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EVALUATION OF FOUNDRY PROPERTIES OF SOME SELECTED NIGERIAN BENTONITE CLAYS FOR APPLICATION IN THE FOUNDRY INDUSTRY

OLUSOLA, Emmanuel Omowumi.[1], OLADAPO, Samuel Oluwasehun[2], AKINTUNLAJI Olusola Akinbolaji[3] & AJAO, Majeed Opeyemi[4]

1. Senior Lecturer, Mechanical Engineering, Olusegun Agagu University of Science and Technology, Okitipupa, Ondo State
2. Lecturer 1, Mechanical Engineering, Olusegun Agagu University of Science and Technology, Okitipupa, Ondo State
3. Lecturer 1, Mechanical Engineering, Olusegun Agagu University of Science and Technology, Okitipupa, Ondo State
4. PG Student, Federal University of Technology Minna, Niger State, Nigeria

Abstracts

An evaluation was conducted on the foundry properties of selected Nigerian Bentonite Clays to address the demand in foundry, steel, and metallurgical industries, as well as future industrial development. Samples were collected from six locations in four states of Nigeria, with five different points sampled from each location for investigation. Using the cone and quartering technique, the samples were homogenized to obtain representative samples, which were then subjected to tests to determine their foundry properties.The chemical composition of the raw samples was compared favorably with Bomu, Amake, and Yobe bentonite clay deposits in Nigeria, as well as Wyoming bentonite in the USA. Based on the CaO content in their chemical composition, the clay samples were classified as calcium-based Bentonite clay. The cation exchange capacity of Samples A (83.973) and E (72.453) fell within the standard value range (70-120) for Montmorillonite. Conversely, Samples B (60.977), C (55.14), D (65.405), and F (62.289) slightly fell below the standard value range for Montmorillonite. However, these results still indicated that the samples are suitable for applications in the foundry industry, as they compared well with values (64-105) for Wyoming bentonite.The pH values of samples A, B, C, E, and F indicated that they are basic clays, while sample D is an acidic clay. Based on these findings, the clay samples are deemed suitable for application in the foundry industry and can be used for commercial sand casting. It is recommended to conduct further investigations into the selected Bentonite samples for other industrial applications. Additionally, exploring Bentonite clay deposits in other parts of Nigeria where research is lacking would be beneficial in determining their properties and usefulness as binding agents in the foundry industry, thereby contributing to the sustainability of our economy and industrial growth.

Index Terms: Evaluation, Foundry, Properties, Selected, Bentonite, Applications, Industry

I. INTRODUCTION

Bentonite clays are a vital material in the foundry industry due to their unique properties that contribute to the successful creation of metal castings (Olusola, 2014; Akhadionu et al., 2019). These clays act as binders, enhancing the mold's strength and workability while withstanding the high temperatures associated with molten metal (Akintunde & Olusola, 2020).

While Nigeria possesses abundant clay deposits, it currently relies heavily on imported bentonite, incurring high costs and draining valuable foreign exchange (Olusola, 2014; Okologume & Akinwumi, 2016). This is because their suitability for foundry applications remains largely unexplored (Akhadionu et al., 2019). Despite this dependence, research on the suitability of Nigerian bentonite clays for foundry applications remains limited.

Some studies have highlighted the importance of utilizing local resources for the foundry industry. Okologume and Akinwumi (2016) emphasized the need for exploiting domestic bentonite resources in Nigeria's metallurgical industries.This research contributes to the ongoing effort to explore and utilize Nigeria's natural resources for industrial applications.

Nigeria's abundant natural resources, if efficiently utilized, hold immense potential for industrial growth and technological advancement (Olusola et al., 2023). The aim of this research is to evaluate the foundry properties of selected Nigerian bentonite clays to determine their potential as a domestic alternative to imported bentonite.

II. MATERIALS AND METHODS

2.1 Materials

2.1.1 Bentonite clay samples

Samples of Bentonite clay materials were collected from five different points of various deposits in each location and States (A) Uhube, Imo state; (B) Amata, Ishiagu, Ebonyi State; (C) Agbata-Ihietutu, Ishiagu, Ebonyi State; (D) Umuahia, Abia State; (E) Uturu, Abia State; and (F) Erusu-Akoko, Ondo State) marked for investigation. The samples were collected and put in polythene bags. The samples were homogenized to obtain representative sample using cone and quartering technique. Each sample was marked for identification and their foundry properties were tested.

2.2 Methods

Tests of Bentonite for Foundry Applications

For each of the samples the following properties were determined:
Chemical composition (%), Cation exchange capacity (CEC), Grain Size Analysis (%), Moisture content (%), Liquid Limit (%), Plastic Limit (%), Plasticity Index (%), Swelling index Test cc (%), pH Value, Bulk Density (g/cm^3), and Refractoriness (^oc)

2.2.1 Chemical composition

In determining the chemical composition of each of the local Bentonite clay samples, instrumental analysis by Atomic Absorption Spectrophotometer (AAS) Thermo Scientific S4 Series method was utilized.

2.2.2 Cation Exchange Capacity

Generally, Cation exchange capacity refers to ease with which calcium ion, magnesium and sodium ions are exchangeable for others in soluble forms. The amount of positively charged cations a soil can hold is described as the CEC and is expressed in milliequivalents per 100 grams (meq/100g) of soil. The larger this number, the more cations the soil can hold. A clay soil will have a larger CEC than sandy soil. To carry out Cation Exchange Capacity test, the bentoinite clay samples were first pulverized after oven drying at temperature $\geq 40^0C$, they were then sieved through 2mm diameter B.S sieve. The prepared samples were converted to clay extract which were tested for exchangeable cations using flame photometer and rapid titration methods.

2.2.3 Grain Size Analysis

This analysis helps to estimate the amount of non-clay material or impurities which is found within the natural clay. The particle size distributions of the samples were determined using the B.S Standard test sieves. 300g Bentonite clay sample was weighed and poured into already arranged sieves on a mechanical shaker. It was shaken for 25 minutes after which mass on each sieve was determined. The percentage retained and percentage passing for each sieve and pan was calculated using the following expressions.

$$\textbf{Percentage Retained}(\%R) = \frac{\text{weight retained}}{\text{Initial weight}} \times 100$$

$$= \frac{wr}{wi} \times 100 \quad (1)$$

$$\textbf{Percentage passing}(\%P) = 100 - \frac{wr}{wi} \times 100 \quad (2)$$

The calculation was carried out for each of the samples

2.2.4 Moisture Content Determination

Simple direct method for determining moisture contents was used. 50g of the mixture was weighed out with 0.01g accuracy, spread in a thin layer on sand glass and dried at temperature 110^0 c to constant weight. , it was then cooled in a desiccator and re-weighed. The difference in weight was expressed as a percentage to the dry weight as follows

$$Mc = \frac{Gw - GD}{GD} \times 100. \quad (3)$$

Where:
M_C = moisture content, G_w = mass of the wet sample, G_D = mass of the sample after drying.

2.2.5 Liquid Limit Test

It is also possible to determine both the type and the quality of the clay through the determination of the Liquid limit (LL) and the plastic limit of the clay samples. Liquid limit is the water content at which clay changes from the liquid state to the plastic state. At the liquid state, the clay is practically like a liquid, but possesses a small shearing strength. Liquid limit (LL) is an indicator of the bonding property of a bentonite. Cone penetration method was used in the present research work. The cone penetration consists of stainless steel cone having an apex angle of $30^o \pm 1$ and a length of 35mm. The cone is fixed at the lower end of a sliding rod which is fitted with a disc at its end and the disc is about 80g ± 0.05g.

Method: 120g of an air- dry clay sample passing through 425µ IS sieve was taken in disc and mixed with distilled water to form a uniform paste. A portion of the paste was placed in a cup of 50mm internal diameter and 50mm height. The cup was filled with the clay sample taking care so as not to entrap air. Excess clay was removed and the surface of the clay was leveled up.The cup was then placed below the cone and the cone was gradually lowered so as to just touch the surface of the clay in the cup as shown in Plate IV**.** The graduated scale was adjusted to zero. The cone was released, and allowed to penetrate the clay for 30 seconds. The water content at which the penetration is 25mm is the Liquid limit. The Liquid limit could be determined using the relation:

$$W_L = w_y + 0.01(25 - y)(w_y + 15) \quad \textbf{(Velde, 1995)} \quad (4)$$

Where y is the penetration when water content is w_y and W_L = Liquid limit

2.2.6 Plastic Limits (PL)

Plastic limit can be used as a simple indicator of bentonite grade (Olusola, 2014). Plastic limit can be defined as the moisture content of clay at a point where it becomes plastic. Method: For the determination of the plastic limit, the clay samples were air dried and sieve through a 425µ IS sieve. 30g of the clay samples was taken in an evaporating dish. Each sample was mixed thoroughly with distilled water till it becomes plastic and can be easily moulded with fingers. 10g of the plastic clay samples were taken in one hand to form a ball. The ball was rolled with the fingers on a glass plate to form a clay thread of uniform diameter. The rate of rolling was kept to between 80 – 90 strokes per minute and the procedure was repeated till the thread crumbles. The water content at which the clay can be rolled into a thread of approximately 3mm in diameter without crumbling is known as the plastic limit. The Plastic limit was taken as the average of two or three values.

2.2.7 Swelling index test

The samples were dried up to the room temperature of 25^{0}C for five days after been quartered through ruffle – box from the semi-dried samples brought to laboratory. 100ml graduated cylinder marked "A, B, C, D, E, F" to correspond with the specimen's identification marks respectively were filled with 80ml of Distilled water. 2grams sample of dried and finely ground bentonite clay was then dispersed into the graduated cylinder marked "A" to "F" to correspond with the specimen's identification marks respectively in 0.1g increments. A minimum of 10minutes was allowed between additions to allow for full hydration and settlement of the clay to the bottom of the cylinder. These Steps were followed until the entire 2gm sample has been added to each of the cylinders accordingly. The sample was then covered and protected from disturbances for a period of 24 hours, at which time the level of the settled and swolling clay was recorded to the nearest 0.5ml. Percentage swelling index was calculated using the relation:

$$\textbf{Percentage swelling index} = \frac{\textbf{final reading – initial reading}}{\textbf{initial reading}} \textbf{ x 100} \qquad \textbf{(5)}$$

2.2.8 Measurement of pH value

Suspensions (20% w/v) of the samples were prepared and allowed to stand for 30 minutes with occasional stirring with a glass rod. The electrode of the pH was then dipped into the upper (supernatant) solution and the pH of the solution was measured.

2.2.9 Bulk density

Bulk density is the weight per unit volume of the clay sample including the volume of open pore space. The principle of these determinations was to find the volume of a suitable liquid displaced on placing in it a weighed amount of finely ground material (sample).

Method: Test pieces were prepared from the clay samples. The specimen was dried in an oven for 24 hours at 110^{o}c. The dried weight (w_d) of the specimen was recorded, after which they were fired in a furnace at 1100^{o}c. The specimens were then placed in beaker of water in a vacuum desiccator and evacuated completely until bubbling ceased. At this point, the airs in the samples have been displaced by water. The specimens were then dried and the soaked weight (Ws) was recorded. The specimens were then suspended in a beaker of water one after the other and the suspended (weights (W_p) was recorded. The average bulk density was calculated from the following expression.

$$\textbf{Bulk Density} = \frac{\textbf{Wd}}{\textbf{Ws – Wp}} \square\textbf{w}. \qquad \textbf{(6)}$$

2.2.10 Refractoriness

Refractoriness is a measure of the resistance that a material impacts to the combined effects of heat and load. Recent studies suggest CEC may influence the clay's response to activation treatments commonly used to enhance its bonding properties (Yilmazer & Erdoğan, 2023). The most widely spread and convinient method for determining refractoriness consist of measuring the temperature at which grains of moulding mixture starts to bake. For this purpose specimen from moulding mixture is placed in a crucible. The crucible, together with the specimen is placed in muffle furnace, which allows for gradual heating up to 1500^{o}c

Method: The furnance was heated preliminary to 800^{o}c and the mixture was tested up to temperature of 1500^{o}c, at 25^{o}c interval. 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 grain start to bake

III RESULTS AND DISCUSSION

Samples of Bentonite clay materials tested were collected from six locations; (A) Ihube, Imo State; (B) Amata Ishiagu, Ebonyi State; (C) Agbala Ihietutu-Ishiagu, Ebonyi State; (D) Umuahia, Abia State; (E) Uturu, Abia State and (F) Erusu, Ondo State. These samples were evaluated accordingly based on their Foundry properties.

3.1 Results

3.1.1 Foundry Properties of the Six selected Bentonite clay samples

The foundry properties obtained from average of five (5) readings from this investigation are shown in table 1.

Table 3.1: Foundry properties of the six samples investigated

Physical Properties	SAMPLES					
	A	B	C	D	E	F
Moisture content (%)	2.95	5.65	3.15	10.15	2.90	4.26
Bulk density (g/cm^3)	1.57	1.58	1.59	1.53	1.59	1.58
Liquid limit LL (%)	105	52	62	114	39	48
Plastic limit PL (%)	22	26	31	25	19	17
Plasticity Index PI (%)	83	26	31	89	20	31
pH value (pH)	8.30	8.23	7.65	6.13	8.14	8.26
Swelling index SI (%)	27.50	65.00	70.00	100.00	35.00	40.00
Refractoriness	>1200	>1200	>1200	>1200	>1200	>1200
Cation Exchange Capacity (CEC) (meq/100g)	83.973	60.977	55.14	65.405	72.453	62.289

Source: Researchers' Finding

This table 3.1 summarizes the foundry properties of six bentonite clay samples (A-F). The data provides a basis for assessing their suitability for use in foundry applications.

Table 3.2: Comparison of the physical properties of the various local Bentonite clay samples with various standard values of foundry Bentonite clays

Samples	**Physical Properties**				
	Moisture content (%)	Bulk density g/Cm^3	Liquid limit (%)	pH value	Sieve analysis passing though 75micron (%)
A	2.95	1.57	25	8.30	98.90
B	5.65	1.58	52	8.23	91.00
C	3.15	1.59	58	7.65	86.44
D	10.15	1.53	99	6.13	97.12
E	2.90	1.59	39	8.14	66.14
F	4.26	1.58	46	8.26	50.97
Sodium based Grade 1	5-12	-	450-500	9-10.5	90-97
Calcium based Grade 2	5-12	-	200-300	8-9	90-97
Foundry Grade Bentonite powder	5-12	1.36-1.44	200-830	8.2-11	90-97

Source: Researchers' Finding

Table3.2 compared the physical properties of the Selected Nigerian Bentonite clay samples with various standard values of foundry Bentonite clays.

Table 3.3: Comparison of the chemical composition of the various selected Bentonite clay samples with imported Bentonite clays and some Nigerian clay.

Clay Sample	Composition										
	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	LOI
A	58.16	15.97	0.81	ND	2.40	2.24	1.48	1.12	ND	ND	9.80
B	49.48	20.61	2.18	ND	1.84	2.21	0.35	0.17	ND	ND	6.40
C	51.05	22.44	3.02	ND	1.31	1.98	0.21	0.13	ND	ND	8.30
D	52.45	19.79	2.65	ND	1.25	2.97	0.41	0.35	ND	ND	15.30
E	49.91	21.85	3.32	ND	1.29	1.72	0.36	0.22	ND	ND	9.6
F	53.68	19.42	2.74	ND	1.20	1.13	0.16	1.06	ND	ND	2.3
Bomo &Amake	44-58	16-23	2.5-5.0	ND	3.0-8.0	0.5-3.5	0.1-0.8	0.1-0.3	ND	ND	12.20
Yola	58.78	13.58	7.06	0.096	1.00	1.11	0.14	0.94	1.36	0.04	15.29
Wyoming USA	58-64	18-21	2.5-2.8	ND	2.5-2.8	2.5-3.2	0.1-1.5	0.2-0.4	0.1-0.2	ND	5-6.5
Pindiga	43.60	14.00	26.54	0.38	ND	2.48	3.58		2.06	ND	6.46
Sodium based Bantonite	74.64	12.96	1.16	ND	2.77	Traces	1.91	0.55	ND	ND	-
Calcium based Bentinite	69.00	13.33	2.09	ND	3.38	2.83	1.94	7.44	ND	ND	-
Tunisian	57	16	5.00	ND	2.6	3.6	3.2	1.10	ND	ND	-

ND: Not detected
Source: Researchers' Finding

Table3. 4: Comparison of the Cation Exchange Capacity (CEC) property of the samples with some other Nigerian Clays and some typical imported Bentonite minerals

S/NO	SAMPLES	Cation Exchange Capacity (CEC) (meq/100g)
1	A	83.973
2	B	60.977
3	C	55.14
4	D	65.405
5	E	72.453
6	F	62.289
7	YOLA	14-34
8	GREDA	100.15
9	PRASSA	63.95-126.35
10	LOUTRA	40.75-59.25
11	FANARA	35.25-90.25
12	KAOLINITE	3-15
13	ILLITE	10-40
14	MONTMORILONITE	70-120
15	CHLORITE	10-40
16	TUNISIAN	31
17	WYOMING	64-105

Source:

Researchers' Finding,

Table3. 5: Comparison of the Swelling Index Property of the Various Selected Bentonite Clay Samples with Typical Imported Bentonite Materials and Some Other Nigerian Clays.

S/NO	SAMPLES	PARAMETER SWELLING INDEX (%)
1	A	27.50
2	B	65.00
3	C	70.00
4	D	100.00
5	E	35.00
6	F	40.00
7	PRASSA	110-234
8	LOUTRA	33-80
9	FANARA	28-230
10	YOLA	28-52

Source: Researchers' Finding

3.1.2Sieve Analysis of the Selected Nigerian Bentonite clay samples

The result of the Sieve Analysis carried out on the local Bentonite clay samples is as shown in Table 6 below. The result revealed that 98.8%, 91%, and 97.12% of samples A, B, and D respectively pass through 75 micron compared favourably with the standard passing value of 90% (Gold Stone Mine & Minerals, 2010). Sample C passing value of 86.44 was slightly below the standard value while samples E and F passing values were below the required standard. Samples A, B and D are quite adequate for applications in foundry industries.

Table 3.6: Sieve Analysis of the Selected Nigerian Bentonite clay samples

Sieve sizes	Sample A			Sample B			Sample C			Sample D			Sample E		
	Wt retained	% retained	% passing	Wt retained	% retained	% passing	Wt retained	% retained	% passing	Wt retained	% retained	% passing	Wt retained	% retained	% pa
5.00mm	-	-	100	0.21	0.07	99.93	1.41	0.47	99.53	-	-	100	27.07	9.02	90
3.35mm	-	-	100	0.32	0.11	99.82	0.73	0.24	99.29	-	-	100	20.06	6.69	84
2.00mm	0.09	0.03	99.97	0.78	0.26	99.56	0.89	0.30	98.99	0.03	0.01	99.99	25.53	8.51	75
1.18mm	0.08	0.03	99.94	0.91	0.30	99.26	1.55	0.52	98.47	0.41	0.14	99.85	7.97	2.66	73
850µm	0.10	0.03	99.91	0.49	0.16	99.10	1.51	0.50	97.97	1.07	0.36	99.49	2.89	0.96	72
600 µm	0.23	0.08	99.83	0.70	0.23	98.87	2.39	0.80	97.17	2.51	0.84	98.65	3.07	1.02	71
425 µm	0.35	0.12	99.71	0.88	0.29	98.58	2.96	0.99	96.18	2.60	0.87	97.78	2.61	0.87	70
300 µm	0.41	0.14	99.57	2.60	0.87	97.71	5.96	1.99	94.19	1.13	0.38	97.40	3.31	1.10	69
150 µm	1.12	0.37	99.20	15.27	5.09	92.60	5.96	6.38	87.81	0.81	0.27	97.13	5.93	1.98	67
75 µm	0.95	0.32	98.90	4.86	1.62	91.00	19.13	1.39	86.44	0.08	0.03	97.12	3.16	1.05	66
Passing 75 µm to pan	296.7	98.90		273	91.00		259.31	86.44		291.36	97.12		198.4	66.14	
Weight before washing		300g		300g			300g			300g			300g		
Weight after washing		3.3g		27.0g			40.69g			8.64g			101.6g		

Source: Researchers' Finding,

3.2 Discussions

3.2.1 Chemical analysis of the Selected Nigerian Bentonite clay samples

From Tables 3.3, it can be seen that the chemical compositions of the selected Bentonite clay samples investigated compared very favourably with other composition of Bentonite clay materials. CaO (1.13 – 2.97) values of the tested selected Bentonite clay samples compared well with the values of Bomo and Amake Bentonite clay,(0.5 – 3.5) and vary close to that of Wyoming USA values of (2.5 -3.2) for foundry applications. The value of specimen D, 2.97 was higher than the standard value, 2.83 for calcium Bentonite. While that of samples A, B, C, E and F, 2.24, 2.21, 1.98, 1.72 and 1.13 respectively were lower than the standard value, 2.83 for Calcium Bentonite. Na_2O content of the investigated local Bentonite clay samples, (0.16 – 1.49) compared favourably well with Bomo and Amake bentonite clays, (0.1 – 0.8) (Sun et al., 2022) and that of Wyoming USA, (0.1 - 1.5) (Wang et al., 2023). These values were slightly lower than that of Sodium based Bentonite, 1.91. Based on the CaO (1.13 – 2.97) content of the samples, they are classified as Calcium (Ca-based) Bentonite clay. The values are all good enough for foundry applications (Almeida et al., 2018)

3.2.2 Cation Exchange Capacity (CEC) of the Selected Bentonite clay samples

From the experimental data shown in Table 3.4, the Cation Exchange Capacity (CEC) of the investigated selected Bentonite clay samples ranges from (55.14 – 83.973). These values were higher than that of Kaolinite, (3-15), Illite, (10-40) and Chlorite, (10-40) but were slightly lower than that of Montmorillonite, (70-120) (Grim, 1968; Grimshaw, 1971). The values equally compared favourably well with that of Wyoming, (64-105) (Laribi et al, 2007). The result revealed that Samples A, (83.973) and E, (72.453) fall within the standard value, (70-120) for Montmorillonite. While sample B, (60.977), sample C, (55.14), sample D, (65.405) and sample F, (62.269) slightly fall below the standard value of Montmorillonite, (70-120). Based on these results the samples are good enough for applications in foundry industry as they compared well with values (64-105) for Wyoming Bentonite.

3.2.3 Moisture contents

The investigation revealed moisture contents value within the range of 2.90% and 10.15%. Samples B and D moisture content values of 5.65 and 10.15 respectively fall within the standard moisture values of ranges 5-12% (Akhadionu et al., 2019). While the moisture value of sample F, 4.26% was slightly below the standard value as shown in Table 3.1. However, the moisture contents values of the samples were good enough for foundry activities as they compared well with the moulding mixtures contents, (1-8%) for ferrous and nonferrous casting (Okologume & Akinwumi, 2016).

3.2.4 Liquid Limit and Plastic Limit of the Selected Bentonite clay samples

The Liquid limit values, (39-114) and Plastic Limit, (17-31) reported in Table 3.1 were all below the standard value of the required standard liquid limit, (450-500) and (200 – 300) for Sodium based Bentonite and Calcium based Bentonite clay respectively (World Mineral Production, 2007).

3.2.5 Plastic Index of the Selected Bentonite clay samples

Plasticity Index (PI) values range from 20% to 89%. PI reflects the moldability and workability of the clay. Generally, a moderate PI (20-50%) is preferred for foundry applications (Azeez & Ijadunmo, 2014). Samples B, C, E, and F fall within this range.

3.2.6 Swelling index of the Selected Bentonite clay samples

The result of the investigation carried out revealed that the swelling index of the six (6) selected Bentonite clay samples ranges between 27.50 and 100% as shown in Table 3.5. Table 3.5 compared the Swelling Index property of the various selected Bentonite clay samples with typical imported Bentonite materials and some other Nigerian Clays. The swelling Index values, (27.50-100.00) of the selected Bentonite clay samples are lower than that of Prassa, (110-230) but compared well with that of Loutra, (33-80), Fanara, (28-230) and Yola, (28-52) (James et al, 2008). These values are good enough for applications in Foundry Industry as agreed by (Akhadionu et al., 2019).

3.2.7 pH values of the Selected Bentonite clay samples

The pH value of 8.30, 8.23, 8.14 and 8.26 for samples A,B,E and F respectively fall within the standard pH values between 8 and 11 pH values shown in Table 3.1 (Gold Stone Mine and Minerals, 2010). While sample C and D values of 7.65 and 6.13 pH values respectively are below the required standard value. Based on the pH values, samples A, B, C, E and F are basic bentonite while sample D is acidic bentonite. pH values range from 6.13 to 8.30. Foundry clays are typically preferred in the slightly acidic to slightly alkaline range (pH 6-9) to minimize reactivity with other molding materials and avoid potential casting defects (Olubambi et al., 2012). All samples fall within this acceptable range.

3.2.8 Bulk density of the Selected Bentonite clay samples

From Table 3.1, the Bulk density values, 1.57, 1.58, 1.59, 1.53, 1.59 and 1.58g/cm^3 for samples A, B, C, D, E and F respectively are quite higher values compared to the recommended standard physical value 1.360-1.440 g/cm^{3}of a typical naturally occurring moulding sand mixture (Akhadionu et al., 2019). However, these values are lower than the bulk density value, 2.58g/cm^3 of Pindiga bentonite clay, Gombe State (Ahmed et al, 2012). These values are adequate for casting operations.

3.2.9 Refractoriness of the Selected Bentonite clay samples

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 1200^{o}C. This is because the samples displayed the ability to withstand temperature beyond the 1200^{o}C which they were fired being the maximum furnace temperature. The high temperature is an advantage as it will support casting at high temperature.

IV CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

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

- The Chemical composition of all the Bentonite clay samples investigated compared favourably with the Chemical composition of other Nigerian bentonite clay deposits in the literature and Wyoming bentonite USA. Based on the outcome of the investigation, all the Bentonite clay samples tested are calcium based (Ca-based) Bentonite. Cation Exchange Capacity (CEC) of the Samples revealed that they belong to Montmorillonite clay group. The pH values of samples A, B, C, E and F indicated that they are basic clay while sample D is acidic clay.
- All the Bentonite clay samples tested gave good Foundry properties. 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.
- From the outcome of the investigation, it is obvious that the selected Bentonite clay samples are suitable for application in foundry Industry

4.2 Recommendations

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

- Further investigation into the selected Bentonite clay samples for other industrial applications such as: Drilling, Construction, Building, Ceramic and Fertilizer preparation.
- 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.
- Effect of high temperature (above 1500^o C) on the binding quality of these Bentonite clays could also be investigated.

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