drying at 110°C, and a further 5.74% upon firing to 1100°C. The high plasticity index of these clays translates to increased shrinkage tendencies, as expanding lattice layers between clay platelets are expelled upon water loss and dehydroxydation.

Table 5 Results of the Linear Shrinkage Tests of Umuoke(OK) Clay

Sample Code	Dry shrinkage (%)	Fired shrinkage (%)	Total shrinkage (%)
OK 1	4.50	7.22	12.60
OK 2	5.20	2.22	7.70
OK 3	5.80	6.58	12.00
OK 4	6.00	4.26	6.50
OK 5	5.00	5.68	10.40
OK 6	4.90	4.52	9.20
OK 7	4.00	4.67	8.00
OK 8	5.00	9.47	14.00
OK 9	7.00	9.14	15.00
OK 10	4.20	3.65	19.20
Average	5.16	5.74	11.46

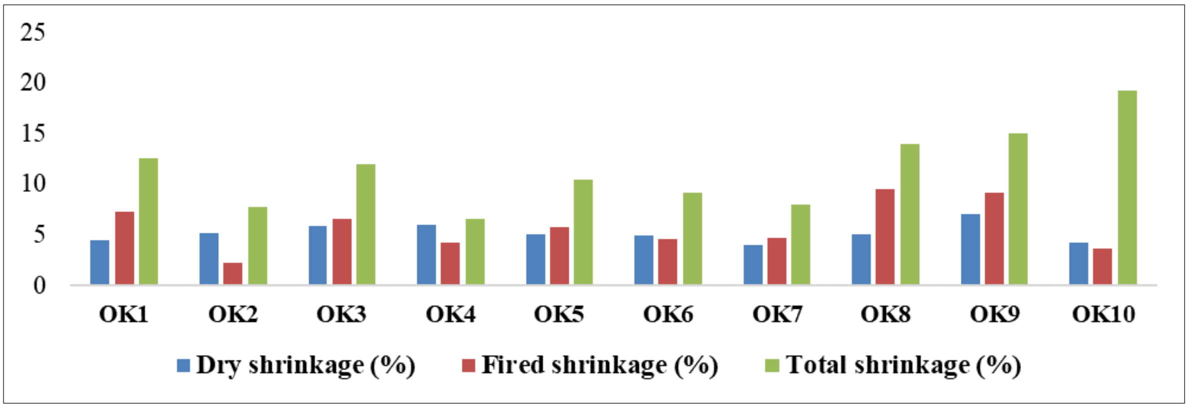

Figure 4 Chart of the Linear Shrinkage of the Umuoke(OK) Clays

3.6. Cold Crushing Strength

The structural strength of Umuoke clay samples fired to 1100°C was evaluated via cold crushing tests. Strength values between 11.33-31.33 N/mm^2 were recorded, with an average of 20.73 N/mm2 (Table 6, Figure 5). These strength levels exceed the minimum industry standards of 15 N/mm2 specified for fireclay bricks (15). Thus, the Umuoke clays demonstrate adequate strength upon firing to be capable of serving as construction material.

Table 6 Result Compressive Strength or cold Crushing of Umuoke (OK) Clays

Sample code	Crushing strength (N/mm^2)
OK1	24.67
OK2	16.00
OK3	20.00
OK4	20.00
OK5	23.33
OK6	16.67
OK7	18.00
OK8	26.00
OK9	31.33
OK10	11.33
Average	20.73

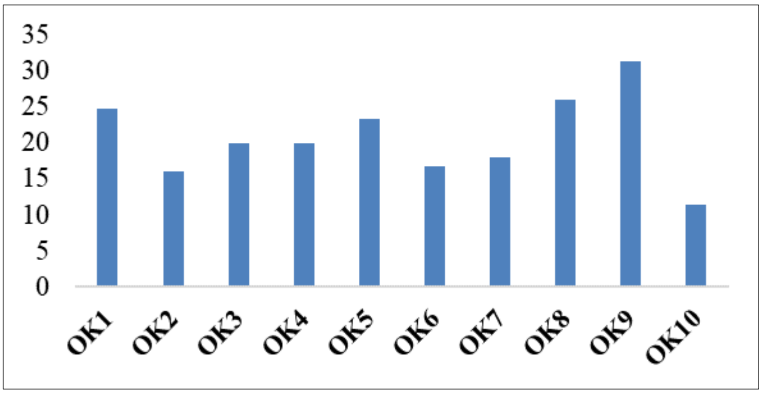

Figure 5 Chart of the Cold Crushing Strength (N/mm2) of Umuoke (OK) Clays

3.7. Refractoriness

Refractoriness estimates derived from the bulk chemical composition of the Umuoke clays average 1680.22°C. This high refractoriness temperature signifies the Umuoke deposits comprise of minerals with elevated melting points, including quartz, kaolinite and hematite. Hence, the Umuoke clays or ceramics produced from them should withstand prolonged exposure to temperatures nearing 1700°C without undergoing softening or deformation.

4. Discussion

The mineralogical and geochemical properties of the Umuoke clay deposits in Obowo, Southeastern Nigeria were assessed to determine their suitability for various industrial applications. The samples were characterized using X-ray fluorescence (XRF) spectrometry, X-ray diffraction (XRD), and evaluation of physical properties.

4.1. Geochemical Composition

The chemical composition of the Umuoke clay samples showed a predominance of silica (SiO_2) and alumina (Al_2O_3), which is typical for aluminosilicate clays (16–18). The silica content ranged from 53.98% to 59.07%, averaging 56.41%, while the alumina content ranged from 30.60% to 35.23%, averaging 32.82%. These high silica and alumina levels are comparable to other Nigerian clay deposits reported in studies by Abdullahi and Audu (19), Falodun et al. (20), and Oluseyi et al. (21). The relative proportion of silica to alumina (SiO_2/Al_2O_3 ratio) affects the physicochemical properties and applications of clays (22). Clays with ratios between 2-4 often exhibit favorable refractory characteristics, plasticity, and ceramic strength (23). The average SiO2/Al2O3 ratio for the Umuoke clays was 1.72, indicating moderately good refractory potential.

Apart from silica and alumina, the Umuoke clays contained several other oxides including iron, alkali metals, and alkaline earth metals. The Fe2O3 content, ranging from 2.20% to 4.78% (average 3.34%), was relatively high. While some iron oxides naturally occur in clays, excessive amounts can adversely impact the coloration and high temperature performance (24). The alkali oxides of sodium and potassium along with alkaline earths like calcium indicate the presence of some feldspathic minerals. Feldspars act as fluxes, promoting liquid phase formation and densification during firing (25). The Umuoke clays showed 0.22% K2O and 0.26% Na2O on average.

The loss on ignition (LOI) values, indicating the organic matter content, was low for the Umuoke clays ranging from 2.06% to 3.42% (average 2.71%). Minimal LOI is favorable for ceramics as high organics can cause defects during firing (26). Overall, the chemical composition highlights the aluminosilicate nature of the Umuoke clays, with high SiO_2, Al_2O_3 and moderately high Fe_2O_3 along with some fluxing oxides.

4.2. Mineralogical Composition

The mineralogical analysis by XRD showed the Umuoke clays were predominantly composed of the clay minerals kaolinite and illite along with non-clay minerals including quartz, feldspars, micas, and metal oxides. Kaolinite ranged from 18.90% to 37.0% among the samples, while illite occurred at 0.5% to 4.15%. The presence of kaolinite and illite as major minerals is typical for many clays worldwide (27,28) and concurs with studies on Nigerian clays (19,29). Kaolinite imparts favorable plasticity, workability, and strength for shaping ceramic products, while illite enhances dry mechanical strength (30,31). The Umuoke kaolinite content compares well with the range of 25-80% seen in ball clays (32).

Among the non-clay minerals, quartz was most abundant ranging from 44.9% to 65.9%. Quartz can help reduce shrinkage and warping tendencies but may also lead to cracking if cooling rates differ considerably during firing (33). Orthoclase feldspar was found from 0.35% to 11.3%, while albite occurred at up to 7.2% in some samples. Feldspars aid vitrification and liquid phase formation leading to high fired strength (25). The Umuoke clays showed higher feldspar levels compared to other Nigerian kaolinitic clays with less than 5% feldspar (29). Other non-clay minerals detected include muscovite (1.0% to 11.1%), chlorite (up to 13.0%), and the iron oxide hematite (0.56% to 2.2%). Overall, the Umuoke clay mineralogy appears well suited for manufacturing ceramic products.

4.3. Physical Properties

The physical properties of the Umuoke clays provide insight into their plasticity, working behavior, and fired characteristics. The Atterberg limits, which measure the plastic and liquid limits, showed high plasticity for the Umuoke clays based on the Casagrande plasticity chart classification. The plasticity index ranged from 25.83% to 29.03%, averaging 26.61%, while the liquid limit was 51.82% on average. High plasticity arises due to the fine particle size, platelet shape, and high surface area of the clay minerals (30). Clays with high plasticity exhibit good moldability and forming behavior, making them adequate for manufacturing bricks, tiles, ceramics, etc. which require shaping (34,35). However, high plasticity also causes increased shrinkage during drying and firing.

The Umuoke clays showed favorable porosity characteristics, which allow the escape of decomposed gases during firing thereby enabling vitrification and densification. Apparent porosity ranged from 12.96% to 28.33%, averaging 21.33%, which agrees with the standard range of 15-30% for refractory clays (36,37). Higher porosity benefits insulation refractories by providing low thermal conductivity (38).

The linear shrinkage, measuring the dimensional changes on drying and firing, lengths ranged from 6.5% to 19.2%, averaging 11.46%. This is close to the ideal 7-10% shrinkage for refractory fireclay bricks (15). Slight additions of non-plastic grog material may help tailor the shrinkage. The bulk density varied from 1.54 to 1.76 g/cm3 averaging 1.67 g/cm3, which is at the lower end of typical values of 1.7 - 2.1 g/cm3 for dense fireclay refractories (39). Lower density causes increased shrinkage.

The cold crushing strength, which indicates the load bearing capability after firing, ranged from 11.33 to 31.33 N/mm^2 averaging 20.73 N/mm^2. This meets the minimum requirement of 15 N/mm2 specified for fireclay bricks (15,40). Good strength develops from densification and liquid phase sintering during firing. Based on the chemical composition using Shuen's formula, the predicted refractoriness was 1680.22°C which agrees with the standard range of 1500–1700°C for refractory fireclays. Overall, the physical properties highlight the high plasticity of the Umuoke clays coupled with adequate porosity, shrinkage, strength, and refractoriness for utilization in ceramics and refractories.

4.4. Suitability for Industrial Applications

The chemical, mineralogical, and physical properties were assessed to determine the suitability of the Umuoke clays for various industrial applications, especially in the ceramics and refractories sector. Table 7 below summarizes the key characteristics based on the analytical results.

Table 7 Summary of Umuoke clay properties and potential applications

Property	Observed	Industrial relevance
Chemical		
SiO2	53.98 – 59.07%	Good refractory oxide
Al2O3	30.60 – 35.23%	Imparts refractory nature
Fe2O3	2.20 – 4.78%	High iron reduces refractory quality
Flux oxides	Present	Improves vitrification
LOI	2.06 – 3.42%	Low organics, good for ceramics
Mineralogy		
Kaolinite	18.90 – 37.0%	Imparts plasticity and strength
Illite	0.5 – 4.15%	Enhances dry mechanical strength
Quartz	44.9 – 65.9%	Reduces shrinkage but can cause cracking
Feldspar	0.35 – 16%	Promotes vitrification and liquid phase
Physical properties		
Plasticity	High	Good moldability and shaping
Porosity	12.96 – 28.33%	Aids refractory insultation
Shrinkage	6.5 – 19.2%	Mostly in ideal range for refractories
Bulk density	1.54 – 1.76 g/cm3	Lower density causes high shrinkage
Strength	11.33 – 31.33 N/mm2	Meets minimum standard for fireclay bricks
Refractoriness	1680.22°C	Suitable for high temperature applications
Potential applications		
- Refractory bricks	- Tableware ceramics	
- Insulation firebricks	- Architectural ceramics	
- Ceramic tiles	- Sculpture clay bodies	

The Umuoke clays demonstrate various properties favorable for refractory materials used in high temperature applications, such as refractory bricks, insulation firebricks, and refractory linings (38,41). The high SiO_2 and Al_2O_3 content coupled with the moderate refractoriness of 1680°C indicates suitability to withstand elevated temperatures without deformation. The porosity meets standards for insulation refractories. The strength satisfies minimum requirements for fireclay bricks which are exposed to abrasion and load. However, the high Fe_2O_3 content needs to be mitigated via mineral processing to avoid coloration issues and further improve the refractory quality.

Additionally, the Umuoke clays also possess characteristics appropriate for structural and traditional ceramics which require shaping and firing at relatively lower temperatures than refractories. The fine grain size and high plasticity arising from the kaolinite and illite minerals enables easy molding into complex shapes. The fluxing oxides help vitrification while quartz acts as a filler reducing shrinkage. After firing, the ceramics develop adequate strength from sintering and liquid phase formation. Hence, the Umuoke clays can be suitable for manufacturing ceramic tableware, architectural bricks, wall/floor tiles, pottery, statues, and artware (42). While the working characteristics are favorable, the high shrinkage needs control through processing adjustments. Blending with non-plastic materials like grog or chamotte can help curtail shrinkage.

5. Conclusions

This study characterized the mineralogical and geochemical properties of clay deposits from Umuoke, Obowo in southeastern Nigeria. The aim was to evaluate their suitability as local raw materials for various industrial applications, especially in the ceramics and refractories sector. Ten clay samples collected from different mining pits across Umuoke were analyzed using X-ray fluorescence (XRF), X-ray diffraction (XRD), and laboratory tests of key physical properties.

The findings from this study demonstrate the suitability of Umuoke clay deposits in Obowo, Southeastern Nigeria for applications in the ceramics and refractories industry, with potential utilization in refractory bricks, ceramic tableware, architectural ceramics, wall tiles, pottery items etc. The chemical composition showed predominantly aluminosilicate nature with high SiO_2, Al_2O_3 and moderately high Fe_2O_3. Clay minerals kaolinite and illite occur along with non-clay minerals including quartz, feldspars, mica and metal oxides. The clays exhibit high plasticity coupled with appropriate fired porosity, strength, and refractoriness. While the properties are mostly favorable, minor mineral processing and blending steps can help mitigate issues like high iron content, shrinkage, and cracking during firing. The local availability of the Umuoke clays can promote indigenous ceramics manufacturing, substituting imports and fueling small-scale enterprises. Further pilot-scale testing will help establish optimal process parameters and applications.

However, certain limitations need mitigation. The high Fe_2O_3 content can lead to undesirably dark colors in ceramics. Hence mineral processing is required to lower the iron levels. Blending with non-plastic diluents such as feldspar and grog may help control the high shrinkage observed. Cracking and warping could also occur during drying and firing due to quartz inversion combined with elevated shrinkage. Introducing appropriate grog additions can minimize these defects by managing shrinkage rates.

Further research can build on these foundational results. Pilot-scale testing should establish optimal formulations and process parameters for targeted applications through empirical adjustments. Additionally, comprehensive nationwide deposit prospecting is recommended to quantify total reserves and spatial distribution thereby facilitating organized exploitation.

Compliance with ethical standards

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Disclosure of conflict of interest

The author, Thaddeus C. Azubuike, declares no conflicts of interest.

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