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Ceramic properties of clay deposits from Anambra Basin, South Eastern Nigeria

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Abstract

Purpose. To determine and evaluate some ceramic properties (plasticity index, linear shrinkage, porosity, and bulk density) of clay deposits from Anambra Basin of South Eastern Nigeria.

Methods. Fifteen clay samples were collected by trenching methods. Samples were tested for plasticity index, linear shrinkage, loss on ignition, porosity, and bulk density using test standards developed by the American Society of Test and Materials. Result data were evaluated using tabulation and statistical graphs.

Findings. Mean plasticity index of the samples range from 14.3 to 21.3. Mean linear shrinkage is from 2.5 to 5.5%. Mean loss on ignition is from 6.56 to 9.75%. Mean porosities is from 6.9 to 30.1%. Mean bulk density is between 2362 and 1692 kg/m^3. The ceramic properties of the deposits varied across location, and no single deposit has the complete set of ceramic properties needed in ceramic industries.

Originality. To the best of the authors' knowledge, this is the first research that looked into the distributions of ceramic properties of clay deposits in Anambra geologic Basin.

Practical implications. The findings will help investors to make informed decisions on clay deposits in their investment plans and can be used as supporting document when applying for mining titles.

Keywords: *ceramic, clay, deposit, plasticity index, porosity, linear shrinkage, bulk density*

1. Introduction

Clay deposit and clay minerals are particularly important industrial materials because they are used in the manufacturing of various household items ranging from ceramic products, cement, sanitary ware, manufacturing of drugs to catalysts in the pharmaceutical industry. Clay minerals also find application in nanotechnology for the manufacturing of crystals. Kaolin, a type of clay is used in glossy paper for high-quality prints. Kaolin is also used in paint manufacturing, as impact strength and fillers in plastics, and in the production of enamel [1].

Clays have wide arrays of properties which makes them suitable for the manufacturing of different products. Ceramic is one of such products. Ceramic has different definitions depending on the point of view adopted [2]. Ceramic is a clay that has been irreversibly transformed to alter its physical and chemical properties through firing [3].

According to National Bureau of Statistics [4], Nigeria produced about one million tons of clay, close to three million tons of shale and fifty thousand ton of kaolin in 2017 as raw materials for her ceramics industries and oil and gas companies. There is a need for further and continuous exploration of clay material. Different categories of ceramics are produced from different varieties of clay deposit, depending on the properties of the clay. Clay properties vary from place to place, even within the same geology. It is, therefore, necessary to have a complete mineralogical information of the clay deposits in Nigeria. The information will give clay mineral explorationists and clay miners the understanding of the geospatial distribution and characteristics of clay in the Nigerian geology.

2. Methods

2.1. Description of the study area

The study area is located within the Anambra geologic basin. Fifteen clay samples were taken from clay deposits in four locations in three states. Four samples were taken from Nsukwe clay deposit in Umuahia South local government area of Abia state on coordinates N5º30'24" E7º26'28". Three samples were taken from Ikwuano in Ikwuano local government Area of Abia State on coordinates N5º21'20" E7º27'04". Four samples were taken from Okigwe in Okigwe local government area of Imo state on coordinates N5º51'04" E7º20'09". And four samples were taken from Ozubulu in Ekwusigo local government area of Anambra state on coordinates N5º58'50" E6º48'34". The samples were taken to the laboratory for test on some important ceramic properties.

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2.2. Determination of plasticity index using ASTM D4318-17 [5]

To determine the plastic limit, about 30 g of air-dried clay from a thoroughly mixed sample which had passed through 425 µm IS sieve was mixed with distilled water in an evaporating dish and left for 24 hours for "maturing". 8 g of the clay paste was rolled with the fingers gently on a glass plate. The rolling and kneading were continued until the clay crumbled. The water content at that instant is the plastic limit. The experiment was conducted three times on the same material and the average was obtained.

The liquid limit was determined by taking 20 g of the clay sample and mixed with 30 ml of water in a porcelain bowl of 10 cm in diameter. A groove was cut with a spatula of 13.5 mm through the clay paste at the bottom of the bowl. The bowl was continually dropped on a hard rubber surface. The height of drop was about 10 cm and the rate of dropping averaged about 120 drops per minutes. The number of drops that caused the groove of 13.5 mm to close was then noted. The moisture content at 25 blows is the liquid limit and was determined by interpolation of the graph of "water content" against "Number of blows".

Plasticity index is the difference between the liquid limit and plasticity limit.

2.3. Determination of linear shrinkage using ASTM C326-09 standard [6]

A molded sample was placed in the furnace for 24 hours at 110°C. It is removed and allowed to cool for 2 hours. The dimensions of the dried samples were measured and then fired to 900°C in the furnace. The sample was removed and allowed to cool for 3 hours. The new dimension was taken again. The change in length expressed as a percentage of the original length is the linear shrinkage.

Percentage shrinkage = change in length / original length:

$$X100\,. \tag{1}$$

2.4. Determination of loss on ignition using ASTM C311 standard [7]

The moisture content of the material was determined by heating a weighed 1 g sample in an oven at 105 to 110°C to a constant mass. The sample was oven-dried before ignition so that mass loss due to the evaporation of surface moisture is not counted as a portion of the ignition losses. Next, the sample was exposed to temperatures of 750 ± 50°C in a muffle furnace. The sample was exposed to the test temperatures until the sample mass became constant. The sample was weighed after the oven-drying phase and again after the ignition phase. The loss on ignition value was then determined as the percentage of mass loss during the ignition phase expressed as a percentage of the oven-dried (pre-furnace) sample mass. The LOI value was calculated as:

$$LOI = \frac{A}{B} \cdot X100\,, \tag{2}$$

where:

A – loss in mass between 105 and 750°C (mass of the sample after ignition − *B*);

B – mass of the moisture-free sample, and LOI calculations are made to the nearest 0.1%.

2.5. Determination of porosity using ASTM C20-00 (2010) standard [8]

The test samples were dried to constant weight by heating to 105 to 110°C and the dry weight, *D*, in grams to the nearest 0.1 g was determined. For saturation, the samples were placed in water and boil for 2 hours. During the boiling period, the samples were entirely covered with water, and allowed no contact with the heated bottom of the container. After the boiling period, the samples were cooled to room temperature while still completely covered with water. After boiling, the samples were kept immersed in water for a minimum of 12 h before weighing.

The weight, *S*, of each sample was determined, in grams to the nearest 0.1 g after boiling and while suspended in water. The weighing was accomplished by suspending the samples in a loop of AWG Gage 22 (0.643 mm) copper wire hung from one arm of the balance. The balance was previously counter balanced with the wire in place and immersed in water to the same depth as was used when the samples were in place. After determining the suspended weight, each sample was lightly blotted with a moistened cotton cloth to remove all drops of water from the surface and determine the saturated weight, W, in grams by weighing in air to the nearest 0.1 g. The blotting operation was performed by rolling the specimen lightly on the wet cloth, which had previously been saturated with water, and then pressed only enough to remove such water as would drip from the cloth.

Calculation exterior volume, *V*.

The volume, *V*, of the test samples in cm^3 were obtained by subtracting the suspended weight from the saturated weight, both in grams, as follows:

$$V\,(cm^3) = W - S; \tag{3}$$

$$\text{Volume of open pore } (cm^3) = W - D; \tag{4}$$

$$\text{Volume of impervious portion} = D - S; \tag{5}$$

$$\text{Apparent porosity (\%)} = (W - D) / V \cdot X100. \tag{6}$$

2.6. Determination of sample bulk density using volumeter method by USP38 standard

The apparatus in Figure 1 consists of a top funnel fitted with a 1.0 mm sieve. The funnel was mounted over a baffle box containing four glass baffle plates over which the powder slid and bounced as it passed. At the bottom of the baffle box was a funnel that collected the powder and allowed to pour into a cup of specified capacity mounted directly below it. The cylindrical cup is 25 cm^3 with inside diameter of 30 mm. An excess of powder was made to flow through the apparatus into the sample receiving cup until it overflowed, using a minimum of 35 cm^3 with the cylindrical cup. The excess powder was carefully scraped from the top of the cup by smoothly moving the edge of the blade of a spatula perpendicular to and in contact with the top surface of the cup, taking care to keep the spatula perpendicular to prevent packing or removal of powder from the cup. Any material from the sides of the cup was removed, and the weight, *M*, of the powder to the nearest 0.1% was determined. The bulk density in g/cm^3 was calculated, by Equation 9. V_0 is the inside volume, in cm^3, of the cup. And *M* is the weight of the powder in g.

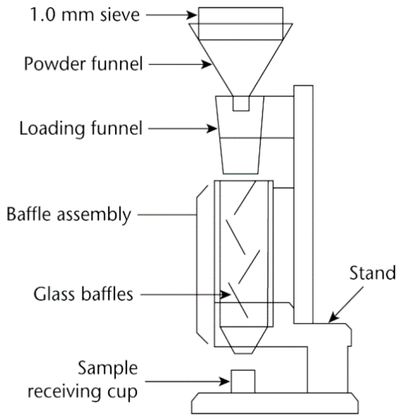

Figure 1. Experimental set-up to measure powder bulk density of sample [9]

3. Results and discussion

3.1. Plasticity index

Table 1 shows that the plasticity indices of the samples are irregular across the locations. All the samples collected at Nsukwe deposits have plasticity index between 8.86 and 25.88 with a mean value of 18.73.

Table 1. Plasticity index of samples [10]

Location	Sample code	Liquid limit	Plastic limit	Plasticity index
Nsukwe	NSW-1	44	24.32	19.68
	NSW-2	44	23.52	20.48
	NSW-3	62	36.12	25.88
	NSW-4	43	34.14	8.86
	Mean			18.73
Ikwuano	IKW-1	49	24.32	24.68
	IKW-2	46	42.91	3.09
	IKW-3	57	76.28	Non plastic
	Mean			13.885
Okigwe	OKW-1	47	25.71	21.29
	OKW-2	40	70.89	Non plastic
	OKW-3	44	55.84	Non plastic
	OKW-4	44	53.03	Non plastic
	Mean			21.29
Ozubulu	OZB-1	18	70.03	Non plastic
	OZB-2	26	50.91	Non plastic
	OZB-3	33	73.94	Non plastic
	OZB-4	46	75.15	Non plastic
	Mean			Non plastic

Sample NSW-4 which was collected at the lowest level shows the least plasticity. This suggests that it is of lowest value in ceramic raw materials. Only two samples from Ikwuano are plastic, with plasticity of 24.68 and 3.09, respectively. The third sample is not plastic and may not be useful as binder in ceramic raw materials. Of the four samples collected at Okigwe, only one is plastic, with plasticity index of 21.29. However, all the four samples collected at Ozubulu deposits shows no plasticity. Clay deposits with little or no plasticity may contain little clay minerals, and therefore may not be suitable as good binders in ceramic manufacturing.

3.2. Linear shrinkage

Clay deposits in Nsukwe and Ikwuano both in Abia state have mean shrinkage values slightly higher than the mean shrinkage values from Okigwe in Abia state and Ozubulu in Anambra State.

Table 2 shows that the mean shrinkage values for Nsukwe is 5.5, 3.3% for Ikwuano, 2.3% for both Okigwe and Ozubulu, respectively.

Table 2. Linear shrinkage of samples [10]

Sample location	Sample ID	Length of shrinkage mould (mm)	Length of sample after oven-dried (mm)	Shrinkage (mm)	% Shrinkage
Nsukwe	NSW-1	128	121.6	6.4	5.0
	NSW-2	128	120.3	7.7	6.0
	NSW-3	128	119.0	9.0	7.0
	NSW-4	128	122.9	5.1	4.0
	Mean				5.5
Ikwuano	IKW-1	128	120.3	7.7	6.0
	IKW-2	128	124.2	3.8	3.0
	IKW-3	128	126.7	1.3	1.0
	Mean				3.3
Okigwe	OKW-1	128	120.3	7.7	6.0
	OKW-2	128	126.7	1.3	1.0
	OKW-3	128	126.7	1.3	1.0
	OKW-4	128	126.7	1.3	1.0
	Mean				2.3
Ozubulu	OZB-1	128	124.2	3.8	3.0
	OZB-2	128	124.2	3.8	3.0
	OZB-3	128	126.7	1.3	1.0
	OZB-4	128	125.4	2.6	2.0
	Mean				2.3

Clay deposit with high shrinkage value have good compressibility [11], and are particularly good for ceramic production. Clay with high plasticity may indicate kaolinite or illite group [12]. This suggests that Clay in Abia state are better ceramic raw material with better shrinkage.

Figure 2 shows the distribution of linear shrinkage in the fifteen samples across the four location with NSW-3 from Nsukwe having the highest number of 7.0. 1.0% was recorded as the lowest shrinkage value.

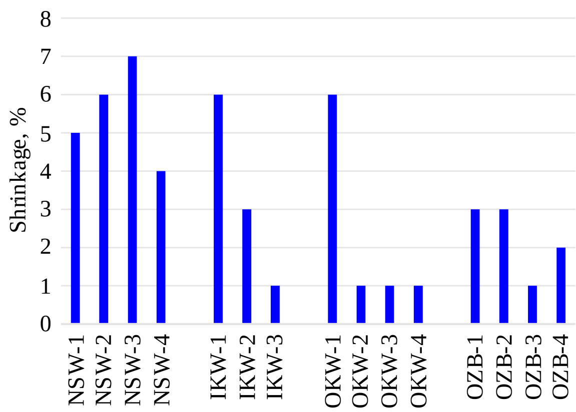

Figure 2. Linear shrinkage form all the samples

Both IKW-3, OKW-2, OKW-3, OKW-4 and OZB-3 recorded lowest value.

3.3. Loss on ignition

Mean loss on ignition (LOI) varies between 6.56 to 9.75%. Again, samples collected at Nsukwe has the highest mean LOI of 9.75%. Mean LOI of samples from Ikwuano is 9.70, slightly lower than that of Nsukwe, which are both located within Abia State. Mean LOI of Okigwe samples is at 9.05%. Ozubulu samples have the lowest mean LOI at 6.56%. Table 3 shows that samples from Abia have higher LOI than those of Imo and Anambra States.

Table 3. Loss on ignition of the samples [10]

Sample location	Sample ID	Loss on ignition (%)
Nsukwe	NSW-1	11.25
	NSW-2	9.25
	NSW-3	8.24
	NSW-4	10.25
	Mean	9.75
Ikwuano	IKW-1	10.50
	IKW-2	10.05
	IKW-3	8.55
	Mean	9.70
Okigwe	OKW-1	10.03
	OKW-2	8.45
	OKW-3	8.05
	OKW-4	9.67
	Mean	9.05
Ozubulu	OZB-1	6.70
	OZB-2	6.82
	OZB-3	6.49
	OZB-4	6.24
	Mean	6.56

Felix and Sonja [13] reported that a loss on ignition greater than 14% indicates carbonaceous matter. None of the sample has an LOI greater than 14% This means that clay deposits from the study area have less or no carbonaceous contents. Higher values of LOI may also suggest high percentage of impurities [14]. Figure 3 shows that NSW-1 has the highest LOI value at 11.25% among the samples collected in Nsukwe.

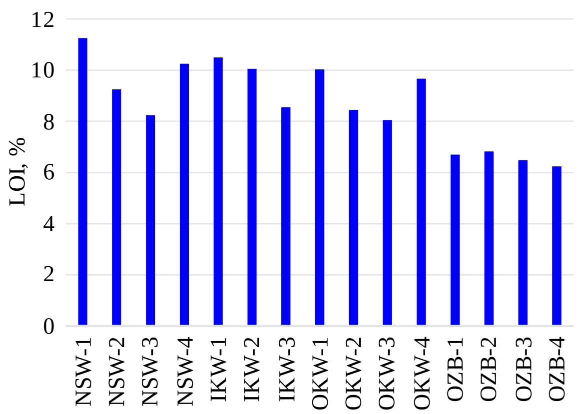

Figure 3. Loss on ignition on samples

IKW-1 also has the highest LOI among the samples collected at Ikwuano deposits at 10.50%. OKW-1 has the highest in the samples taken from Okigwe at 10.03%, and OZB-2 has the highest LOI value at 6.82% among the samples taken from Ozubulu. Except samples taken from Ozubulu, all the samples have LOI greater than 7.0%.

3.4. Porosity

Table 4 shows that mean porosity of samples from Nsukwe is 25.9%. This is slightly greater than the mean porosity of sample from Okigwe at 28.4%. Ikwuano mean sample is within average at 12.9% while Ozubulu samples show the least of porosity at 6.9%. Despite being in the same state and with about 30 km apart, mean porosities of samples from Nsukwe and Ikwuano are remarkably far apart with range of about 13%. This is because clay deposits could show wide variation in properties even in deposits within the same geology [15].

Table 4. Porosity of samples [10]

Sample location	Sample ID	*W-D* (cm^3)	V_p (cm^3)	Porosity (%)
Nsukwe	NSW-1	44	24.32	19.68
	NSW-2	44	23.52	20.48
	NSW-3	62	36.12	25.88
	NSW-4	43	34.14	8.86
	Mean			25.9
Ikwuano	IKW-1	50.24	6.0	11.9
	IKW-2	50.24	6.5	12.9
	IKW-3	50.24	7.0	13.9
	Mean			12.9
Okigwe	OKW-1	50.24	12.6	25.0
	OKW-2	50.24	14.0	27.9
	OKW-3	50.24	15.0	29.9
	OKW-4	50.24	15.5	30.9
	Mean			28.4
Ozubulu	OZB-1	50.24	4.0	8.0
	OZB-2	50.24	3.5	7.0
	OZB-3	50.24	3.3	6.6
	OZB-4	50.24	3.0	6.0
	Mean			6.9

From Figure 4, the porosity of both samples from Nsukwe and Okigwe are higher. While the porosities of samples from Ikwuano and Ozubulu are lower. Clay deposits of very higher porosity indicates higher percentage of pore spaces within the particle and may not be suitable as binders in ceramic [16].

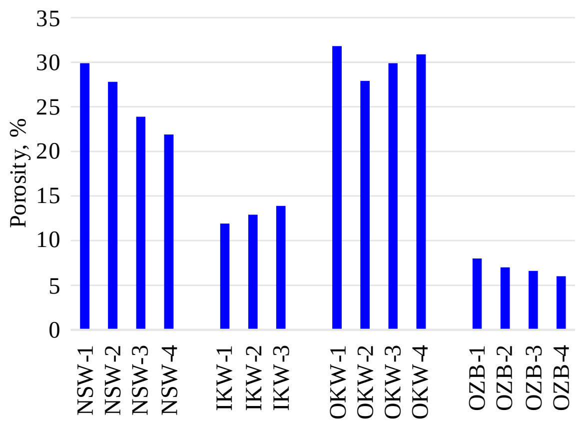

Figure 4. Porosity of samples

3.5. Bulk density

The bulk density of the samples varies from place to place in all the locations as shown in Table 5.

Samples from Nsukwe and Ikwuano, both from Abia State have generally low bulk densities. Their mean bulk densities are 1672 and 1847 kg/m^3, respectively. Whereas bulk density of samples from Imo and Anambra States are considerably higher. The mean bulk densities of Okigwe and Ozubulu are 2362 and 2255 kg/m^3, respectively. Clay deposits with higher bulk density are generally sort after by ceramists. This is because clay deposits with lower bulk density tend to have higher shrinkage properties [17] which is undesirable in ceramic making.

Figure 5 shows that of the fifteen samples tested, NSW-3 has the lowest bulk density at 1502 kg/m^3 compared to the highest bulk density of 2608 kg/m^3 for OKW-2.

Table 5. Bulk density of samples (4)

Sample location	Sample ID	Bulk density (kg/m^3)
Nsukwe	NSW-1	1788
	NSW-2	1602
	NSW-3	1502
	NSW-4	1875
	Mean	1692
Ikwuano	IKW-1	1650
	IKW-2	2050
	IKW-3	1841
	Mean	1847
Okigwe	OKW-1	1642
	OKW-2	2608
	OKW-3	2597
	OKW-4	2599
	Mean	2362
Ozubulu	OZB-1	2079
	OZB-2	2008
	OZB-3	2604
	OZB-4	2329
	Mean	2255

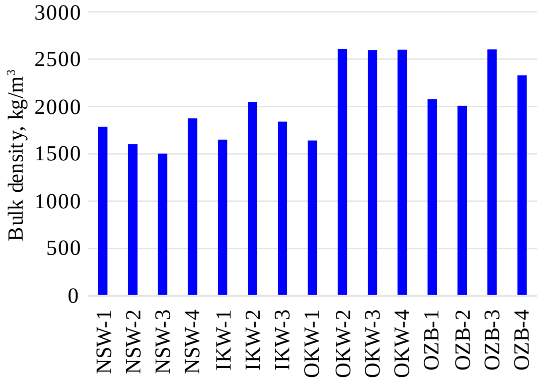

Figure 5. Bulk density of samples

4. Conclusions

This study evaluates some ceramic properties of clay deposit in three states of the Anambra geologic basin in Southeastern Nigeria. Plasticity index, linear shrinkage, loss on ignition, porosity and bulk density were evaluated. The results showed that these ceramic properties have no definite trend across the geologic basin. Only seven samples out of the fifteen tested are plastic. Mean linear shrinkage range between 2.3 to 5.5%. Mean loss on ignition range between 6.56 to 9.75%. Mean porosity range between 6.9 to 28.4%, and mean bulk density range between 1692 to 2362 kg/m^3.

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Керамічні властивості глини із родовищ басейну Анамбра, Південно-Східна Нігерія

В.А. Айодель, М.А. Салю, Б.О. Олаолува

Мета. Визначення та оцінка керамічних властивостей глини (індекс пластичності, лінійна усадка, пористість та насипна щільність) із родовищ басейну Анамбра на південному сході Нігерії.

Методика. 15 зразків глини було відібрано методом борозенного випробування. Зразки були випробувані на індекс пластичності, лінійну усадку, втрати при прожарюванні, пористість та насипну щільність із використанням стандартів випробувань, розроблених Американським товариством випробувань та вимірювань. Отримані дані оцінювалися, виходячи з таблиць та статистичних графіків.

Результати. Встановлено фізико-механічні характеристики властивостей глини для її придатності до керамічної промисловості: середній індекс пластичності зразків коливається від 14,3 до 21,3; середня лінійна усадка становить від 2,5 до 5,5%; середня втрата при прожарюванні – від 6,56 до 9,75%; середня пористість – від 6,9 до 30,1%; середня насипна щільність – від 2362 до 1692 кг/м^3. Керамічні властивості відкладень варіювалися залежно від розташування і було встановлено, що жодне з родовищ не має повного набору керамічних властивостей, необхідних для їх використання у керамічній промисловості.

Наукова новизна. Для умов родовища глин басейну Анамбра експериментально визначено їх фізико-механічні характеристики та обґрунтовано ступінь їх придатності до керамічної промисловості.

Практична значимість. Отримані дані допоможуть інвесторам приймати обґрунтовані рішення щодо родовищ глини при плануванні інвестицій і можуть бути використані як підтверджуючий документ при подачі заявки на отримання ліцензії на видобуток.

Ключові слова: *кераміка, глина, родовище, індекс пластичності, пористість, лінійне усадка, насипна щільність*