

# Suitability of Selected Nigerian Anthill Clays for Possible Industrial Applications

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**Abstract**— One raw material that is very useful for most industrial manufacturing processes is the clay because of its unique physico-chemical properties and chemical compositions. Anthill clay in particular, is a distinct clay because of the extraordinary stockpiling method where tiny clay particles are carried and erected as anthill by termites. When utilizing ant hill clay for industrial applications, it is important to analyze its chemical makeup. In this study, the physico-chemical properties of anthill from Kono Town, Khana LGA (KK1) and Umuebulu, Etche LGA (UE1) of Rivers State, Nigeria were successfully investigated and compared with a commercial bentonite clay (CB2). A combination of analytical techniques such as FTIR and SEM – EDS were utilized to characterize the properties of the selected anthills samples. Specific gravity, specific surface area, water absorption capacity (WAC), swelling index (SI) and cation exchange capacity (CEC) were investigated. SEM - EDS and FTIR results showed that kaolinite is the major clay mineral in anthill clay samples with albite, illite, and muscovite present in variable amounts and quartz as major non-clay mineral. CB2 sample had montmorillonite as major clay mineral and calcite as minor clay mineral. Physical properties results showed CB2 had WAC of 610% while KK1 and UE1 had WAC of 120% and 200% respectively. From SI analysis, CB2 had 29.5ml, while KK1 and UE1 were 0ml. The results showed that the anthill clay samples are suitable for refractories and insulating materials production but are not appropriate for the formulation of drilling fluids.

**Keywords**— Clay, specific gravity, water absorption capacity, swelling index, refractories.

## I. INTRODUCTION

Anthill clay exhibits a unique degree of compositional heterogeneity compared to other clay types. This variation stems from its geographically dependent origin. Similar to other clays, the initial formation of anthill clay likely involves the transportation and deposition of sediments by wind, rain, or gravity [1]. However, the crucial factor differentiating anthill clay is the subsequent selection and modification of these sediments by termites during anthill construction [2]. This selective process by termites leads to geographically distinct compositions of anthill clay. Consequently, the industrial applications of anthill clay, which include applications in silo construction, ceramics, foundry bonds, and soil amendment, are likely influenced by the specific location where the anthill clay is sourced [3]. Dominant applications include pottery, ceramics and porcelain production, and the manufacturing of building materials.

In contrast to anthill clays with their geographically dependent composition, natural clays exhibit a broader

spectrum of chemical diversity [4], [5], [6]. This inherent variation is attributed to the interplay of two primary formation processes: weathering and sedimentation. As a consequence of this compositional complexity, clays serve as a versatile natural resource in numerous industrial applications [7]. These applications encompass a wide range, including the production of ceramics (e.g., refractories), construction materials, drilling fluids, pharmaceuticals, paints, and clarification agents for water and wine [8].

Nigeria's current industrial sector relies heavily on imported raw materials and finished products. This dependence presents an opportunity for significant economic benefits if the nation can leverage its domestic clay resources. Local sourcing of raw materials for refractory products, drilling fluids, and other ceramic goods could lead to several advantages. Firstly, it would decrease production costs by minimizing import reliance. Secondly, it would foster the development of domestic production capacity, promoting self-sufficiency. Finally, it would reduce the demand for foreign exchange, strengthening the national economy [9]. Bentonite clays, commonly used in various clay-based industrial processes, are readily available in Nigeria. Research by [10] and [11] suggests that anthills, prevalent throughout the country, hold promise as a viable source material for clay-dependent industries.

Several studies have corroborated the potential of anthill clay as a valuable resource for ceramic production. [11] investigated the suitability of anthill clay in Ghana and found it to be a viable source material. In a similar way, [12] examined the possibility of employing Kenyan anthill clay as a refractory lining by analyzing its physicochemical characteristics. Further research by [13] employed standard procedures to characterize anthill clay samples physically and chemically. Their findings suggest a broader applicability of anthill clay beyond ceramics, including applications in water treatment, rigid material production, catalyst development, and refractories. Taken as a whole, these investigations offer strong support for the possibility that anthill clay could be a valuable ingredient in a wide range of industrial applications.

Further research has explored the potential of anthill clay beyond its basic form. [9] The application of sawdust- and rice husk-reinforced Ghanaian red anthill clay (RAC) in the manufacture of thermal insulating bricks was studied. Their findings demonstrated that these composite materials possess suitable physical, thermal, and mechanical properties for use as refractory materials, potentially enhancing the overall efficiency of refractory applications. In a separate study, [14]

employed X-ray fluorescence (XRF) to analyze the chemical compositions of three distinct clay types found in various locations across Sri Lanka. Their analysis revealed the presence of elements like iron (Fe), titanium (Ti), barium (Ba), and potassium (K) in varying proportions across the different clay types.

Nigeria's heavy reliance on imported raw materials for various industrial processes, including ceramics and drilling fluid formulations (bentonite clay), has placed a significant strain on the nation's foreign exchange reserves. This challenge is further exacerbated by the recent global oil price collapse, which has drastically reduced revenue and imposed financial constraints on import-dependent industries. In response to this critical situation, this research aims to investigate and compare the physicochemical properties of selected Nigerian anthill and bentonite clay samples. The primary objective is to assess their suitability as locally sourced raw materials for both ceramic production and drilling fluid formulation. This study directly aligns with the core principles of the Nigerian Content Act, which prioritizes the development of local content within Nigerian industries by promoting the exploration and utilization of domestic resources.

## II. MATERIALS AND METHODS

### 2.1 Materials

Anthill clay samples from Kono Town in Khana Local Government Area (KK1) and Umuebulu in Etche Local Government Area (UE1) both in Rivers State, Nigeria were collected and stored in a polythene bag during the dry season by following important precautions to maintain the accuracy of the results of further analysis. The Imported bentonite (CB2) from Atlantic Fluids and Integrated Services (AFIS) were collected for the investigations in this study. The raw anthill clay samples were dried at 110°C for 6 hours after which they were pulverized using mortar and pestle to grind them to powder form. The resulting powdered samples were sieved with a 90µm manual sieve. There was no need for further processing of the bentonite sample used as it had already been processed for commercial/industrial use.



Fig. 1. Anthill

### 2.2 Methods

The three clay samples were characterized using Scanned Electron Microscopy with Energy Dispersive Spectroscopy (SEM/EDS) and Fourier Transform Infrared Spectroscopy (FT-IR) to determine their mineralogical and chemical compositions. Cation exchange capacity and physical properties such as specific gravity, pH, swelling index, calculated surface area, and water absorption capacity of all three samples were also investigated. These parameters were used to determine the suitability of these clays for industrial applications such as drilling fluids formulation, and ceramics production.

### 2.3 Determination of physicochemical properties

#### 2.3.1 Specific Gravity

The specific gravity of the clay samples was determined using a specific gravity bottle or Le Chatelier flask method in accordance with IS: 2720 (Part III/Sec 1).

Calculations:

$$\text{Specific gravity} = \frac{W_2 - W_1}{(W_2 - W_1) - (W_3 - W_4) \times 0.82} \quad (1)$$

Where  $W_1$  = weight of empty flask

$W_2$  = weight of flask + clay sample

$W_3$  = weight of flask + clay sample + kerosene

$W_4$  = weight of flask + kerosene

0.82 = specific gravity of kerosene

#### 2.3.2 Water Absorption Capacity (WAC)

The test method DIN 18132 was used to determine the water absorption capacity (WAC) of clay soils [15], [16].

Calculations:

$$\text{WAC (\%)} = \frac{M_2}{M_1} \times 100 = \frac{\rho(V_1 - V_2)}{M_1} \times 100 \quad (2)$$

Where  $M_1$  = weight of dry clay sample (g)

$M_2$  = weight of clay sample after soaking at room temperature for 24 hours (g)

$V_1$  = Initial volume of distilled water used for soaking (ml)

$V_2$  = Final volume of distilled water after soaking and filtering (ml)

#### 2.3.3 Swelling Index

Sodium bentonite clay's overall swelling characteristics are determined using the Free Swell test or Swell Index approach. The swell index was calculated using the ASTM-D5890 test technique. Two grams of the clay sample, consisting of dried and finely ground bentonite clay, were divided into 0.1 gram increments and placed into a 100 ml graduated cylinder to conduct this test. At least 10 minutes must pass between each 0.1 gram addition in order to allow the clay to fully hydrate and settle to the bottom of the cylinder. Until the full 2g sample has been added to the cylinder, the 0.1g addition is performed. The sample is then covered and shielded from disruptions for 16–24 hours, during which time the level of the settled and expanded clay is measured to the nearest 0.5 ml.

#### 2.3.4 Calculated Surface Area

The calculated surface area of the samples was determined using the methylene blue adsorption method [17].

Calculations:

$$\text{Surface Area (m}^2/\text{g)} = \left( \frac{\text{Methylene Blue (ml)}}{\text{Mass of Clay Sample (g)}} \right) \times 782.9 \quad (3)$$

#### 2.3.5 Cation Exchange Capacity (CEC)

The Cation Exchange Capacities of the clay samples were determined using the methylene blue adsorption method [18].

Calculations:

$$CEC(meq/100g) = \left( \frac{\text{Methylene Blue (ml)}}{\text{Mass of Clay Sample (g)}} \right) \quad (4)$$

### 2.3.6 Determination of pH

The pH of the clay samples was determined by mixing the samples in distilled water and using a pH strip to determine the acidity or alkalinity.

## 2.4 Sample Characterization

### 2.4.1 Scanning Electron Microscopy/Energy Dispersive Spectroscopy (SEM-EDS)

JEOL JSM-7600F SEM was used to conduct morphological, quantitative, and qualitative studies on the clay samples. The mineral analysis of representative samples using SEM and EDS was carried out in two phases. The chemical element makeup of the samples was determined by EDS [12], while SEM was used to examine the structure and shape of the surface of bentonite and ant hill clay samples.

### 2.4.2 Fourier Transform Infrared Spectroscopy Analysis (FT-IR)

The infrared region of the electromagnetic radiation spectrum, which has a longer wavelength and a lower frequency than visible light, can be measured quantitatively in a sample using FTIR analysis when the sample is exposed to infrared radiation (IR). The fundamental principle at play is that light is absorbed by the connections between different elements at different frequencies. An infrared spectrometer that generates the infrared spectrum output is used to measure the amount of light. Using a Perkin Elmer 400 FT-IR [19], [13], the FT-IR study of the specimens was performed.

## III. RESULTS AND DISCUSSIONS

### 3.1 Physical Properties of Anthill (KK1 and UE1) and Bentonite (CB2) Clay Samples

The physical properties of the anthill and bentonite clay samples were investigated and the results obtained are presented in Table 1.

TABLE 1. Physical properties of anthill and bentonite clay samples

| Parameters                       | KK1   | UE1   | CB2   |
|----------------------------------|-------|-------|-------|
| Specific Gravity                 | 2.24  | 2.26  | 2.20  |
| Swelling Index (ml)              | 0     | 0     | 29.5  |
| WAC (%)                          | 120   | 200   | 610   |
| CEC (meq/100g)                   | 5.4   | 5.8   | 100   |
| pH                               | 7     | 7     | 10    |
| Surface Area (m <sup>2</sup> /g) | 42.28 | 45.41 | 782.9 |

The results presented in Table 1 show that the anthill and bentonite clay samples: KK1, UE1 and CB2 have similar specific gravities: 2.24, 2.26, and 2.20 for KK1, UE1, and CB2 respectively. Generally, a higher specific gravity (around 2.7 or above) suggests a higher concentration of heavier montmorillonite compared to lighter impurities like quartz or organic matter [20], [21]. For most drilling fluid applications, the specific gravity of bentonite clay is in the range of 2.6 to 2.8 which is considered acceptable. This range ensures a good balance between contributing to the desired mud weight and

avoiding using excessive bentonite, which can affect other properties of the drilling fluid [22]. The specific gravity obtained from the analysis for the three samples is >2 which is similar to that reported by [23], [16], and [12].

Once again, bentonite clay is well known for its remarkable capacity for water absorption, which can reach hundreds of times its own weight (up to 1000%). This property allows it to swell significantly when it comes into contact with water [24], [25]. This swelling characteristic makes bentonite ideal for sealing applications. From the above results, CB2 had a water absorption capacity (WAC) of 610%, which is within the acceptable range for bentonite used in the formulation of drilling fluids as reported in [8] and [26]. Generally, a good quality bentonite clay for most applications is expected to have a water absorption capacity in the range of 300 - 700% by weight [27]. The high water absorption capacity of bentonite clay is fundamental to its swelling, sealing, binding, filtration, and thickening properties. These properties make bentonite a versatile material with applications in various industries [28]. However, UE1 and KK1 had WAC values of 200% and 120% respectively, this low WAC values for the anthill clay samples suggest the absence of exchangeable cations such as Na<sup>+</sup> and Ca<sup>2+</sup> as documented in [15].

Furthermore, Bentonite clay particles naturally possess a negative electrical charge on their surfaces. This negative charge arises from the way the clay minerals are structured. The pH of the surrounding solution can influence the extent of this negative charge. In acidic conditions, protons (H<sup>+</sup>) from the solution can interact with the clay surface, reducing the overall negative charge. Conversely, in basic conditions, hydroxyl ions (OH<sup>-</sup>) can be attracted to the surface, strengthening the negative charge [29]. The pH of bentonite clay plays a significant role in its behavior and functionality across various applications [30], [31]. In this study, the pH of both UE1 and KK1 was 7, while that of CB2 was 10, showing that CB2 was alkaline and was within the pH range of 8-10 for bentonite [8], [32]. The ideal pH range for bentonite clay can vary depending on the specific application. For instance, drilling fluids might function best in a slightly alkaline range (pH 7.5 - 9), while some pollution remediation processes might require a more acidic environment (pH 5 - 6) as reported by [12], [16].

The swelling index (SI) for CB2 was 29.5ml from the obtained results while for UE1 and KK1, it is 0. The SI of CB2 at 29.5ml is within the acceptable range of 24 - 36ml for standard commercial bentonite (ASTM D5890). The acceptable swell index for bentonite clay can vary depending on the specific application. For drilling fluids, a typical acceptable range for the swell index of bentonite clay is between 20 ml and 40 ml. This range ensures a good balance between scaling and filtration control, rheology properties and cost-effectiveness (ASTM D5890). In drilling fluids, bentonite's swelling ability is crucial for sealing gaps in the wellbore and controlling fluid filtration into the formation. A zero swell index renders the selected anthill samples in this study ineffective for these purposes, potentially leading to wellbore instability and fluid loss issues [9].

Cation Exchange Capacity (CEC) refers to the clay's ability to attract and hold positively charged ions (cations) like sodium,

calcium, or potassium. This allows bentonite to adsorb and retain various cations from surrounding solutions [14]. The CEC of CB2 was 100meq/100g and is within the range of 80 - 150meq/100g for montmorillonites, CEC for KK1 and UE1 were 5.4meq/100g and 5.8meq/100g respectively, this is within the range of 3 - 10meq/100g for kaolin as reported by [10], [18], [33]. Again, the calculated surface area of CB2 was 782.9m<sup>2</sup>/g while for KK1 and UE1 were 42.28m<sup>2</sup>/g and 45.41m<sup>2</sup>/g respectively. This shows that the surface area for CB2 is considerably larger than those of the studied anthill samples and hence, CB2 is more reactive when compared to both studied anthill clay samples, this is in agreement with that reported by [10], [16].

### 3.2 Characterization of Clay Samples Using SEM-EDS

Table 2 shows the results of the elemental chemical components of the studied anthill and bentonite clay samples obtained from the SEM- EDS technique.

The EDS analysis of the studied samples presented in Table 2, Figures 2, 3, and 4 showed that the most abundant species in all three clay samples are the Silica (59.8% for UE1, 48.0% for KK1 and 50.19% for CB2) and Alumina oxides (14.4% for UE1, 14.9% for KK1 and 30,65% for CB2). These results indicate that the clay samples are predominantly smectite. The

most significant members of the phyllosilicate mineral family known as smectite are montmorillonite, beidellite, nontronite, saponite, and hectorite [12]. The CB2 sample has a higher percentage of Si and Al oxides, this suggests that CB2 has montmorillonite as the predominant clay mineral [30]. Also, the higher percentage of Nitrogen, Oxygen, and Carbon present in the anthill clay samples suggests the presence of organic materials in UE1 and KK1 clay samples [34].

TABLE 2. Comparison of the elemental chemical composition of Anthill clays (UE1 and KK1) and Commercial Bentonite (CB2) Samples Obtained using EDS

| Element | Weight % |      |       |
|---------|----------|------|-------|
|         | UE1      | KK1  | CB2   |
| Si      | 59.8     | 48.0 | 50.19 |
| Al      | 14.4     | 14.9 | 30.65 |
| Fe      | 4.2      | 3.0  | 0.52  |
| N       | 5.7      | 8.0  | -     |
| C       | 3.6      | 6.0  | 2.24  |
| O       | 12.9     | 20.1 | 10.30 |
| Mg      | -        | -    | 1.32  |
| Mn      | -        | -    | 1.10  |

Again, plates 2a – c showed the SEM images of the studied anthill and bentonite clay samples obtained using SEM-EDS.

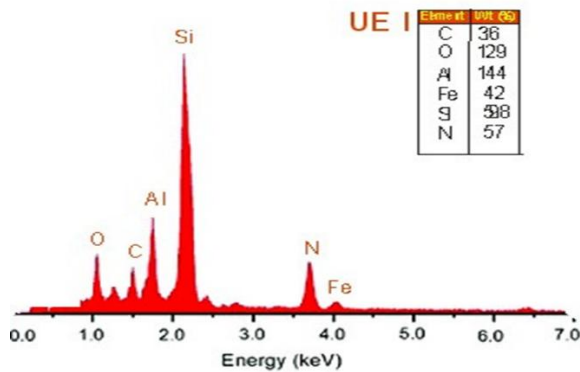


Figure 2. EDS Image of Anthill clay UE1

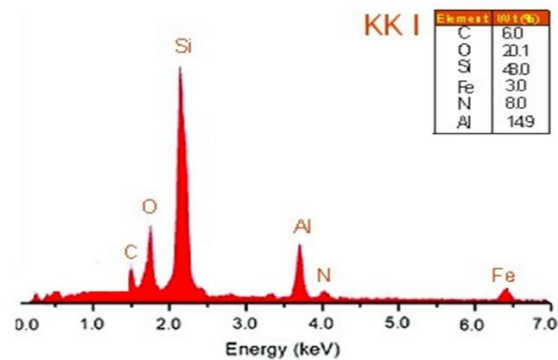


Figure 3. EDS Image of Anthill clay KK1

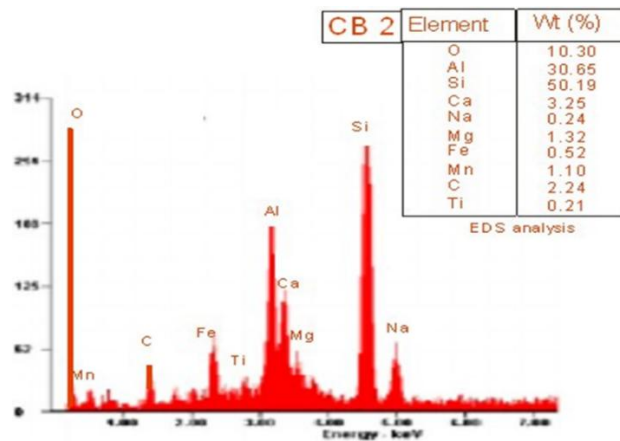


Figure 4. EDS Image of Commercial Bentonite CB2

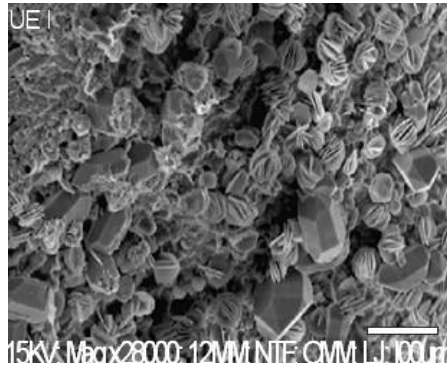


Plate 1a SEM Image of UE1 at 28,000x Magnification

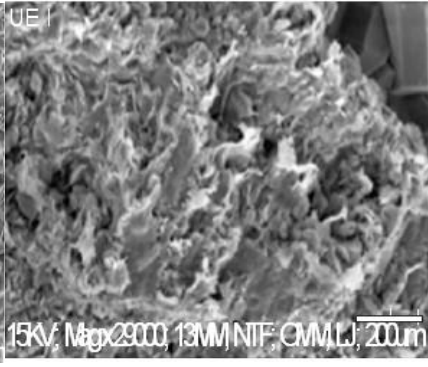


Plate 1b SEM Image of UE1 at 29,000x Magnification

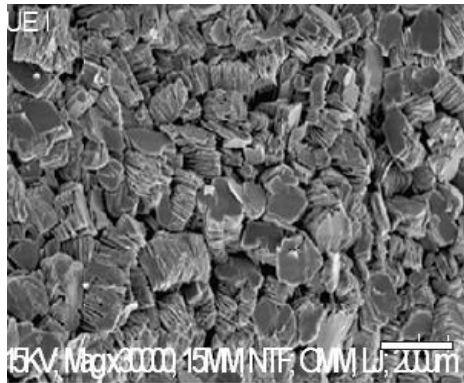


Plate 1c SEM Image of UE1 at 30,000x Magnification

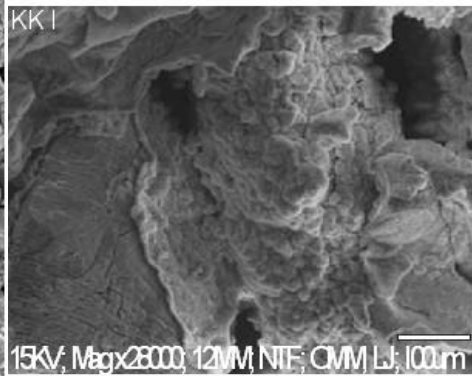


Plate 2a SEM Image of KK1 at 28,000x Magnification

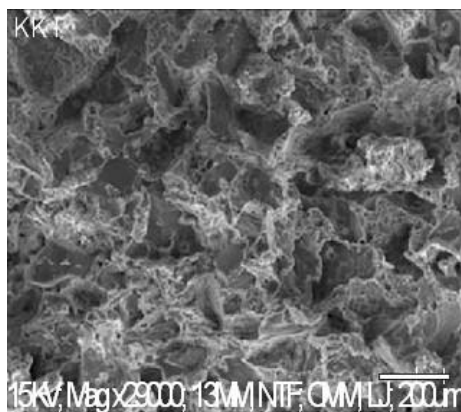


Plate 2b SEM Image of KK1 at 29,000x Magnification

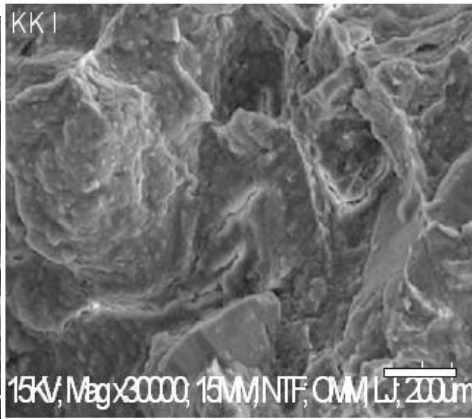


Plate 2c SEM Image of KK1 at 30,000x Magnification

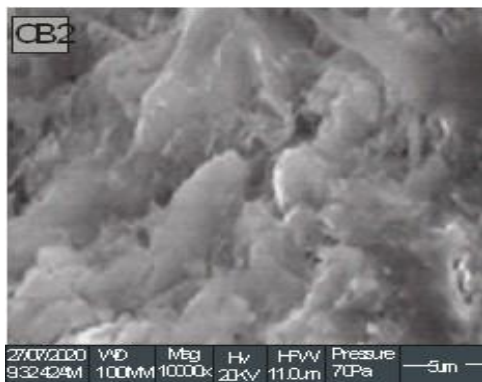


Plate 3a SEM Image of CB2 at 10,000x Magnification

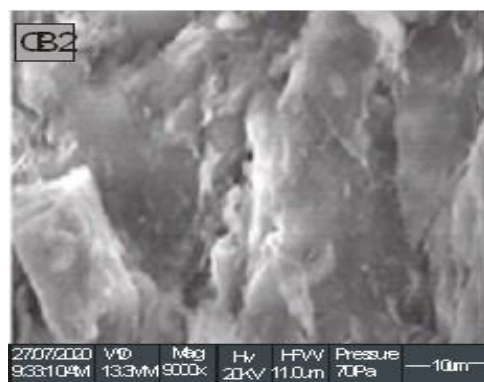


Plate 3b SEM Image of CB2 at 9,000x Magnification

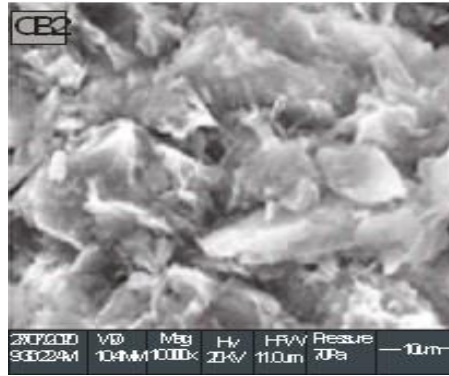


Plate 3c SEM Image of CB2 at 11,000x Magnification

The results of the analysis from SEM for CB2 as shown in Plate 3a – 3c indicate that it has smoother surfaces as compared to UE1 and KK1. The CB2 sample's low-magnification SEM revealed a sandy substance made up of fresh quartz and feldspar grains held together by a network of clay coatings and plenty of pore space. The clay itself was made up of a twisted mass of flat, exceedingly minute platy particles, each with a diameter of around 1-2  $\mu\text{m}$  and frequently curled edges. The clay-rich nature of CB2 is apparent from low magnification SEM, the whole comprising of crinkled flakes and aggregates oriented in sub-parallel fashion and with copious void space. This is similar to that obtained in research work carried out by [26], [35], suggesting that the clay sample is predominantly montmorillonite. From the SEM analysis of KK1, as shown in Plate 2a – 2c, the clay sample was observed to have a heterogeneous surface as it has large, medium, and small grains with pores as documented in [16], [35] coated with relatively fresh surfaces of feldspar. The heterogeneous surfaces increase the surface area which gives them room for good reactivity. A greater magnification revealed that the coatings were composed of spherical micro-aggregates with an average diameter of  $5\mu\text{m}$ , which were made up of radially oriented tube-like particles that gave the micro-aggregate a pincushion-like appearance overall. Individual particles are  $200\mu\text{m}$  long showing dominance of kaolinite over halloysite after the formamide test. SEM images of UE1 as shown in Plate 1a – 1c, showed sandy material with abundant pore space held together by a meshwork of clay

coatings over relatively fresh quartz and feldspar grains. The surface is heterogeneous as it also has large, medium, and small grains with pores. This suggests an increased surface area which gives them room for good reactivity as well as recorded in [26], [35].

#### 4.1.4 Characterization of Clay Samples Using Ft-Ir

Figures 5, 6, and 7 show the FT-IR spectrum of the studied anthill and bentonite clay samples

The FT-IR spectra of three clay samples (UE1, KK1, and CB2) were measured in transmittance between  $400$  and  $4000\text{cm}^{-1}$ . From the FT-IR spectrum for CB2 in Figure 7, the characteristic infrared (IR) band of montmorillonite appeared at  $3,412\text{cm}^{-1}$ . This band can be interpreted as the basic stretching vibrations of different  $-\text{OH}$  groups present in  $\text{Mg}-\text{OH}-\text{Al}$ ,  $\text{Al}-\text{OH}-\text{Al}$ , and  $\text{Fe}-\text{OH}-\text{Al}$  units in the octahedral layer [26], [35]. The strong peak that appears at  $1,012\text{cm}^{-1}$  is related to the stretching vibrations of  $\text{Si}-\text{O}$  groups, while the bands at  $525$  and  $466\text{cm}^{-1}$  are due to  $\text{Al}-\text{O}-\text{Si}$  and  $\text{Si}-\text{O}-\text{Si}$  bending vibrations respectively [32]. The peak at  $878\text{cm}^{-1}$  is assigned to  $\text{O}-\text{Si}-\text{O}$  asymmetric stretching, while the peak at  $406\text{cm}^{-1}$  is due to  $\text{O}-\text{Si}-\text{O}$  bending mode [19]. On the other hand, the peak at  $1,650\text{cm}^{-1}$  is for  $\text{H}-\text{O}-\text{H}$  bending whereas the peak at  $923\text{cm}^{-1}$  is due to  $\text{OH}$  bending bounded to  $\text{Fe}^{3+}$  and  $\text{Al}^{3+}$  as reported in [13], [14]. From the FT-IR spectra for both UE1 and KK1 in Figure 5 and Figure 6 respectively, deformations relative to the  $\text{OH}$  hydroxyl groups are presented in both UE1 and KK1 as  $\text{Fe}-\text{OH}-\text{Al}$ .

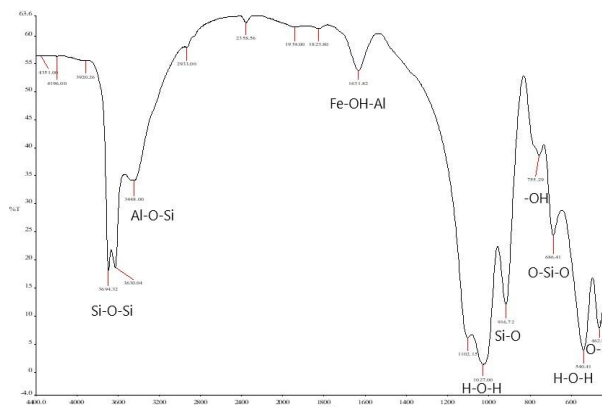


Figure 5. FT-IR Spectrum for UE1

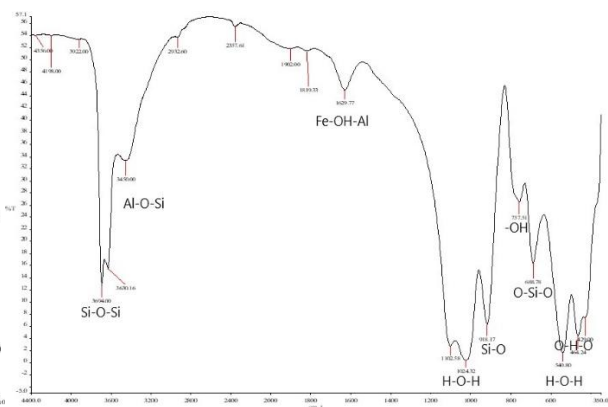


Figure 6 FT-IR Spectrum for KK1

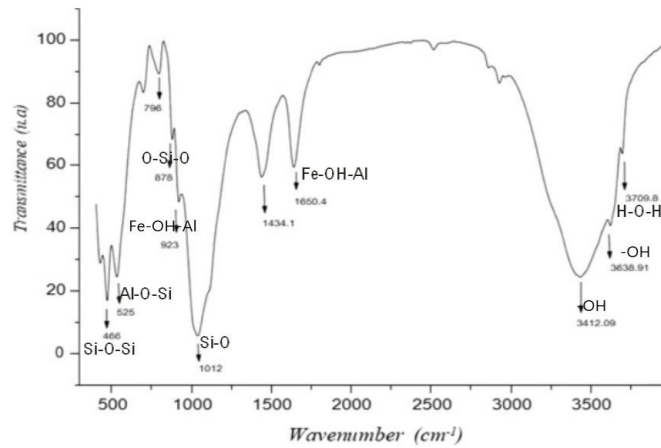


Figure 7. FT-IR Spectrum for CB2

The vibration bands of valence at 3400 and 3500 $\text{cm}^{-1}$  and the deformations at 1619 and 1641 $\text{cm}^{-1}$  are characteristic of the vibration of the hydroxyl function of the water of hydration of the clay samples and this suggests the presence of kaolin as documented in [13], [14], [33]. The Si-O group band, intense centered around 1139, 639, and 485 $\text{cm}^{-1}$  are ascribed to binding valence vibration in clay minerals. The vibrational band of valence at 2039 $\text{cm}^{-1}$  is attributed to the characteristics of the CO stretching, which confirms the presence of carbonates and other organic impurities in both UE1 and KK1 anthill clay samples. The comparison of the FT-IR spectra of all three clay samples being studied showed that the characteristic FT-IR band for montmorillonite is absent in both UE1 and KK1 clay samples but present in CB2 as expected. The characteristic FT-IR band for kaolinite is found in both UE1 and KK1 but not in the CB2 clay sample.

#### IV. CONCLUSIONS

The rising cost of imported bentonite and ceramic products has led to significant capital flight from the Nigerian economy. This necessitates the identification of suitable local alternatives for bentonite-dependent industries. The feasibility of utilizing anthill clays (UE1 and KK1) as substitutes for bentonite was examined in this research. The compositional analysis revealed similarities between UE1, KK1, and the reference bentonite (CB2), suggesting their potential as local raw materials for ceramic production. The physicochemical properties of the anthill clays indicated their suitability for various ceramic applications, including refractories, high-melting clays, and insulating materials for industrial cables and laboratory crucibles. These properties are comparable to those of bentonite for these specific applications.

However, limitations were identified for UE1 and KK1 in drilling fluid formulation. Both samples exhibited a zero-swell index, indicating no expansion upon contact with water. This property is crucial in drilling fluids for sealing wellbore gaps and controlling fluid filtration. The absence of swelling renders these anthill clays unsuitable for drilling applications, potentially causing wellbore instability and fluid loss. Additionally, the lack of montmorillonite and very low Water Absorption Capacity (WAC), Swelling Index (SI), and Cation Exchange Capacity (CEC) further limit their applicability in

drilling fluids. While UE1 and KK1 anthill clays hold promise as locally sourced raw materials for ceramic production, their lack of swelling properties excludes them from being viable substitutes for bentonite in drilling fluid formulations.

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ABBREVIATION

|         |   |
|---------|---|
| LGA     | Local Government Area   |
| KK1     | Kono, Khana LGA   |
| UE1     | Umuebulu, Etche LGA   |
| CB2     | Commercial Bentonite  |
| FTIR    | Fourier Transform Infrared Spectroscopy                         |
| SEM-EDS | Scanned Electron Microscopy with Energy Dispersive Spectroscopy |
| WAC     | Water Absorption Capacity                                       |
| SI      | Swelling Index  |
| CEC     | Cation Exchange Capacity  |