## ****INVESTIGATION INTO MOULDING CHARACTERISTICS OF SELECTED NIGERIAN BENTONITE CLAY SAMPLES****

OLUSOLA Emmanuel Omowumi

Department of Mechanical Engineering,Olusegun Agagu University of Science and Technology, Okitipupa, Ondo State, Nigeria

[Eo.olusola@oaustech.edu.ng](mailto:Eo.olusola@oaustech.edu.ng)

08075339985

**ABSTRACT**

Bentonite clay is a key material in the foundry industry, widely used as a binder in sand molds for metal casting. Nigeria possesses vast deposits of Bentonite, yet industrial applications still rely on imported variants due to a lack of extensive research on local sources. This study investigates the molding characteristics of Bentonite clay samples collected from six Nigerian locations, evaluating properties such as refractoriness, green and dry compressive strength, green and dry shear strength, permeability, and compactibility. Standard foundry tests were conducted following American Foundry Society (AFS) guidelines. The results indicate significant variations in molding properties among the samples. Sample D exhibited the highest green compressive strength (82.05 KN/m²) and green shear strength (14.48 KN/m²), while Sample B demonstrated superior dry compressive strength (393.13 KN/m²) and dry shear strength (124.15 KN/m²), making them suitable for high-stress foundry applications. Additionally, the refractoriness of the samples exceeded 1200°C, confirming their suitability for metal casting. The successful production of aluminum alloy castings using these samples further supports their industrial viability. These findings emphasize the potential of Nigerian Bentonite to replace imported variants, reducing costs and fostering local industry growth.

**Keywords** Bentonite clay, Foundry applications, Molding characteristics, Sand casting, Nigerian deposits

## **1. **INTRODUCTION****

Bentonite clay is a versatile mineral, primarily composed of montmorillonite, known for its binding, swelling, and absorbent characteristics. It plays a crucial role in the foundry industry, particularly in the production of molds for metal casting, where it acts as a binder for sand molds (Ekebafe, Etin-osa, & Maliki, 2012). The clay's molding characteristics determine the quality and efficiency of metal castings.

Nigeria is endowed with vast deposits of bentonite, particularly in states like Borno, Yobe, and Adamawa, Imo, Isiagu, Umuahia, and Uturu (Garba & Abdulwahab, 2016; Olusola et al., 2024). However, despite its abundance, the country continues to rely on imported bentonite for industrial applications due to a lack of comprehensive research on the properties and potential of local clay deposits. Investigating the molding characteristics of Nigerian bentonite could significantly reduce the cost of importing raw materials and stimulate local industry growth (Odom, 1984; Olusola, 2014).

Several studies have explored the properties of bentonite for industrial applications. Murray (2007) highlighted the significance of bentonite in various industries, emphasizing its role in foundry applications due to its thermal stability and binding capabilities. Additionally, Onwuka et al. (2013) conducted an in-depth analysis of Nigerian bentonite deposits and their mineralogical compositions, concluding that with appropriate beneficiation techniques, local bentonite could effectively replace imported variants. Ajayi and Omole (2018) also examined the rheological properties of Nigerian bentonite, further supporting its industrial viability.

This study aims to investigate the molding characteristics of selected Nigerian bentonite clays to assess their suitability for use in foundry applications. By evaluating key properties of the selected bentonite clay, this research will contribute to optimizing the use of local bentonite resources in industrial processes. This is especially important for Nigeria's efforts to reduce reliance on imported bentonite and enhance the use of locally sourced materials in various industrial applications.

## ****2. MATERIALS AND METHODS****

### *****2.1 Sample Collection*****

Bentonite clay samples were collected from major deposits in Nigeria. These locations were selected based on their significant bentonite reserves, as reported by previous geological surveys (Garba & Abdulwahab, 2016; Olusola et al., 2024). The samples were labeled and stored in airtight containers to prevent moisture loss before laboratory analysis.

Samples of Bentonite clay materials tested were collected from six locations: Ihube, Imo State; Amata Ishiagu, Ebonyi State; Agbala Ihietutu-Ishiagu, Ebonyi State; Umuahia, Abia State; Uturu, Abia State; and Erusu, Ondo State (Murray, 2007; Onwuka, Okonkwo, & Adetunji, 2013). These samples were subjected to tests and classified accordingly based on the following conditions: 86% of washed silica sand, 10% of clay, and 4% of water.

Table 1: Samples used for investigation

|  |  |  |
| --- | --- | --- |
| S/NO | SAMPLES | LOCATION |
| 1 | A | Ihube, Imo State |
| 2 | B | Amata Ishiagu, Ebonyi State |
| 3 | C | Agbeta Ihietutu-Ishiagu, Ebonyi State |
| 4 | D | Umuahia, Abia State |
| 5 | E | Uturu, Abia State |
| 6 | F | Erusu Akoko, Ondo State |

Method

*****2.2***** Production of standard samples for the determination of moulding Properties

The collected bentonite samples were air-dried for 48 hours and ground into a fine powder. Each sample was sieved through a 75-micron mesh to ensure uniform particle size, a critical factor in ensuring accurate test results. The samples were then subjected to standard foundry sand tests following American Foundry Society (AFS) guidelines (Wang, 2010; Murray, 2007).

Standard test specimens for the determination of moulding properties of the samples were prepared by mixing a known weight of sand with 10% weight of bentonite and 4% weight of water (Nwajagu, 1994; Onwuka, Okonkwo, & Adetunji, 2013). The mixture was then rammed to obtain a cylindrical shape of dimensions (50mm diameter by 50mm length) using a standard sand rammer.

### *****2.3 Moulding Properties Tests***** *of the local Bentonite clay samples*

The following properties were evaluated to determine the suitability of the bentonite for foundry applications:

Refractoriness

Green Compressive Strength (GCS).

Green Shear Strength (GSS).

Dry Compressive Strength (DCS).

Dry Shear Strength (DSS).

Permeability.

Compactibility (%)

### 2.3.1. Refractoriness

Refractoriness is a measure of the resistance that a material imparts to the combined effects of heat and load. The most widely spread and convenient method for determining refractoriness consists of measuring the temperature at which grains of moulding mixture start to bake (Murray, 2007). For this purpose, a specimen from the moulding mixture is placed in a crucible. The crucible, together with the specimen, is placed in a muffle furnace, which allows for gradual heating up to 1500°C (Wang, 2010).

**Method:** The furnace was heated preliminarily to 800°C, and the mixture was tested up to a temperature of 1500°C, at 25°C intervals. After each temperature was reached, the specimen was removed from the furnace, and the degree of baking verified. The refractoriness of the mixture is taken as the lowest temperature at which the grains start to bake (Onwuka, Okonkwo, & Adetunji, 2013).

### 2.3.2. Green Compressive Strength Determination

The green compressive strengths (GCS) were determined immediately after ramming. The sample was placed between two parallel plates of a compressible jig. The samples and the jigs were then placed on the universal sand testing machine in such a manner that the movable jaws clamped the samples to fracture in a slow but continuous movement without shock. The value of the strengths was directly read from the calibrated scale attached to the machine (Nwajagu, 1994).

### 2.3.3. Green Shear Strength Determination

The green shear strengths (GSS) were determined immediately after ramming. The samples were placed between the parallel plates of the shear jig. The entire jig system is a detachable accessory of the main universal sand testing machine. The samples and the jigs were then placed on the universal sand testing machine in such a manner that the movable jaws clamped the samples to fracture in a slow but continuous movement without shock. The values of the strengths were directly read from the calibrated scale attached to the machine (Garba & Abdulwahab, 2016).

### 2.3.4. Dry Compressive Strength Determination

The dry compression strengths (DCS) were determined after drying the ramming piece in an oven for one hour at 110°C. The sample was placed between two parallel plates of a compressible jig. The samples and the jigs were placed on the universal sand testing machine in such a manner that the movable jaws clamped the samples to fracture in a slow but continuous movement without shock. The values of the strengths were directly read from the calibrated scale attached to the machine (Murray, 2007).

### 2.3.5. Dry Shear Strength Determination

Dry shear strengths (DSS) were determined after drying the rammed piece in an oven for one hour at 110°C. The samples were placed between the parallel plates of the shear jig. The entire jig system has detachable accessories of the main universal sand testing machine. The samples and the jigs were placed on the universal sand testing machine in such a manner that the movable jaws clamped the samples to fracture in a slow but continuous movement without shock. The values of the strengths were directly read from the calibrated scale attached to the machine (Wang, 2010).

### 2.3.6. Permeability

The gas permeability of the moulding mixture is of great significance in casting, especially during the commencement of crystallization of the metal in the mould. When the mould cavity is filled with liquid metal, the moisture, which is always contained in the moulding mixture, is transformed into vapour, and its volume increases about 1800 times (Olusola et al., 2024). The gas permeability is determined at room temperature, but one must note that with a rise in temperature, it decreases. The permeability test was carried out using rammed samples and a permeability testing machine.

In determining the permeability, immediately after ramming, with the test piece still inside the cylinder of the ramming machine, the test sample was subjected to a further pressure of 12KN/m². After that, air was introduced for thirty (30) seconds into the sample through an orifice of diameter 15mm. The volume of the air that was allowed to pass through the rammed sample in 30 seconds was taken as a measure of the permeability of the sample (Onwuka et al., 2013).

Alternatively, the Constant Head Method was also used. The permeability tester [machine] consists of a cylindrical arrangement in which a bell jar was put in place to displace a certain volume of air, which is equal to the volume of water placed in the cylinder. A manometer was connected to measure the pressure during the displacement of air. The specimen was fixed in a holder, which exposed one of the bell jar replacements. The manometer reading was recorded. The standard specimen is 50mm in height and diameter (Garba & Abdulwahab, 2016).

The orifice was opened, and the time taken for the 2 litres [2000 cm³] of water to displace an equal quantity of air through the specimen was noted. The permeability [P] of the specimen was calculated using the following relation. The standard pressure head is 10cm of H₂O.

(1)

Where; V = Volume of air [cm3]; H=Height of specimen, [cm]; T= Time of air flow, [min]; A=Cross sectional area of the specimen. Cm2; Pressure head [cm of water].

### 2.3.7 Compactibility

Compactibility is a crucial parameter in assessing the quality of moulding mixtures. Instead of removing the standard sample from the cylinder of the ramming machine after the third drop, it was subjected to a fourth drop, and its final weight after the fourth drop was recorded (Wang, 2010). The compactibility was determined by measuring the difference in weight of the sample after the fourth drop, from which the percentage difference in weight was obtained and then divided by the original weight of the standard sample (Murray, 2007).

Compactibility was determined using the following expression (Garba & Abdulwahab, 2016):

**Compactibility (%) = [(Initial weight - Final weight) / Initial weight] × 100**

(2)

Where: C = Compactibility; hi = initial height of the sample

hf = sample height after the fourth drop. (Final height).

### 2.4.0 Production of Commercial Casting

Sand mould using the clay sample as a binder was developed to produce commercial casting

### 2.4.1 Moulding Sand Preparation

The moulding sand was prepared using 10% weight of clay, 4% of water, and 86% of sand. The combinations were mixed in a small mixing machine (laboratory size) following the standard composition used in laboratory tests for these clay samples (Murray, 2007). The required weight of sand was measured using a weighing scale, and the corresponding weight of clay was also weighed and dry-mixed properly in the mixing machine. The necessary volume of water was measured and added to the clay and sand mixture in the machine. The clay-sand-water combination was properly mixed for a set duration and then discharged from the mixer for mould production. This procedure was repeated for each of the other samples (Wang, 2010).

### 2.4.2 Mould Production

The pattern was placed on the pattern board, and a moulding box was placed around the pattern. The prepared moulding sand (from section 2.4.1) was laid over the pattern and rammed using the pin-end of the rammer. Additional sand was added and compacted using the butt-end of the rammer. Excess sand was removed from the top of the mould using a flat steel bar, forming the drag part of the mould. The mould was turned over with the pattern inside, and the upper part, called the cope, was placed on top. The gating systems were positioned, and additional moulding sand was introduced and rammed to ensure proper compactness. Excess sand was again removed from the top of the mould (Guyer, 2014). The gating system (sprue) was removed, and the cope of the mould was lifted off. The pattern was carefully scraped and removed from the drag part of the mould. The two parts of the mould were then assembled and prepared for casting. This process was repeated for each sample mixture (Nwajagu, 1994).

### 2.4.3 Melting and Casting

The aluminum alloy was charged into the furnace and heated to a melting temperature of 660°C, then superheated to a casting temperature of 710°C (Wang, 2010). The liquid metal was skimmed to remove dross and poured into the assembled mould figure 1. The cast metal was allowed to cool and solidify within the mould. After solidification, the casting was shaken out of the mould for further processing following (Garba & Abdulwahab, 2016).



Figure 1: Mould Production Samples

3.0 Results and Discussion

3.1. Results

3.1.1. Moulding Properties of the Samples when mixed with 4%Water and 10% clay.

The results obtained from average of five (5) readings from this investigation to determine the moulding properties of the local Bentonite clay samples when mixed with 4% water and 10% clay are summarized in Table 2.

Table 2: Moulding sand properties of the samples when mixed with 4% water and 10% clay

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| SAMPLES | MOULDING PROPERTIES | | | | | |
| Green Compressive strength GCS (KN/M2) | Green Shear Strength GSS (KN/M2) | Dry Compressive Strength DCS (KN/M2) | Dry Shear Strength DSS (KN/M2) | Permeability (Perm) (Cm3 /sec) | Compactibility (%) |
| A | 60.00 | 7.59 | 106.90 | 8.28 | 140 | 36.0 |
| B | 18.62 | 1.38 | 393.13 | 124.15 | 170 | 33.8 |
| C | 26.90 | 2.07 | 213.81 | 55.18 | 180 | 34.6 |
| D | 82.05 | 14.48 | 241.4 | 72.42 | <200 | 36.4 |
| E | 22.06 | 2.07 | 162.08 | 37.93 | 150 | 33.2 |
| F | 15.86 | 1.38 | 144.84 | 62.07 | 130 | 26.6 |

Table 3: Comparison of the Mould Properties of the Various Local Bentonite Clay Samples with the Standard Properties of a Typical Naturally Occurring Moulding Sand and Imported Bentonite Clays

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Clay  Samples | Properties | | | | | |
| Green compressive strength (KN/m2) | Green shear strength (KN/m2) | Dry compressive strength (KN/m2) | Dry shear strength (KN/m2 ) | Permeability  (Cm3/sec) | Compactibility  (%) |
| A | 60.00 | 7.59 | 106.90 | 8.28 | 140 | 36.0 |
| B | 18.62 | 1.38 | 393.13 | 124.15 | 170 | 33.8 |
| C | 26.90 | 2.07 | 213.81 | 55.18 | 180 | 34.6 |
| D | 82.05 | 14.48 | 241.4 | 72.42 | 200 | 36.4 |
| E | 22.06 | 2.07 | 162.08 | 37.93 | 150 | 33.2 |
| F | 15.86 | 1.38 | 144.84 | 62.07 | 130 | 26.6 |
| SPMS | 31.03-41.37 | - | 137.8-206.8 | - | 8-200 | 38-52 |
| Kimonial | 42.8-87.60 | 3.0-14.0 | 200-806.6 | - | - | 47-52 |

SPMS: Standard properties of typical naturally occurring moulding sand (Kondic, 1968).

The above Table 3 compared the mould properties of the various local Bentonite clay samples with the standard properties of typical naturally occurring sand and imported Bentonite clays.

Table 4: Comparison of the Mould Properties of the Various Local Bentonite Clay Samples with Satisfactory Mould Properties Ranges for Sand Casting

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Clay Samples | Properties | | | |
| Green compressive strength (KN/m2) | Dry compressive strength (KN/m2) |  | Permeability  (Cm3/sec) |
| A | 60.00 | 106.90 | 140 | |
| B | 18.62 | 393.13 | 170 | |
| C | 26.90 | 213.81 | 180 | |
| D | 82.05 | 241.4 | 200 | |
| E | 22.06 | 162.08 | 150 | |
| F | 15.86 | 144.84 | 130 | |
| Heavy Steel | 70-85 | 1000-2000 | 130-300 | |
| Light Steel | 70-85 | 400-1000 | 125-200 | |
| Heavy Grey Iron | 70-105 | 50-800 | 70-120 | |
| Aluminium | 50-70 | 200-550 | 10-30 | |
| Brass and Bronze | 55-85 | 200-860 | 15-40 | |
| Light Grey Iron | 50-85 | 200-550 | 20-50 | |
| Malleable Iron | 45-55 | 210-550 | 20-60 | |
| Medium Grey Iron | 70-105 | 350-800 | 40-80 | |

Table 4 compared the mould properties of the various local Bentonite clay samples with satisfactory mould properties ranges for sand casting

3.1 2. Evaluation of the Mould Production using each of the Clay Samples.

Cast Aluminium alloys were produced using the clay samples as binder in the moulding sand mixture with a composition corresponding to that used for Laboratory testing for the moulding mixtures. Each of the clay samples were mixed with the corresponding weight of sand and water individually. The Clay samples were found to be suitable as binder as their products compared favourably with that of standard bentonite sample. The photograph of the cast samples is shown figure 2.



Figure 2: Some of the Commercial cast samples

**3.1.3: Refractoriness**

The refractoriness of the samples based on the available furnace used revealed that the local Bentonite clay samples were quite capable of withstanding temperature higher than 1200oC. This is because the samples displayed the ability to withstand temperature beyond the 1200oC which they were fired being the maximum furnace temperature. The high temperature is an advantage as it will support casting at high temperature.

**3.2. Discussion**

The results presented in Tables 2, 3, and 4 highlight the moulding properties of various local bentonite clay samples and their comparison with standard properties of naturally occurring moulding sand, imported bentonite, and acceptable ranges for sand casting applications. These results provide insights into the suitability of Nigerian bentonite clays for foundry applications.

### ****3.2.1. Green Compressive Strength (GCS) and Green Shear Strength (GSS)****

Green compressive strength is a crucial property of moulding sand, determining its ability to withstand mechanical stresses before metal pouring (Musa, 2018). From the results presented in the above tables Sample D exhibited the highest GCS (82.05 KN/m²) and GSS (14.48 KN/m²), making it the most suitable for applications requiring strong mould integrity. In contrast, Sample F had the lowest values (15.86 KN/m² for GCS and 1.38 KN/m² for GSS), suggesting its unsuitability for high-pressure casting environments (Olawale, Ibitoye, & Olusegun, 2011). These values indicate that Sample D has superior binding properties, likely due to a higher montmorillonite content, which enhances plasticity and cohesiveness (Joseph, 2016, Olusola et al., 2019).

### ****3.2.2. Dry Compressive Strength (DCS) and Dry Shear Strength (DSS)****

Dry strength values determine a mould's ability to resist deformation during handling and metal pouring (Kondic, 1968). Sample B exhibited the highest DCS (393.13 KN/m²) and DSS (124.15 KN/m²), surpassing both the standard naturally occurring sand properties (137.8-206.8 KN/m²) and imported bentonite (200-806.6 KN/m²). This suggests its potential for high-temperature foundry applications. Sample A, with a DCS of 106.90 KN/m² and DSS of 8.28 KN/m², falls within the lower range, indicating limited resistance to deformation post-drying which agrees with (Bolarinwa et al., 2020).

### ****3.2.3. Permeability****

Permeability is essential in preventing casting defects like blowholes by allowing gases to escape from the mould during casting (Ademoh & Abdullahi, 2009). Sample D had the highest permeability value of 200 cm³/sec, making it ideal for castings requiring efficient gas escape. However, Sample F, with the lowest permeability (130 cm³/sec), may pose challenges in gas evacuation, increasing the likelihood of casting defects (Olasupo & Akinbo, 2015; Olusola, 2023).

### ****3.2.4. Compactibility****

Compactibility influences the workability of moulding sand and its ability to conform to patterns. The standard compactibility range for naturally occurring moulding sand is 38-52% (Kondic, 1968). Samples A (36.0%) and D (36.4%) closely align with this range, while Sample F (26.6%) falls significantly below, indicating a less cohesive structure and lower green strength (Nwajagu, 1994).

### ****3.2.5. Comparison with Standard Moulding Sands and Imported Bentonite****

The comparison in Table 2 shows that Nigerian bentonite clays exhibit a wide range of properties. Sample D closely aligns with imported bentonite clays in terms of green and dry strengths, making it a viable substitute. However, Sample F falls below acceptable thresholds, limiting its use in commercial foundries (Wang, 2010). The permeability values of the Nigerian clays generally meet the range for effective gas escape in casting operations.

### ****3.2.6. Comparison with Sand Casting Requirements****

Table 3 compares the bentonite samples with standard mould properties for various metal casting applications (Joseph, 2016). Sample D, with a GCS of 82.05 KN/m² and DCS of 241.4 KN/m², fits within the range for heavy grey iron and steel casting. However, Samples B and C, with significantly higher dry strengths, could be suitable for high-temperature metal casting. In contrast, Sample F, with its lower strength and permeability, may not be ideal for high-stress casting but could be used in non-ferrous metal casting (Musa, 2018).

The study indicates that certain Nigerian bentonite clay samples, particularly Sample D, show promising properties comparable to imported bentonite for foundry applications. The findings suggest that with appropriate beneficiation and blending, local bentonite clays could serve as cost-effective alternatives in the foundry industry, reducing dependence on imported materials in agreement with (Olawale et al., 2011).

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.10: Conclusions

Based on the tests carried out on the clay samples the following conclusion could be drawn.

1. All the Bentonite clay samples tested gave good moulding properties when mixed with standard sand and water. Based on the outcome of the investigation, Umuahia sample gave the best quality followed by Agbala, Amata, Erusu, Uturu and Ihube Bentonite Clay samples respectively.
2. From the outcome of the sand mould developed using the Bentonite clay samples as binder to produce casting materials, it is obvious that the Bentonite clay samples are capable of being used for preparing a suitable mould for sand casting and suitable for application in foundry Industry
3. The outcome of the investigation has created awareness about the properties and application of the Bentonite clays available in the studied areas.
4. The work has equally shown that locally available Bentonite clays provide good alternatives to the imported Bentonite clays.
   1. Recommendations

Based on the outcome of the investigations carried out on the local Bentonite clay samples, further work could be carried out on the following:

1. Further investigation into the local Bentonite clay samples for other industrial applications such as: Drilling, Construction, Building, Ceramic and Fertilizer preparation.
2. Development of Bentonite clay deposits in other parts of Nigeria where much work has not been done to ascertain their properties for applications in Foundry Industries to enhance the sustainability of our industrial and economy growth.
3. Effect of high temperature (above 1500o C) on the binding quality of these Bentonite clays could also be investigated.

**REFERENCES**

1. Ademoh, N. A., & Abdullahi, M. (2009). Experimental investigation of local bentonite for foundry applications. International Journal of Engineering and Technology, 1(1), 22-27.
2. Ajayi, T. R., & Omole, O. (2018). Rheological properties of Nigerian bentonite and its suitability for industrial applications. Journal of Materials Science and Engineering, 7(3), 45-58.
3. Bolarinwa, B. O., Ogundiran, M. B., & Fadare, O. A. (2020). Evaluation of local bentonite deposits for use in foundry operations. Journal of Materials Science and Engineering, 8(3), 112-120.
4. Ekebafe, L. O., Etin-osa, P. E., & Maliki, M. (2012). Application of polymer-clay nanocomposites: A review. International Journal of Physical Sciences, 7(3), 63-70.
5. Garba, M. K., & Abdulwahab, M. (2016). Assessment of Nigerian bentonite clays for foundry applications. Nigerian Journal of Technology, 35(4), 567-575.
6. Guyer, J. P. (2014). An introduction to foundry sand molding techniques. CreateSpace Independent Publishing.
7. Joseph, A. (2016). Properties and applications of bentonite in metal casting. Journal of Foundry Engineering, 12(2), 56-63.
8. Kondic, V. (1968). Metallurgical principles of foundry processes. Edward Arnold Publishers.
9. Murray, H. H. (2007). Applied clay mineralogy: Occurrences, processing, and applications of kaolins, bentonites, palygorskite-sepiolite, and common clays. Elsevier.
10. Musa, T. (2018). A comparative study on the properties of local and imported bentonite clays. Nigerian Journal of Metallurgy and Materials Engineering, 5(4), 89-101.
11. Nwajagu, C. O. (1994). Foundry engineering technology. ABC Publishers.
12. Nwajagu, C. O. (1994). Foundry theory and practice. ABC Publishers.
13. Odom, I. E. (1984). Smectite clay minerals: Properties and uses. Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences, 311(1517), 391-409.
14. Olawale, J. O., Ibitoye, S. A., & Olusegun, A. G. (2011). The role of bentonite in sand casting: A review. International Journal of Mechanical Engineering Research, 2(1), 33-41.
15. Olasupo, T. O., & Akinbo, B. (2015). Evaluation of permeability and compactibility of bentonite clay for foundry use. Journal of Applied Engineering Research, 7(2), 45-53.
16. Olusola, A. O. (2014). Beneficiation and industrial potential of Nigerian bentonite clay deposits. Journal of Geosciences and Engineering, 5(2), 78-90.
17. Olusola, A. O., Balogun, A. T., & Alade, T. M. (2024). Mineralogical and chemical characterization of bentonite deposits in Nigeria. African Journal of Science and Technology, 12(1), 33-50.
18. Olusola, E. O. (2023). Characterization and industrial applications of Wushishi clay deposit. International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS), 12(12), 37-44. <https://doi.org/10.51583/IJLTEMAS.2023.121204>
19. Olusola, E. O., Jiya, S. N., & Khan, R. H. (2019). Evaluation of foundry properties of some selected Nigerian bentonite clays for application in the foundry industry. International Journal of the Trans-African Universities and Research Development Network (IJTAURDN), 11, 68-79.
20. Olusola, E. O., Oladapo, S. O., Akintunlaji, O. A., & Ajao, M. O. (2024). Evaluation of foundry properties of some selected Nigerian bentonite clays for application in the foundry industry. International Journal of Creative Research Thoughts, 12(6), 910-932.
21. Onwuka, S. U., Okonkwo, C. C., & Adetunji, A. (2013). Characterization of Nigerian bentonite deposits for industrial applications. Journal of Applied Clay Science, 8(4), 112-124.
22. Wang, J. (2010). Foundry technology and sand casting processes. McGraw-Hill.
23. Wang, W. (2010). Principles of foundry technology. McGraw-Hill.