Evaluation of Termite Hill as Refractory Material for High Temperature Applications

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ABSTRACT

Evaluation of termite hill as refractory material for high temperature applications has been successfully carried out as an effort to meet the present demand in our foundry, steel and metallurgical industries and future development of other industries. The level of exploitation and degree of development of the resources is also likely to continue to play a central role in economic wellbeing of the nation in future. Therefore, the need to carry out investigation on the evaluation of termite hill as refractory material for high temperature applications is highly essential. The samples were collected from five different points of the termite hill deposits in and around the Niger State Polytechnic, Zungeru and were marked for investigation. The samples were homogenized to obtain representative sample using cone and quartering technique and were then subjected to tests to determine the refractory properties and quality of the termite hill clay sample. The physical Appearance of the Termite Hill clay sample before firing was brown. The following tests were carried out in order to determine the properties of the clay before its use for brick making for furnace lining. The tests include plasticity, moisture content, shrinkage, porosity, (Apparent porosity), permeability, refractoriness density, nitrification, water absorption, and chemical composition analysis. This paper presents some results of the investigation carried out on the refractory properties of sample obtained from the Termite hill clay sample. The sample revealed the following properties: Moisture contents (7%); Fired shrinkage at 1100^{o}c (9.18%); Thermal shock Resistance at 900^{o}c (15); apparent porosity at 1100^{o}c (22%); Plasticity (40%) and Water absorption (37.64%). Others are Solid density (3.33g/cm^{3}); bulk density (1.948g/cm^{3}), specific gravity (2.81), permeability (80.4), and refractoriness (1200^{o}c). The chemical analysis of the clay sample revealed a fairly high proportion of silica and alumina contents. Therefore, the clay sample could be classified as Alumino-silicate or fire clay group. The refractoriness of the brick produced based on the available furnace used revealed that the brick was quite capable of withstanding temperature range of as high as 1200^{o}c – 1500^{o}c. With the result obtained from this investigation, the termite hill clay sample is a suitable material capable of being used for bricks making for applications in furnace lining and metallurgical industries.

Key words: Investigation, Refractory, Properties, Termite hill, Temperature and applications.

INTRODUCTION

In the last few years, there has been increasing awareness on the scope, role and importance of Iron and steel

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in the industrial development of Nigeria. Some works have been done on the various refractory clay deposits in Nigeria and have found them suitable for use in metallurgical industries with some additives (Hassan *et al.* ,2023). Generally, refractory materials are considered as inorganic materials, consisting of mixture of oxides obtained from naturally occurring minerals and capable of withstanding very high temperature conditions without an undue deformation, failure or change in physical shape and chemical properties or composition (ASTA 1975) (Hongming *et al.*, 2023). Fire clay refractories are alumino-silicate refractories produced mainly from clays, which have alumina content between 25 to 45%. They are probably the first refractories used by man and are most common alumina of refractory materials. Currently alumina silicates, magnesite, chrome-magnesite, carbon and dolomite are the major types of refractories used in Nigeria (Olusola, 1998).

Termite hills, also known as mounds, have long fascinated scientists and engineers due to their remarkable durability and resilience in the face of extreme environmental conditions. These intricate structures, constructed by termites using a mixture of soil, saliva, and excrement and their colours range from light brown to dark brown to deep red depending on the surrounding soil (Temitayo, 2023). They have proven to be exceptionally resistant to heat and fire (Shumuye *et al.,* 2021). This unique characteristic has piqued the interest of researchers and innovators seeking sustainable and cost-effective materials for high-temperature applications.

In a world where industries such as metallurgy, construction, and aerospace demand materials capable of withstanding extreme temperatures, the exploration of unconventional sources like termite hills holds the promise of discovering innovative solutions. The utilization of termite hill material as a refractory substance for high-temperature applications has the potential to revolutionize various industries by offering a renewable, environmentally friendly, and economically viable alternative to conventional refractory materials (Folorunso *et al*., 2012).

The pressing needs in Nigeria and the availability of abundant natural resources demand that the direction of utilization of our resources be up-graded through scientific and technological insight and new and improved Technology to meet needs and specific insight of our industries. (Fanisi, 2023).

Owing to the development of Iron and steel industries there has been a great increase in the use of refractory materials. For instance, over =N=1.5 million worth of fire clay bricks are consumed annually in steel melting shop of Delta steel company (DSC) (Hassan, 1990).

In addition to the enormous amount spent on the importation of these products despite the availability of clay, which serve as the major raw-material of fire clay refractories, the need to locally source and manufacture these products is considered a worthy venture.

Termite hill material exhibits a unique ability to withstand high temperatures, with some reports suggesting they can endure temperatures exceeding 1,000 degrees Celsius (Temitayo, 2023). This remarkable resilience, combined with their abundant availability in many regions of the world, presents an enticing opportunity to harness their properties for high-temperature applications (Dansarai et al., 2020). This approach aligns with the growing global emphasis on sustainable and environmentally friendly solutions.

This research is aimed to delve into the evaluation of termite hills as refractory materials, for high temperature applications, shedding light on their composition, thermal properties, and potential applications in industries requiring resistance to extreme heat materials. By uncovering the secrets of nature's architects, we aim to unlock the hidden potential of termite hills as a sustainable solution to the challenges posed by high-temperature environments.

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MATERIALS AND METHOD

Materials

Samples of clays for this investigation were collected in and around the Niger State Polytechnic, Zungeru. The physical Appearance of the Termite Hill clay sample before firing was brown.

Methods

Determination of Refractory Properties

The following tests were carried out in order to determine the properties of the clay before its use for brick making for furnace lining. The tests include plasticity, moisture content, shrinkage, porosity, (Apparent porosity), permeability, refractoriness density, nitrification, water absorption, and chemical composition analysis.

Plasticity

500g of the clay sample sieved through BS No 500 sieve (500µm) was weighed out. Two litres (2000 Cm^3) of water was added from a burette followed by kneading till a smooth consistency was obtained.

Water of plasticity was calculated using the following expression.

$$\text{Water of plasticity (\%)} = \frac{\text{weight of water}}{\text{Weight of clay}} \text{X } 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.1$$

Moisture Content

5g of the sample weighed and dried at 110oc in an electric oven for 24 hours, it was cooled in a desiccator and re-weighed. The difference in weight was expressed as a percentage to the dry weight as follows

$$\text{Moisture content (\%)} = \frac{\text{wet weight} - \text{Dry weight}}{\text{Wet weight}} \text{X } 100\ \% \quad \ldots\ldots\ldots\ldots\ldots\ldots. 2.2$$

Determination of Linear Shrinkage of The Clay Sample

500g of the clay sample was passed through BS 180 µm sieve, sufficient water to make a creamy – ship was added and dewatered on the plaster bat. The plastic clay was kneaded carefully to remove air. 5 slabs were made from the plastic clay. 2 fine lines 5cm long and 2cm apart were marked with a pair of divider on the slabs. The slabs were dried for 3 days. The wet to dry shrinkage was measured using the relation.

$$\%\ \text{wet shrinkage} = \frac{\text{change in length}}{\text{Original length}} \text{x } 100$$

$$\text{i.e.\% wet shrinkage (W.S)} = \frac{\text{DL}}{\text{L}} \text{x } 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. . \ldots. 2.3$$

$$\text{Fired shrinkage (F.S)} = \frac{\text{Change in length}}{\text{Original Length}} \text{x } 100$$

$$\text{Fired shrinkage (F.S)} = \frac{\text{DLi}}{\text{Li}} \text{x } 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 2.4$$

Sieve Analysis (Grain Size Distribution)

This was determined using B.S Standard test sieve. 500g clay sample was weighed and poured into an already arranged sieve on a mechanical shaker. It was shaken for 25 minutes after which mass on each sieve was determined. The percentage retained and percentage passing was calculated using the following expressions.

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

$$\text{Percentage Retained (\%)} = \frac{\text{W r}}{\text{Wi}} \text{x } 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .2.5$$

$$\text{Percentage passing (\%p)} = 100 - \frac{\text{W r}}{\text{Wi}} \text{x } 100 \ \ldots\ldots\ldots\ldots\ldots\ldots..\ldots\ldots\ldots .2.6$$

The calculation was carried out for each sieve and pan.

Thermal shock resistance

The test samples of size 50mm in diameter and 50mm in length were made from the clay sample. They were inserted into an electric furnace which has been maintained for one hour at a temperature of 900^{o}c. The pieces samples were left in the electric furnace for 10minutes and then taken out to cool in a stream of air and then put back into the furnace, which is kept at 900^{o}c for another 10 minutes. This process was continued until the test sample were in such condition that, after cooling, it can be readily pulled apart, but failure was not deemed to have occurred until the test piece broke into two equal pieces [Parts] the number of complete cycles required to cause failure in each specimen was recorded. The test usually discontinued after fifteen (15) reversals.

Apparent Porosity

The test pieces used for fire shrinkage were put into an electric oven at 1100^{0}c for 30 minutes. They were then put into boiling water and cooled under water. The test pieces were weighed completely immersed in water and also weighed suspended in water. The apparent porosity is then calculated from the relationship below.

$$\text{Apparent porosity} = \frac{\text{Ws} - \text{Wd}}{\text{Ws} - \text{Wp}} \text{x } 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .2.7$$

Where Ws= soaked weight; W_d= Dry weight ; W_p=Suspended weight.

Permeability

The test was done using a rammed samples and permeability Testing machine.

The permeability tester [machine] consists of cylindrical Arrangement in which a bell jar is put in place to displace a certain volume of air which was equal to the volume of water placed in the cylinder. A manometer was connected to measure the pressure during displacement of air. The specimen was fixed in a holder which exposed one of the bell jar replaced. The manometer reading was recorded. The standard specimen is 5.08cm in height and diameter. The orifice was opened and the time taken for the 2 liters [2000 cm^3] of water to displace equal quantity of air through the specimen was noted. The permeability [P] of the

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specimen was calculated using the fo9llowing relation. The standard pressure is 10cm of H_2O. Time taken was recoded to be 37.36 sec.

$$P = \frac{V \times H}{T \times A \times P} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.8$$

Where; V = Volume of air [cm^3]; H=Height of specimen, [min]; T= Time of air flow, [min]; A=Cross sectional area of the specimen. Cm^2; Pressure head [cm of water].

Refractoriness

A test cone was prepared and placed in the electric furnace along with pyro-metric cones designed to deform at 1100^oc, 1350^oc and 1500^oc respectively (comparison with an American pyrometric cones according to the temperature was then raised at 10^oc per minute. The temperature was determined by the means of an optical pyrometer. The maximum temperature of the available electric furnace was 1200^oC. The test piece did not show any sign of failure or deformation at this temperature.

Specific Gravity Determination

Some ground clay samples were passed through 100 sieve B.S.S., and then introduced using a glass funnel into a previously weighed specific gravity (SG) bottle (W_a), and weighed (W_b). The powder sample was covered with distilled water under vacuum and bottle suspended in water of a known temperature, for approximately 15 minutes to liberate uniformly followed by weighing, (W_c) . The bottle was washed, filled with distilled water and allowed to equilibrate for another 15 minutes and weighed, (W_d) . The specific gravity was calculated based on the following expression.

$$S.G = \frac{Wb - Wa}{(Wd - Wa)\ (Wc - Wb)} \times \rho w \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.9$$

Where S. G. = Specific gravity; Wa = weight of S.G. bottle; Wb = Wt of S.G bottle + sample: Wc = wtof S. G bottle + sample + Distilled water ; Wd = wt of S.G. bottle + distilled water; ρw = Density water at room temperature (T°C)

Average Bulk and Solid Densities

Test samples were collected from the clay and were dried in an electric oven for 24 hours at 110^oc. The dried weight (w_d) of the specimen were recorded, after which they were fired in an electric 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 air in the samples had been displaced by water. The specimens were then dried and the soaked weight (We) was recorded. The specimens were then suspended in a beaker of water one after the other and the suspended (weights (W_p) were recorded. The average bulk and solid densities were calculated from the following expressions.

$$\text{Bulk Density} = \frac{Wd}{(Ws - Wp)} \times \rho w \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.10$$

$$\text{Apparent solid density} = \frac{Wd}{(Wd - Wp)} \times \rho w \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.11$$

Vitrification

The Samples were dried at 110^oc and fire slowly to 1100^oc in an electric furnace. The sample were drawn out at the following temperatures, 700, 800, 900 and 1100^oc respectively and tested for shrinkage, porosity,

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strength and density.

The degree of vitrification properties of ceramic such as cold strength, porosity, density and shrinkage and porosity were used to determine the temperature for maximum durability of various clays. The temperature at which the proportion of closed pores begins to increase is where porosity drops. This is known as the point of incipient vitrification.

Water Absorption

The sample made from the clay sample was dried in an electric oven till a constant weight was obtained. The sample was then submerged in the boiling water in such a way that did not touch the bottom of the vessel. The evaporated water was replaced by boiling water. After boiling period of 4 hours the vessel was cooled to about 25^{o}C.

After moving the adhering water from the sample with moist cloth, the specimen was then percentage water absorption was calculated using the formula given below.

$$\% \, W.A = \frac{Sw - Dw}{Dw} x \, 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . 2.12$$

Where Sw = Soaked weight; Dw = Dried weight; WA = water absorption

Chemical Analysis

The chemical Analysis of the clay sample was carried out using instrumental analysis by Atomic absorption spectrophotometer (AAS) method.

RESULT AND DISCUSSION

All the results obtained from average of five (5) readings from this investigation are summarized in the Table show below.

Table 3.1 properties of the termite hill.

S/N	PROPERTIES	VALUE
1	Moisture content (%)	7
2	Loss on ignition at 1100^{o}C (%)	14.3
3	Fired shrinkage at 1100^{o}C (%)	9.18
4	Thermal shock resistance at (900^{o}C)	15 (good)
5	Apparent porosity at 1100^{o}C (%)	22
6	Plasticity (%)	40
7	Solid Density (g/cm^3)	3.33g/cm^3
8	Bulk Density (g/cm^3)	1.948g/cm^3
9	Specific Gravity	2.81
10	Water Absorption (%)	37.64
11	Permeability	80.4
12	Refractoriness (PCE)	1200^{o}C

Fired Colour

The surface colour of the sample clay changed from dark brown after firing to reddish brown, i.e. the fired colour is reddish brown. This compared favourably with internationally acceptable fired colour that all the clay sample with red burning colour could be used for either building materials likes, floor tiles and sewer pipes. The high temperature one can be used for technical ceramic like refractory bricks for furnace lining. Based on this the investigated sample could therefore be used for some of the above stated uses. There is equally an indication that the sample contains a high proportion of Fe_2O_3.

Moisture Contents

The average moisture content was about 7%. This figure seems reasonable however, for the workability of the material, little amount of water could be added.

Plasticity

Water of plasticity content was found to be 40%. This was found to be good for mouldability of the brick. This agreed with the internationally acceptable standards that a plastic clay will need more water to reach its plasticity stage and the quantity of water to be added depends on how plastic the clay is. The percentage water of plasticity of the clay sample is reasonably high, therefore the clay sample could be classified as a plastic clay material.

Linear Shrinkage Of The Clay Sample

From the above Table the firing shrinkage at 1100^{o}C is 9.18%. This is no the high side compared to 4%, 2% firing shrinkage of chanchana and saukakahuta respectively as reported by Manukaji (2004). However, this value comparable to 7 – 10% values normal for kaolin and fire-clay.

Seive Analysis

This a guide method of determining the particle size distribution of the sample. From the above result it could be seen that at about 60% portion most of the samples would have passes through 200's mech sieve (75µm). This compare favourably with the acceptable international standard. Therefore the sample under investigation may be classified as having more clay in it.

Thermal Shock Resistance

The material is found to have a resistance to thermal shock of 15 cycles at a temperature of 900^{o}C. This is at low side comparing with 30. cycles for Chanchaga (Abifarin ,1999). However, it compared favourably with the acceptable standard 10+ cycle for siliceous fire clay. Therefore, the thermal shock resistance (15) is good enough for general purpose brick for re-heating furnaces, ladles and etc.

Apparent Porosity

From the above table, the clay sample has an apparent porosity of 22% at 1100^{o}C. This value compared very favourably with the porosity value of 21.7% and 18.9% of Bomo and Kaurandole, both in Kaduna state. It equally compared favourably with 22-25% for imported fire clay. This value also falls within the required apparent of refractoriness which lies between 20-30% (Olufemi *et al*., 2023).

Permeability

From the investigation, the permeability of the sample is 80.4. This value is higher than the permeability value of kuyi clay (7.5), Chanchanga (10.38), Maitumbi (15.24), Kpakungu (21.42) and Saukakahuta (7.5) all in Niger state of Nigeria. However the permeability value of the sample under investigation falls within the acceptable value of 25-90 for international standard.

Refractoriness

The refractoriness of the brick produced based on the available furnace used shows that the brick produced from the clay sample was quite capable of withstanding temperature range of as high as 1200 – 1500^{o}C. This is because the brick displayed the ability to withstand temperature beyond the 1200^{o}C which it was fired being the maximum furnace temperature. The material could be used for making bricks of medium temperature furnace.

Specific Gravity

The specific gravity is 2.81. This value compares very well with the specific gravity values of some Nigerian clays such as Kpakungu (2.810) and Maitumbi (2.836), as reported by Hussaini (1997), Kankara (2.78), Zungeru (2.81) Olusola (1998) and Termite Hill in Akungba Akoko (2.67) Temitayo, (2023). The investigated specific value equally compares favourably with the internationally acceptable range of between 2.0-2.8. The clay sample material has a fine particle (grain) size distribution.

Average Bulk and Apparent Solid Densities

The average bulk density and apparent solid density were found to be 1.948 and 3.33g/cm^3 respectively the bulk density value compared well to the normal value range of between 1.7 to 2.1g/cm^3. However, the apparent solid density value is higher than the apparent solid density of some Nigerian clays. This is equally higher than the internationally acceptable range of 1.7 – 2.1g/cm^3. This could be as a result of inadequate sintering during firing.

Chemical analysis.

The chemical analysis, though can be of great value and may even be crucial, it is more often used as a method of classifying materials.

The percentage composition of the various constituents are recorded as shown in the table 2.1 below.

Table 3.2 chemical composition of the termite hill

METAL SYMBOL	METALLIC VALUE	MULTIPLYING FACTOR	METAL OXIDE FORMULAR	VALUE (%)
Si	31.828	2.139	SiO_2	68.08
Al	14.878	1.890	Al_2O_3	28.12
Fe	0.699	1.430	Fe_2O_3	1.00
Ti	0.654	1.668	TiO_2	1.09
Ca	0.214	1.399	CaO	0.30
Mg	0.229	1.658	MgO	0.38
Na	0.780	1.348	Na_2O	2.4

The chemical analysis of the Termite hill compared with typical composition of refractory materials are given in Table 3.2

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Table 3.3 chemical analysis of termite hill with typical composition of imported refractory materials.

CONSTITUENTS	TERMITE HILL	INDIAN CLAY	CORNISH CHINA CLAY	FIRE CLAY	SILCEOUS FIRE CLAY
SiO_2	68.08	55-70	45.46	60-5	59.0
Al_2O_3	28.12	25-38	38.33	33-8	25.0
Fe_2O_3	1.00	2-5	0.55	2-2	5.9
TiO_2	1.09	1-1.5	0.34	1-2	0.6
CaO	0.30	0.5-1	0.06	–	0.6
MgO	0.38	0.2-0.8	0.12	–	–
Na_2	2.4	—	0.43	–	–
K_2O	–	1 – 2	2.22	1-2	2-3
L.O.I	14.3	—	-12.44	–	–

CONCLUSION AND RECOMMENDATIONS

Based on the investigations carried out on the properties of Termite Hill, it was observed that their values compare favourably with the imported fire clay refractories. The refractoriness of the brick produced based on the available furnace used revealed that the brick was quite capable of withstanding temperature range of as high as 1200^oc – 1500^oc.

Moreover, with the result obtained from this investigation, the clay sample could be recommended for the following applications:

i. The clay is capable of being used for ovens and furnaces of which temperature limit would not exceed 1200^oc (medium temperature furnace).

ii. It is also good for general purpose brick for re-heating furnace and ladle.

iii. It is equally capable of been used for refractory base of electric stove.

Other properties such as refractoriness – under-load, thermal conductivity cold crushing strength, spalling and fusion temperature should be determined.

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