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Firing Temperature Effect on the Thermo-structural Properties of Clay for Refractory Purposes: A Comparative Study on Nigerian Clay Deposits

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Abstract: *A comparative study on firing temperature effect on the thermo-structural properties of clay for refractory purposes, have been carried out on three Nigerian clay deposits (Mgbom, Amokwe and Amagu Ishiagu clay deposits). Three firing temperatures; 900, 1100 and 1200^{o}C were considered in the study. Standard clay preparation procedures were employed in setting up the experiment, these include; crushing, soaking, drying, grinding, sieving, blending and moulding. Six refractory property tests (linear shrinkage, bulk density, apparent porosity, water absorption, thermal shock resistance and refractoriness) were carried out on the prepared clay according to ASTM standards. For the purpose of microstructural characteristics, the Scanning Electron Microscope (SEM) test was also conducted. The test result gave a 27.26 - 42.53N/mm^2, 4.09 – 9.27% 1.66 – 2.07g/cm^3 1.01 – 15.65% 19-28 cycles for modulus of rupture, linear shrinkage, bulk density, apparent porosity and thermal shock respectively. The microstructural analysis showed a level of similarity between that of Mgbom and Amagu while that of Amokwe gave a number of visible pores. From the analysis of the obtained results 1200^{o}C firing temperature was recommended among the studied temperatures.*

Keywords: *furnace, firing, heat, refractory, brick, temperature*

I. Introduction

Clay is a natural earthy fine grained material with particle size less than 2µm, which is plastic when wet, powdery when dry and hardened upon drying and firing. Most clays are crystalline with a definite repeating arrangement of atoms in them. The majority of them are made up of plane oxygen, silica and aluminum atoms ionically bonded together. According to Folaranmi (2009), clay is a very fine grained, consolidated rock matter, which is plastic when wet, but becomes hard and stony when heated. It has origin in natural processes, mostly weathering, transported and deposited by sedimentation within geological periods.Clays are anhydrous compound composed of silica (SiO_2) and alumina (Al_2O_3) that exist in various proportions and contained varied amount of impurities of iron, organic matters and residual minerals (John & Olayinka, 2014). Upon firing, clays, lose their chemically bonded water and plasticity at about 500^{0}C thus improves mechanical strength between 950^{o}C and 1350^{o}C as the firing temperatures increases (AL-Amaireh, 2009). Clay materials are classified according low melting, high melting and refractory (Nnuka & Agbo, 2000). They can also be classified based their capacity to change volume (swelling) by absorbing water molecules. Other classification is based on their relative plasticity, strength when moist (green strength), and after drying (dry strength), air shrinkage properties and their vitrification range i.e, process by which clay molecules begin to fuse when exposed to heat. Clay's vitrification range describes the temperature levels between which the clay begins to fuse and when it achieves its final fusion or hardness.

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Developing the clay industry through poverty alleviation initiatives can create jobs in extraction, processing, and manufacturing, thereby improving livelihoods and reducing unemployment (Javed et al, 2021). Clay has a lot of industrial applications which is very useful to the development of the national economy and as well to technological advancement (Chima et al, 2017). Despite the large deposits of clay mineral in our country, the properties of most deposits have not been brought to light; hence, the usefulness not being exploited. Nigeria has a lot of clay deposits. Some have been characterized while so many of them have not been characterized, and as such this mineral is not put into proper industrial use. Such mineral deposits should not be left wasting away without exploiting them to enhance industrialization. There is need to ascertain the chemical and mineralogical constitution of our clay deposits and other refractory raw materials in the country to enhance their utilization in engineering applications.

There is equally a need to determine to what degree and in what ways the results of such analyses and characterization studies indicate the industrial potential of the raw materials. Also important is the determination to what degree the properties conform to or compare with world class specification standard. Consequently, this would lead to the development of sustainable material resources that could encourage investment in the manufacture of ceramic and refractory product for local consumption. Sustainable practices, including eco-friendly mining, waste recycling, and efficient resource utilization, help maintain long-term economic and environmental balance (Rusli et al, 2021). Integrating these factors—refractory clay utilization, sustainable development, and responsible business policies—ensures economic resilience, poverty reduction, and industrial competitiveness while preserving resources for future generations (Romanus et al, 2024). Studying the firing temperature effect on the thermo-structural properties of Nigerian clays is crucial for optimizing their refractory performance. This research enhances industrial applications by identifying the best clay types for high-temperature use, supporting sustainable practices, economic sustainability, and poverty alleviation through improved local material utilization and reduced import dependency.

II. Research Methods

2.1 Clay Samples

Three clay samples where studied in this research, which are clay samples obtained from Mgbom, Amokwe and Amagu Ishiagu clay deposits all in Ebonyi State, Nigeria.

2.2 Clay Preparation

The preparation of the clay raw material involved crushing, soaking, sieving, grinding and blending.

a. Preliminary Crushing and Soaking

The raw clay samples were allowed to dry properly before processing. The dry clay samples were crushed to fine particles using a mortar. The crushed clay was soaked in water for three days to eliminate soluble alkali oxides (NaO and K_2O) which is responsible for retarding mullite formation and hence lower refractoriness and strength. It also helps in removing organic matters which could aid porosity and shrinkage.

b. Drying

The soaked samples were sieved and allowed to sediment before decanting off the water. The slurry was allowed to dry and was further sun dried for three days before crushing.

Drying was necessary, as damp or wet clays are difficult to crush or grind, due to their sticky nature. About 50% of each of the dried clay sample was calcined by heating up to 800^oC for an hour. This is done so that the clays lose their plasticity, thereby forming a grog or chamotte in the process.

c. Grinding and Sieving

The dried clay samples as well as the calcined portions were ground into powder form using a pestle and mortar. For each of the studied clay, dried and calcined samples were mixed and ground in the proportion of 1:3, respectively, and consequently sieved to a particle size of 150μm.

d. Blending and Wetting of Moulding Mass

The accepted aggregates obtained from sieving were remixed and blended. Water was added to make the material plastic, and the mixture was thoroughly worked into a plastic state.

2.3 Test for Refractory Properties of Clay

Several test were conducted on the fired clay to determine some of its refractory properties. These tests are linear shrinkage, bulk density, apparent porosity, water absorption, thermal shock resistance, refractoriness and modulus of rupture. These tests were conducted in accordance with ASTM standard test procedures for each of them.

2.4 Micro Structural Analysis

The Scanning Electron Microscope (SEM) was used to analyze the micro structure of the various clay samples. The scanning electron microscope (SEM) uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals that derive from electron-sample interactions reveal information about the sample including external morphology (texture), chemical composition, and crystalline structure and orientation of materials making up the sample. In most applications, data are collected over a selected area of the surface of the sample, and a 2-dimensional image is generated that displays spatial variations in these properties.

III. Results and Discussion

3.1 Chemical Composition

Table 1. Chemical composition of clay samples

Oxides	Compositions		
	Mgbom	**Amokwe Ishiagu**	**AmagiIshiagu**
Al_2O_3	28	21.9	23.0
SiO_2	58.6	35.1	36.1
MnO		0.19	0.19
SO_3	0.09		
K_2O	1.5	0.74	0.726
CaO	0.487	0.827	0.868
TiO_2	1.45	4.26	3.65
V_2O_5	0.08	0.21	0.20
Cr_2O_3	0.016		
Fe_2O_3	8.68	32.26	33.4
CuO	0.0096	0.031	0.031
ZnO	0.004	0.040	0.038

Ga_2O_3	0.013		
MoO_3	0.09		
Ag_2O	0.76	1.49	1.47
Eu_2O_3	0.038	0.31	0.27
Bi_2O_3		2.6	
Re_2O_7	0.069	0.05	0.07

The chemical compositions of the three different clay deposits - Mgbom, Amokwe Ishiagu and Amagu Ishiagu are shown in Tables 1. The chemical composition of the three clay deposits studied in this work showed that the alumina content of Mgbom, Amokwe and Amagu clay are (28, 21.9 and 23%) respectively while the silica content are (58.6, 35.1 and 36.1%) respectively. Hence Mgbom clay qualifies for fire clay[6], while Amokwe and Amagu clays are classified under high melting clay.[4]Mgbom clay has a higher alumina content compared to Amokwe and Amagu and this suggest a higher value of refractoriness and related properties. The silica content of Mgbom clay satisfies that required for both fire clay and refractory brick (Omowumi, 2001). The alumina content in clay is a strong indicator of its refractoriness. The higher the amount of alumina in the clay the higher is the amount of refractoriness of the clay. Hence the clay can be used for lining of furnace wall. The results obtained in the refractoriness tests of the three clay deposits confirmed this fact. Silica as an oxide has higher melting point and such its high quantity in clay suggests high melting point.
The iron oxide (Fe_2O_3) content of Mgbom, Amokwe and Amagu clays were (8.668, 32.26 and 33.4%) respectively. The iron oxide content of Mgbom clay was within the limit required for high melting clay but not for refractory clay.[4]It was found that the iron oxide content in Amokwe and Amagu clays were excessively high compared to the required value in international standard. These values are higher than the standard of 0.5 – 2.4 for refractory brick and that of fire clay. This led credence to the reddish colour of the samples when they were fired to 1200^oC. Such level of iron oxide has been reported to impact reddish colour to clay when fired, hence making it attractive as ceramic raw material and most suitable for structural engineering work. However, the high iron oxide content is believed to have affected the fired strength (Aremu et al, 2013).The alkali oxide content of each of the clays are within the specified range for both fire clay and refractory brick. This suggests that there is no need for further beneficiation during processing. The composition of titanium oxide in Amokwe and Amagu clay are 4.26% and 3.65% respectively. This value is relatively high compared to that in Mgbom clay which is 1.45%. Titanium on its own is quite refractory which forms glass by itself. It is insoluble in silica melt which stiffen the melt and stabilize the fire glass against leaching. It can also act as fluxing agent in silica melt and therefore is believed to have affected the density of the clay material.

3.2 Linear Shrinkage Test

The linear shrinkage results for the clays studied in this work are shown in figure 1. It was observed that the shrinkage values for Mgbom clay at (900, 1100 and 1200^oC) firing temperatures were (4.09, 6.7 and 9.27%) respectively. Amokwe clay had linear shrinkage values of (4.5, 6.1 and 8.8%) for respective firing temperature while the linear shrinkage values for Amagu clay were (5.6, 7.7 and 8.8%) in the same trend. It was noted that all the three clay deposits understudied had values of linear shrinkage within the acceptable range of 4-10% for fire clay and for refractory purpose (Omowumi, 2001; Aremu et al, 2013) This showed an indication of good material stability of the clays at high temperature and that the clay materials do not have tendency of wrapping and cracking which may cause loss of heat in the furnace when used as lining. It was also noted that firing temperature had effect on the linear shrinkage value of all the clay deposits. The shrinkage values increased with increase in firing temperature in all the clays. This shows that the property investigated is a function of firing temperature. At higher firing temperature, the clay material contracted more, which led to shrinkages. Comparing the values obtained in the clay deposits studied, it was observed that good shrinkage values associated with clays could be traceable to particle size or fineness and chemical composition. Finer particles have stronger bond than coarse particle hence maintain better stability.

It was also found that Mgbom clay has the highest percentage composition of silicon oxide-58.6% compared to Amokwe Ishiagu and Amagu Ishiagu which had 35.1% and 36.1% respectively. The presence silicon oxide is found to be useful for reducing linear shrinkage of clay material (Chima et al, 2016). It functions as filler which aids inter particle binding when fused together. Hence, it can be seen that the high silica content in Mgbom clay reduced excessive shrinkage in the brick sample made with the clay. It was also found that composition of silicon oxide in Mgbom clay is within the recommended range of 46-62% for refractory material. Excess of this oxide could cause warping and increase in brittleness of the brick (Chima et al, 2016).

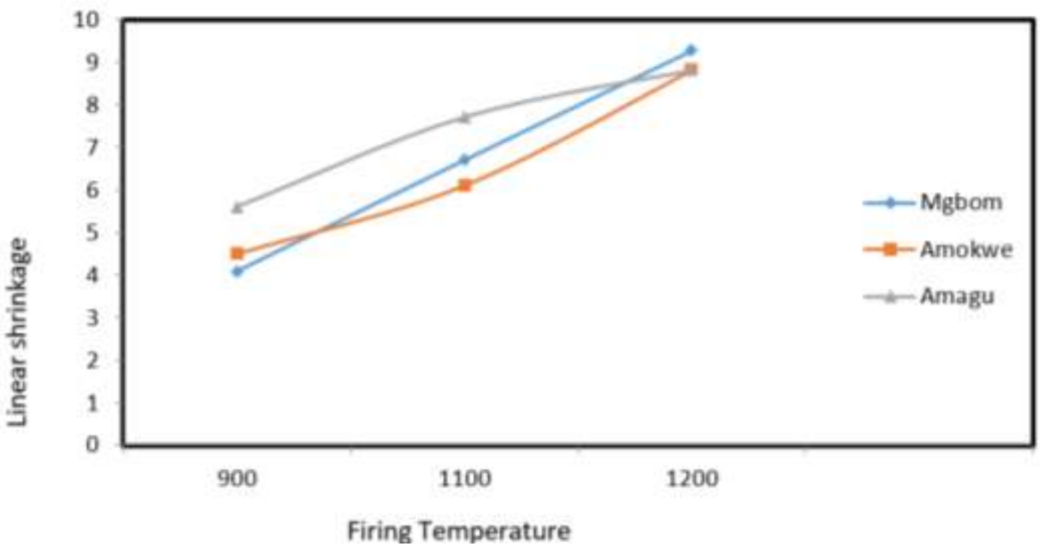

Figure 1. *Effect of firing temperature on linear shrinkage of the various clays*

3.3 Plasticity and Making Moisture Test

The plasticity indicates the ease with which the clay material can change it shape when mixed with water. The value of modulus of plasticity for Mgbom, Amokwe and Amagu clays were 1.17, 1.245 and 1.28 as shown in table 2. The plasticity of clay material is dependent on the composition of calcium oxide. Higher composition of the oxide yields higher plasticity. The chemical composition of the three clay deposits reveals that the composition of calcium oxide in the Mgbo, Amokwe and Amagu is 0.487, 0.827 and 0.868%). Hence, the increasing values of plasticity of Mgbo, Amokwe and Amagu clay had good credence to the result obtained in the chemical composition.

Table 2. Plasticity and making moisture

Property	Mgbom Clay	Amokwe Clay	Amagu Clay
Modulus of plasticity	1.17	1.245	1.28
Making moisture	23.09	24.07	22.71

3.4 Apparent Porosity Test

The results of apparent porosity are shown in figure 2.Mgbom clay had apparent porosity values of 15.65, 2.09 and 1.01%for 900^{0}C, 1100^{0}C and 1200^{o}C firing temperatures respectively. Amokwe clay has values of 4.76, 3.23 and 2.44% for 900^{o}C, 1100^{0}C and 1200^{0}C firing temperatures respectively while Amagu clay had 4.92, 3.03 and 2.5% in the same trend. Mgbom clay was observed to have high porosity value at 900^{o}C. However, the values reduced as the firing temperature increased. This correlates with high values of shrinkage and density at higher temperatures for the clay. It was also noted that generally, the porosity drastically reduced with increased in firing temperature. This indicates that for increase in firing temperature shrinkage increases, which reduces porosity and increases density. Hence the three properties; shrinkage, porosity and density are interrelated as reported by Nnuka and Agbo (2000).

In Amokwe and Amagu clays, the values of apparent porosity also decreased with increase in firing temperatures. This could be traceable to loss of moisture content and burning off which left the clay structure less porous at higher temperature due to shrinkage. It was noted that all the values in the result except Mgbom at 1200^{o}C were within the recommended international range of 2.0 – 30%. The porosity is related to the clay mineralogy and internal brick structure. During firing of clay based products, liquid phase formation begins at temperatures above 900^{0}C that helps in elimination of voids and pores via filling the inter-granular area (Safeer et al, 2014). This is the reason for the reduction of porosity with increase in firing temperature.

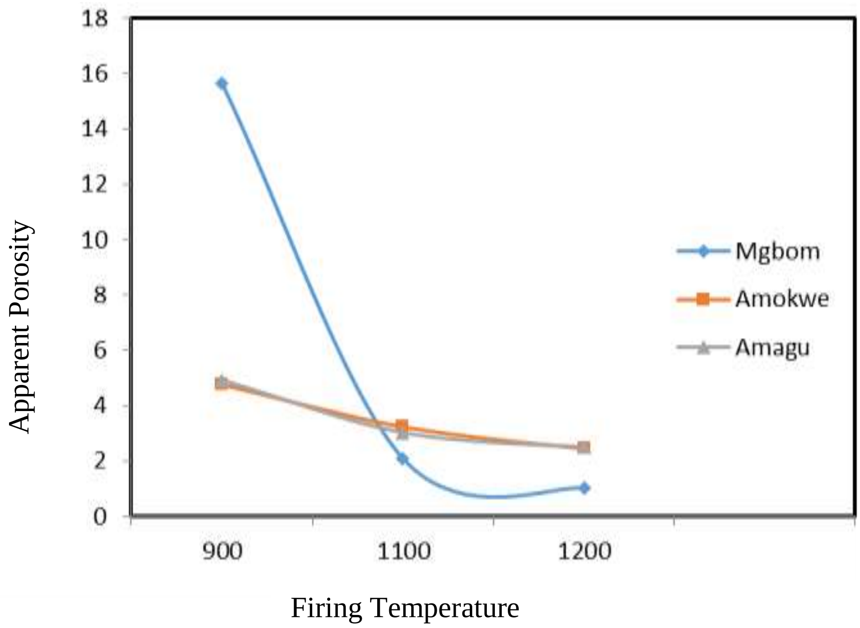

Figure 2. *Effect of firing temperature on apparent porosity of the various clay*

3.5 Bulk Density Test

The result for bulk density shown in figure 3 indicate that the Mgbom clay has bulk density value of (1.84, 1.98 and 1.99g/cm^3)for the three respective firing temperatures while that of Amokwe and Amagu were 1.66, 2.00, 2.1g/cm^3 and 1.73, 2.00, 2.07g/cm^3 respectively in the similar trends. Mgbom and Amagu clay was observed to have bulk density values within the acceptable range of 1.71 – 2.1g/cm^3 in all the fired temperature while Amokwe clay maintained such values at 1100^{o}C and1200^{o}C. Mgbom had average values at all the temperatures observed while Amokwe and Amagu had higher bulk density at higher firing temperature.

The increase in bulk density is traceable to decrease in apparent porosity or closure of pores due to shrinkage. Hence it was noted that when firing temperature increase, clay material tends to contract or shrink with closure of pores and consequently increase the density. The increase in the bulk density could also be traceable to the presence of some fluxing materials which melt at increase in temperature and fuse with the clay, thereby densifying the material.

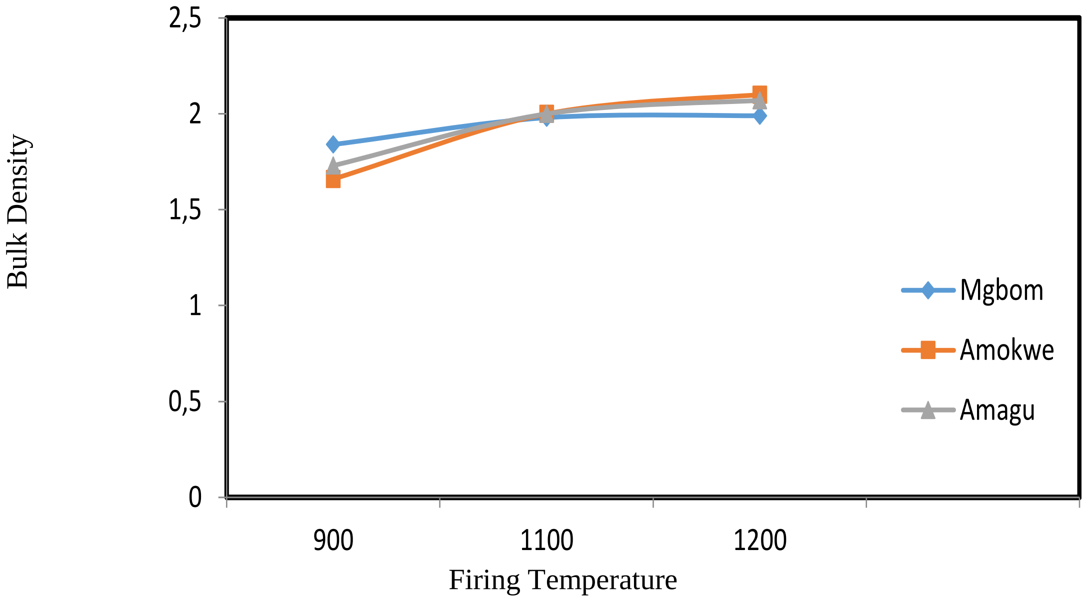

Figure 3. *Effect of firing temperature on bulk density of the various clays*

3.6 Water Absorption Tested

The water absorption values for Mgbom clay were 8.49, 1.06 and 0.51% while those of Amokwe and Amagu were 2.3, 1.61, 1.48% and 2.3, 1.52, 1.44% for 900^{o}C, 1100 and 1200^{o}C firing temperatures respectively, as seen in figure 4. These values correlate with the results of bulk density, apparent porosity and linear shrinkage. High porosity yielded higher water absorption and high density gave rise to low water absorption. This shows that the more porous a material become, the more it has the capacity to absorb water and the reverse occurs with regard to density. Hence, it is seen that water absorption is closely related to the apparent porosity. The internal structure of bricks must be dense to stop the intrusion of water. This shows that the water absorption of clay material varies directly to apparent porosity and inversely to bulk density.

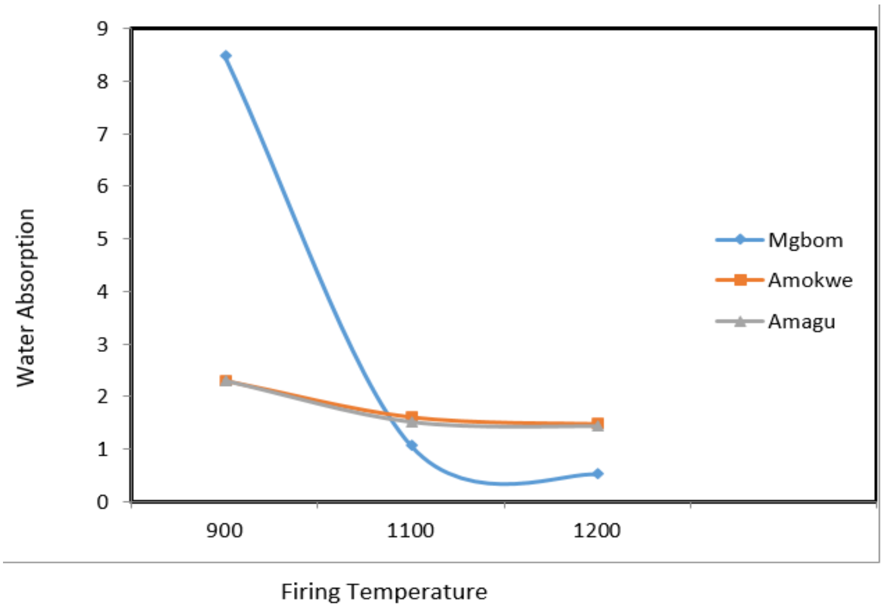

Figure 4. *Effect of firing temperature on water absorption of the various clays*

3.7 Modulus of Rupture Test

The results of this test were shown in figure 5. Mgbom clay has values of 27.26, 36.92 and 39.28. N/mm^{2}Amokwe clay has values of 37.1,39.29 and 40.43 N/mm^2 while Amagu clay was 38.2, 40.68 and 42.53N/mm^2 for the respective firing temperatures. It was observed that the transverse strength is a function of firing temperature. This shows that the strength grows with increase in firing temperature. This could be traceable to the development of some phases like the mullite in the structure of clay which is responsible for strength improvement. The phases develop and grow with increase in temperature. The results obtained show that those phases developed and grew with increased fired temperature. Amagu clay had the best value of modulus of rupture, followed by Amokwe and Mgbom clay.

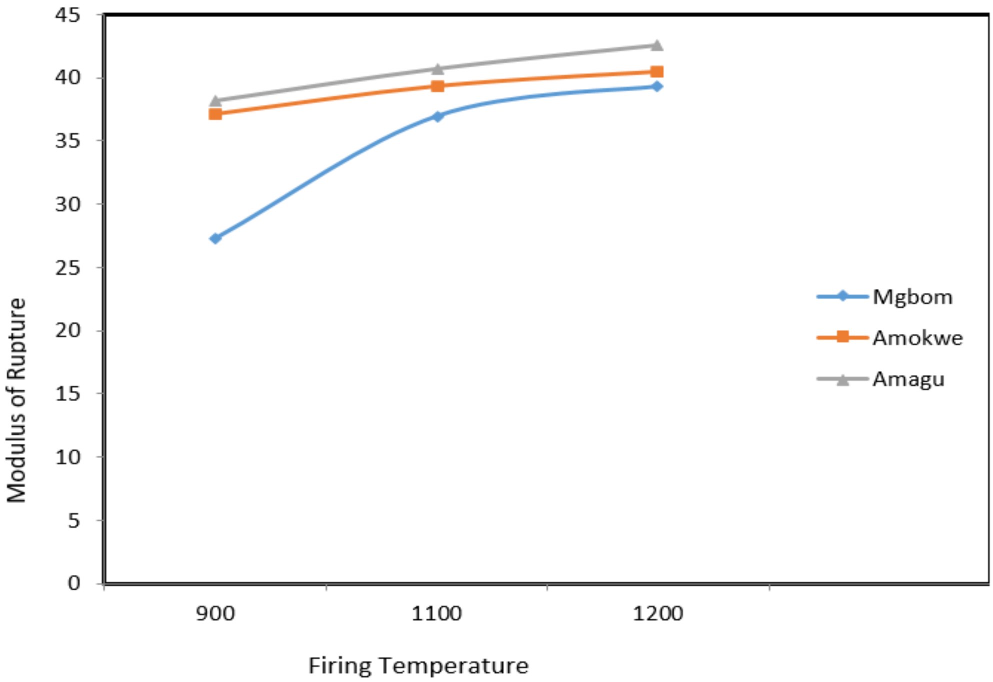

Figure 5. *Effect of firing temperature on modulus of rupture of the various clays*

3.8 Thermal Shock Resistance Test

The thermal shock resistance values of the clays were shown in figure 6. Mgbo clay had 21, 28 and 28 cycles while Amaokwe and Amagu have 19, 23, and 28 cycles for 900, 1100 and 1200^{o}C firing temperatures respectively. It was noted that Amokwe and Amagu clays have the same thermal shock behavior while Mgbo clay proves best among the three. It was observed that Mgbo clay has the value within the acceptable range of 25-30 at 1100^{o}C and 1200^{o}C while Amaokwe and Amagu had acceptable value for this property at only 1200^{o}C firing temperature. Hence, optimum value of this property could be obtained at above 1100^{o}C firing temperature for the clay deposits investigated. The thermal shock response could be traceable to particle size, nature of bonding and chemical compositions of the clay material.

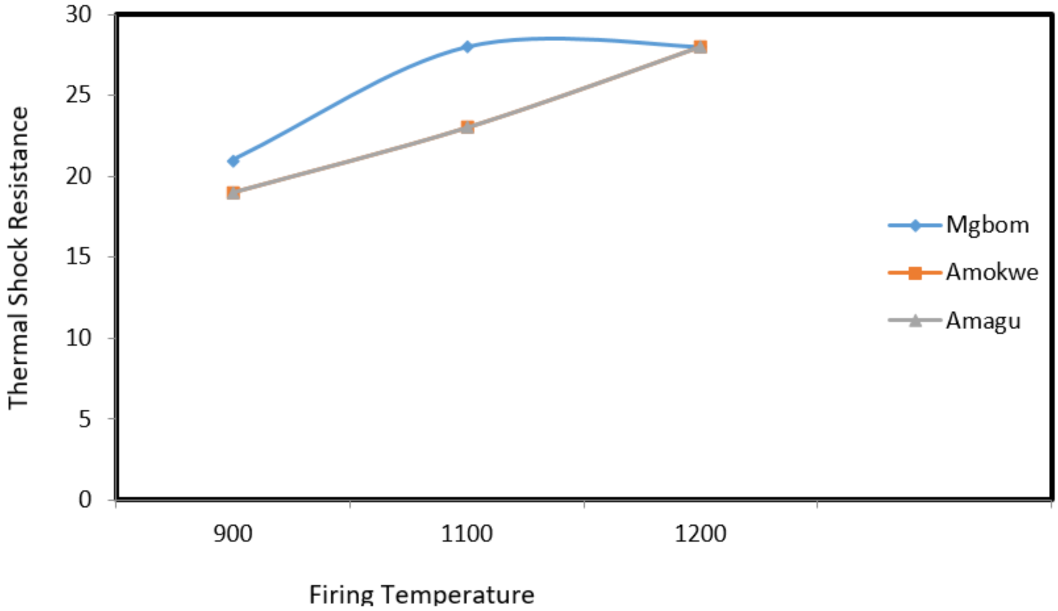

Figure 6. *Effect of firing temperature on thermal shock resistance of the various clays*

3.9 Refractoriness Test

The value of the refractoriness was shown in figure 7. Mgbom clay had refractoriness value ranging from 1250 – 1650^{o}C while Amokwe and Amagu ranges were 1100 – 1500 ^{0}C and 1100 – 1550 ^{0}C. All of them met the requirement for refractory purpose for internationally accepted standard of (1500^{o}C – 1700^{o}C) as reported by Omowumi (2006). However, Mgbom clay has a better refractoriness than the others. The high refractoriness value is traceable to high value of alumina in the clay compared to other two. This alumina is responsible for mullite development which has direct effect on the refractoriness and other strength related property of the clay material.

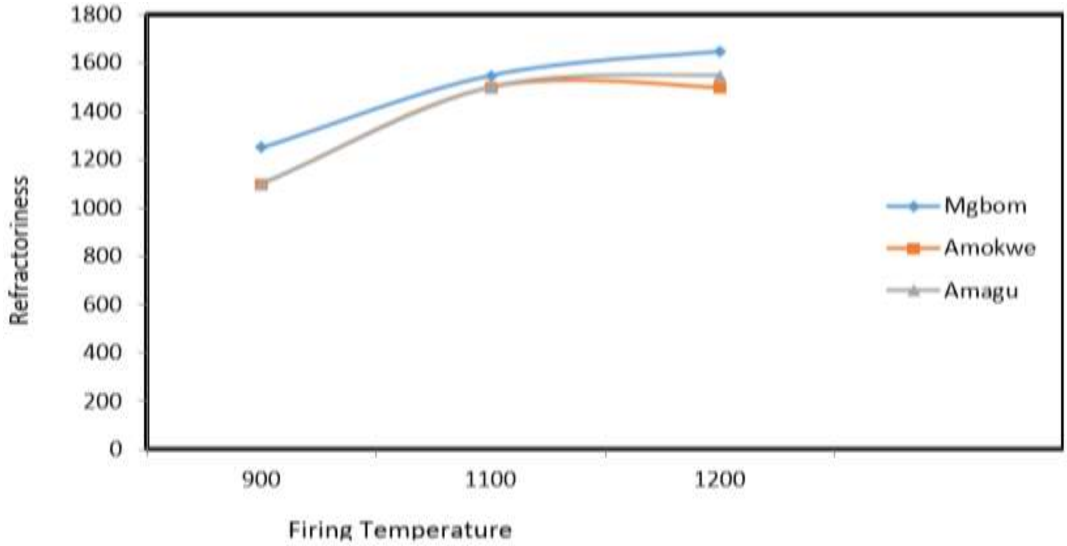

Figure 7. *Effect of firing temperature on refractoriness of the various clays*

3.10 Scanning Electron Microscope (SEM)

Figure 8 Shows the SEM result for clay samples Amokwe, Amagu and Mgbom. From the diagram we could see a level of similarity between that of Mgbom and Amagu. The SEM image of the clay sample of Amokwe reveals a lot of pores on its structure unlike those of Mgbom and Amagu. The presence of these pores on the clay sample of Amokwe will have a negative effect on the heat resistance properties of the clay. This means that the samples of Mgbom and Amagu will definitely have higher heat resistant properties than that of Amokwe. Comparing the clay samples of Mgbom and Amagu, that of Mgbom appears to be more closely packed and with lesser pores than that of Amagu. Hence, the clay sample of Mgbom will be a better refractory material that the other two samples.

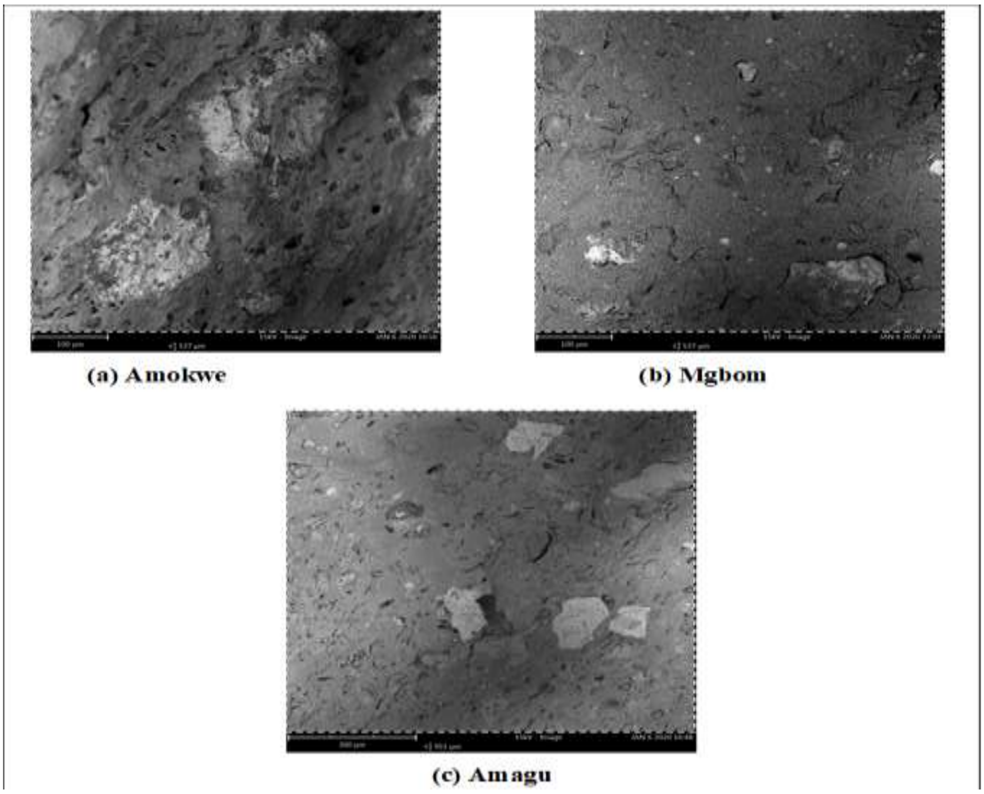

Figure 8. *SEM result for the samples*

The SEM result also presents the elemental constituents of the various samples of the clay as shown in table 3. The major difference in constituent elements in the clay is the unlike those of Amokwe and Mgbom, the Amagu sample contains manganese. The comparison of the elemental constituents in terms of atomic and weight consentration are presented in figures 9 and 10, resectively.

Table 3. Elemental Constituents of the Various Clay Samples

Element Name	**AMOKWE**		**MGBOM**		**AMAGU**	
	Atomic Conc.	**Weight Conc.**	**Atomic Conc.**	**Weight Conc.**	**Atomic Conc.**	**Weight Conc.**
Iron	27.52	39.26	11.57	19.59	20.08	30.90
Silicon	33.21	23.83	54.49	46.42	40.83	31.60
Aluminium	15.32	10.56	21.12	17.29	19.00	14.12
Titanium	8.34	10.20	1.37	1.99	4.73	6.24
Chlorine	3.87	3.51	1.21	1.30	1.21	1.18
Potassium	3.32	3.32	4.50	5.34	1.87	2.01
Calcium	3.20	3.27	1.75	2.13	3.28	3.63
Silver	1.19	3.27	1.03	3.37	1.41	4.20
Magnesium	1.21	0.75	0.88	0.65	2.15	1.44
Sulfur	0.92	0.75	0.95	0.93	1.06	0.94
Phosphorus	0.85	0.67	0.86	0.81	1.51	1.29
Sodium	1.07	0.63	0.26	0.18	2.13	1.35
Manganese	-	-	-	-	0.73	1.11

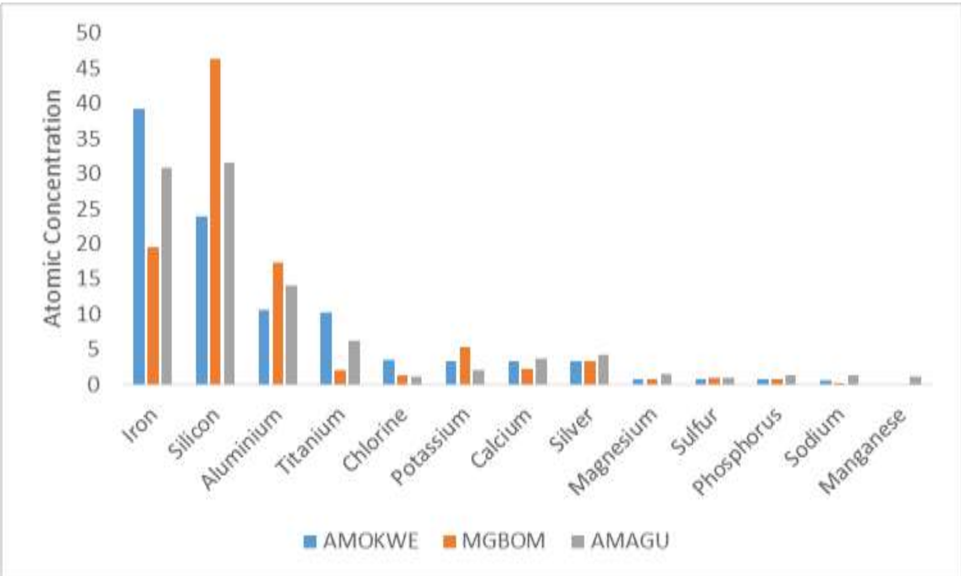

Figure 9. *Comparison of the Elemental constituents in terms of Atomic concentration*

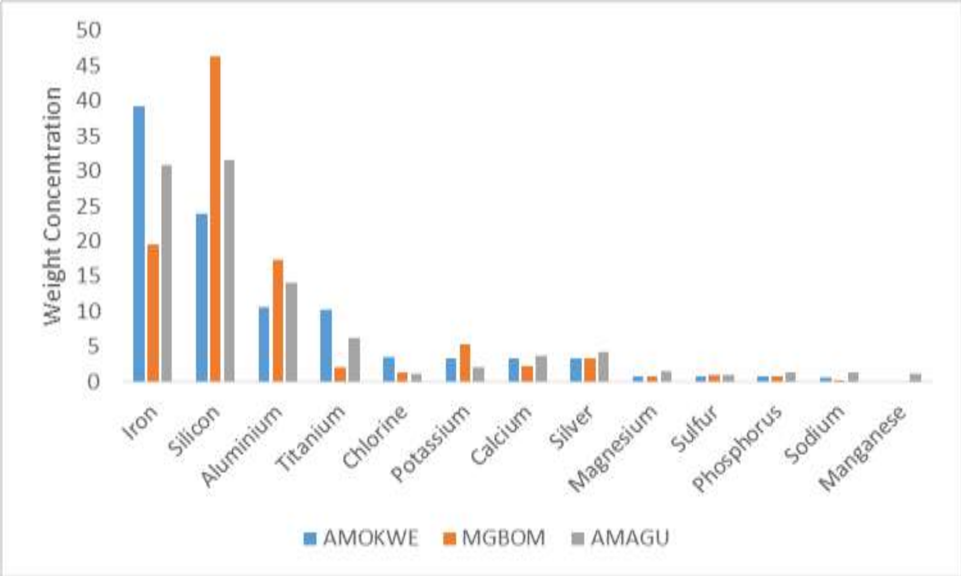

Figure 10. *Comparison of the Elemental constituents in terms of Weight concentration*

3.11 Comparison of Result Findings with Previous Related Works

Omowumi[6] and Aremu et al[7], showed the international accepted standard specified for oxide composition of refractory materials as shown in Table 4 while Aliyu et al (2012) and Omowumi, (2001), gave the specifications for refractory properties of clay as 1.71 – 2.1g/cm^3, 2 – 30%, 25 – 30 cycles, 7 – 10% and 1500^{o}C – 1700^{o}C for bulk density, apparent porosity, thermal shock resistance, linear shrinkage and refractoriness respectively. This is shown in table 4. Specified values for chemical compositions for fire clay and refractory clay were used to compare with chemical compositions obtained in the clays studied. This is shown in Table 4. It was found that the three clays studied compare relatively well with accepted standards.

Comparison of these standard specification with the results obtained in the properties of the clays used in this study are shown in Table 4.

Table 4. Comparison of the Chemical Composition of the Clays with Internationally Accepted Standards for Different Applications

Chemical Constituent	Fire Clay (%)	Refractory Brick (%)	High Melting Clay	Mgbom Clay	Amagu Ishiagu Clay	Amokwe Ishiagu Clay
SiO_2	55-75	51-70	57 - 73	58.6	36.1	35.1
Al_2O_3	25-45	25-40	16 - 29	28	23	21.9
Fe_2O_3	0.5-2.0	0.5-2.4	1 - 9	8.68	33.4	32.26
MgO	<2.0					
K_2O	<2.0			1.5	0.72	0.74
L_2O	12-15					

Comparison of the specified standards in terms of oxide compositions and refractory properties of refractory clay with those of the three different clay deposits studied are shown table 5. It was found that Mgbom, Amokwe and Amagu compare favourably with these deposits previously investigated and as such recommended for refractory purpose which is the major aim of this study. Also, Mgbo clay qualifies to be classified as refractory clay while Amagu and Amokwe Ishiagu qualified for high melting clay. For Mgbo clay, the linear shrinkage, apparent porosity, thermal shock resistance and refractoriness values compares well with that of standard fire clay. However, the bulk density slightly falls below the recommended 2.3 g/cm^3 according to Aliyu et al (2012)

Amokwe and Amagu were seen to have bulk density that could be acceptable since it was above 2 g/cm^3. The linear shrinkage, thermal shock resistance and refractoriness had values that are acceptable but at higher temperature of (1200^{o}C). Hence, they could qualify if fired up to 1200^{o}C. Based on these comparisons, the three clay deposits investigated could be recommended for refractory purposed which is the major aim of this study.

Table 5. Comparison of Specified Standard Properties with the Properties of the Clays Studied.

Sample Location	**Linear shrinkage %**	**Apparent porosity %**	**Bulk Density g/cm^2**	**Modulus of rupture N/mm^2**	**Thermal shock resistance (Cycle)**	**Refractoriness (^{o}C)**
Mgbom Clay	4.1-9.3	1.01-15.65	1.84-1.99	27.26-39.28	21-28	1250-1630
Amagu Ishiagu clay	5.6-8.8	2.50-4.92	1.73-2.07	38.2-42.53	19-28	1100-1550
Amokwe clay	4.5-8.8	2.44-4.76	1.66-2.10	37.1-40.43	19-28	1100-1500
Specified Standard	4 -10	2 -30	2.3		20-30	1500 - 1700

IV. Conclusion

This research investigation characterized the three clay deposits and determined their properties. The studies also understudied the influence of the firing temperature on these properties. In view of these, it was found that the major oxide in the clays were Al_2O_3, SiO_3, TiO_2, Fe_2O_3 and other oxides in trace quality. It is observed that Mgbom clay has high composition of Al_2O_3 of 28% which improved some properties like refractoriness and thermal shock resistance. Amokwe and Amagu clays have lower alumina value compared to Mgbom clay. The physio-mechanical properties of these clays show that they have excellent thermal shock stability, refractoriness and strength for high temperature application.

It was also found from the results obtained those properties like linear shrinkage, apparent porosity bulk density and water of absorption are interrelated. High porosity yielded higher water absorption with low bulk density. The properties investigated were found to be within the accepted standard.

From the results and findings obtained from these research studies, the following conclusions were made:

1. Among the deposits investigated, Mgbom clay deposit ranks the best in terms of high temperature characteristics like refractoriness and thermal shock resistance while Amokwe Ishiagu and Amagu Ishiagu clay performed better in physical and mechanical properties like bulk density and modulus of rupture. Mgbom clay possessed the highest value of alumina. This clay should be classified as fire clay and should be utilized for refractory application.
2. Amokwe and Amagu Ishiagu clay deposits are classified as high melting clay with good physio-mechanical properties that makes them suitable for lining in furnace used in melting nonferrous metals.

3. The raw materials have good qualities for exploration to meet refractory need for both petrochemical and metallurgical industries which will substitute importation and serve the need for foreign exchange.
4. The properties of clay materials are interrelated and are unique for each particular clay.
5. The performance of the properties of clay material is dependent on the chemical composition, the manufacturing process and firing temperature.

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