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Characterization and Mechanical Properties Improvement of Termite Mound Clay for Sustainable Construction Materials

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Abstract

In this work, the characteristics of termite mound clay are studied and enhanced with the addition of alumina. The clay was washed to remove the unwanted dust particles and then sun and oven-dried at 110°C for 8 hours. For XRF analysis, samples were crushed and sieved to 90µm, and for other tests, to 150µm. The average chemical composition results of the samples showed that 55.89% SiO_2, 14.19% Al_2O_3, 10.14% Cao, 6.58% Fe_2O_3, 1.01% MgO, 0.87% H_2O, and other trace elements had a 9.08% LOI. The chemical composition results of the samples fall under the category of high silicate clays. This result leads us to add a percentage of alumina from market to reach at least the minimum requirement for refractory materials properties. The liquid limit test established the amount of water required for the best clay plasticity prior to sample preparation. Apparent porosity decreased from 29.79% to 20.3% as Al_2O_3 content increased from 10% to 20%. This is because Al_2O_3 closes the open spaces within the samples during moulding and it could not burn off during firing but increased the bulk density value from 1.46 to 1.769 g/c^3. The compressive strength also increased from 7.11 to 12.52 MPa with the increased addition of Al_2O_3. Since there were less pore spaces, the compressive strength increased, and the load-bearing cross-sectional area increased. The percentage linear fired shrinkage of the samples at 900 °C along the length, width, and height was decreased from 2.42 to 1.02%, 5.16 to 1.02%, and 6.09 to 0.01% respectively, with increased addition of 10 to 20 wt. % of Al_2O_3.

Keywords: *Alumina, characterization, refractory material, silica, termite mound clay*

1. Introduction

The most common refractory materials used in the production of refractories are Al_2O_3, SiO_2, and magnesia. Calcium (lime) oxide is an oxide commonly observed in refractories. Fire clay is also widely used to make refractory materials (Ombaka , 2016). Hence, refractory materials play very essential roles in industrial development. Therefore, excluding refractory materials, not all scientific and technological inventions and developments, we know today would have been possible. Therefore, refractory materials are essential to the successful operation of any industry in which high temperatures are used. Termite mound clay is found mostly on high fertilising land, and it causes damage to destroy a crop, and any kind of grass type. Currently, converting such clay into a useful raw material is a big task for all researchers.

1.1. Termite mound clay properties and applications

Researchers found that some natural stones and some clay had a greater temperature resistance than others. So, refractoriness can be defined as the fact that the material will not melt or deform (shrink) under prolonged service in the furnace environment. It is known that the refractoriness of a material is highly dependent on its chemical composition. Clay is known as “fireclay” because of its resistance to high temperatures. It has become preferred for use in refractory products based on their reputation as successful raw materials for refractories. In time, conveniently located natural stone products were depleted (Denis & Charles, 2009). Clay is a naturally occurring material composed of layered structures of fine-grained minerals that exhibit the property of plasticity at an appropriate water content but become permanently hard when fired (Ombaka, 2016).Currently, clay is used as a useful raw material in many fields (ceramics, paper, paint, petroleum industry, catalysis, etc.). Clay’s suitability is determined based on mineralogy, chemistry, and plasticity, as well as the firing conditions, such as temperature, soaking time, heating rate, and atmosphere. To study clay for manufacturing bricks or roofing, floor, and wall tiles, clay’s technological properties are related to its mineralogical composition, physical properties, and relative proportions. Different physical properties, such as porosity, shrinkage, bulk density, mechanical strength, etc., are common quality determination parameters. To produce a good enough quality of construction brick material, various additives have been used by different researchers, such as the addition of rice husk, rice husk ash, and sawdust (Tonnayopas, 2014). Termite mound clay contains clay, which consists of many inorganic materials (i.e., minerals and water) that make it fire resistance and inflammable. Some termite mounds contain white asbestos, which comes from the surrounding soil. Termite mound clay materials are all sourced on-site and are all biodegradable. Termite mound clay is being selected for use in silo construction because of its improved plasticity, and thereby, being less prone to cracking when compared with ordinary clay (Umaru et al., 2012). Ethiopia is one of the developing countries in different sectors, especially, science and industrial technology. All metal and engineering corporations used different ferrous and non-ferrous melting furnaces. The raw materials for making furnace linings or crucibles are like alumina and silica. Hence, this study needs to study the locally available termite mound clay as shown in (Figure-1)

a **b** **c**

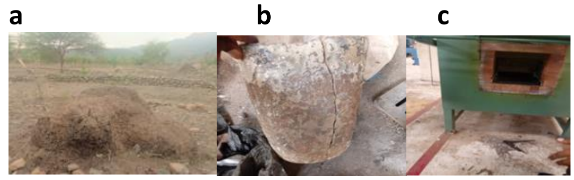

Figure 1
a) *Termite mound clay, b) Crucible c) oven*

2. Motivation and Contribution

Ethiopian agricultural research has found that termite mound clay is found almost all-over rural areas of Ethiopia, with a varied percentage from place to place. Areas covered by termite mound clay are free of any crops or grasses, even though it destroys any type of crop around it. Termite mound clay has had a high negative impact on crops for a long time, until today. Many biologists and agricultural-based researchers studied how to control the termite pest. However, termite pests and termite mound clay are there and continuously destroying our crop. So now it has to be converted into valuable engineering applications. Saying this; currently, most of the Ethiopian industries use alumina (Al_2O_3) and silica (SiO_2) refractory materials for different high-temperature resistant applications. Hence, this study aims to characterise the physical, mechanical, thermal, and chemical composition properties of locally available termite mound clay. The contributions of this article are listed as follows:

- Analyse the chemical composition of termite mound clay.
- Determine the thermal, mechanical, and physical properties of termite mound clay.
- Examine the effect of the addition of Al2O3 on the properties of termite mound clay.

This article will have significance regarding promoting the refractoriness of termite mound clay and opens an opportunity for coming researchers to do with such kinds of soil for different industrial applications.

3. Related Works

TMC is available in different Ethiopian rural areas, especially in western Ethiopia. It is known that this kind of soil is harmful to agricultural activities, especially the cultivation of crops. However, until now no sound engineering studies have been performed on this harmful soil type to convert it into useful raw material for industrial applications. According to. (Çadırli, 2012), research on termite mound clay in Ethiopia has been focused on only the pest control aspects. Therefore, generally in Ethiopia and specifically in this study area, the soil's physical-thermal properties have not yet been studied. The study aims to identify the chemical composition and study the refractory properties of the termite mound clay. Termite mounds have a clay content that is about 20% higher than that of the surrounding soil, reflecting the preference of termites for smaller clay particles for the construction of their mounds. While the soil is being transported in the insects' mouths, it is saturated by alkaline and other chemicals that modify the soil (ASTM international D 4318, 2000). A conference centre was also reported to have been built in Kenya, East Africa, from sun-dried termite mound clay bricks, while it has also been used as a substitute for cement in the construction of floors in pit latrines (Aliyu et al., 2013). According to the Raw Materials Research and Development Council of Nigeria (Sultana, 2014), clays are one of the major Nigerian mineral deposits, with an estimated proven reserve of billions of tones, and these clay deposits are scattered all over the states in the country. A. (ASTM international C20, 2005) studied Nigerian clays, and results showed that the locally available clay can replace the bricks used for lining. The procedures and equations used in this research are more standard than those taken from the published paper. Such as testing methods for apparent porosity, water absorption, and bulk density of a refractory brick by boiling water', the percentage range for the chemical composition of a good refractory clay is listed according to the manufacturing of standard refractory materials.

(Berger, 2010) studied different methods of manufacturing bricks from silica sand, and the methods used to determine the different physical properties, chemical composition, and thermal properties are very interesting and common for all researchers doing research related to refractories materials or bricks. (ASTM international C 133, 2008) studied the refractory properties of selected clays in north-central Nigeria, and the results were compared with other standard refractory material properties. samples are grouped under high silicate clays, and the silicon oxide values fall within the standard range of 46–62% that is required for the production of good refractory materials (ASTM international C20, 2005). Also, (Chukwudi, 2008) reported that clays with appreciable amounts of iron are not recommended, as the presence of iron tends to have deleterious effects on the process. All the above clays are suitable internal furnace linings without Nyikangbe clay due to their relatively large iron content, which is beyond the recommended range of 0.5-2.4% (ASTM international D 2487, 2000). Results show that the selected samples of clay have a lower bulk density than the reference clay. However, they have a high enough apparent porosity to make them suitable for insulating applications. Also, the compressive strength values were lower than the references, but the refractoriness was higher compared with the reference taken.

(Umaru, 2007) studied the effects of rice husk ash and asbestos on the characteristics of lightweight clay bricks, and the results showed that the effect of adding asbestos and rice husk on the temperature of the termite mound clay increased up to 1600℃ and 1050℃, respectively. However, there are some limitations, such as the fact that asbestos is harmful to humans and that the mechanical and physical properties of rice husks are not like those of asbestos. (Sultana et al., 2014) studied the influence of rice husk ash and fly ash on the properties of red clay, and the table below shows the physical properties values studied by the researchers. The shrinkage values were lower, which indicated that it reduces the risk of defects such as warping and cracking. The water absorption percentage was within 6 to 10% for the different mixtures. (Ndaliman, 2006), studied the different Refractory properties of termite mound clays under different percentages of additives. The results of the chemical composition and refractory properties of termite hill clay under varied proportions were determined as follows:

According to (Karim, 2016) termite hill clay can be grouped under high silica clay based on its chemical composition. The selected properties, like refractoriness and linear shrinkages, remained the same as the proportions of additives increased. The improvements obtained were because the additives, such as specific gravity, decreased gradually as the additives increased, while density and porosity varied in a reverse manner.

Hassan (2014) has studied the effects of sawdust and rice husk additives on the properties of local refractory clay, and the results showed that the use of additives caused an increment in the apparent porosity of the samples and a decrease in the bulk density of the material, with the addition of rice husk having a higher effect.

The use of additives affects the reduction of shrinkage and refractoriness. However, it has been shown that apparent porosity increased to a higher value of 45.3% with sawdust addition and 36.74% with the addition of rice husk. In both cases, it has also shown a reduction in bulk density. (Kumar, 2011) achieved his work by studying the effect of plastic clay to silt ratio, the effect of pore size, and heat treatment on the properties of insulating fire clay brick. (Etukudoh et al., 2016), studied how cassava peel can affect the insulating properties of some selected ‘Ogugu’ clay deposits, and results showed that increasing the composition of cassava peel in the clay has an effect on increasing linear shrinkage and water absorption. (Akinwekomi et al), studied the effect of anti-mound clay mixed with high-alumina cement regarding foundry properties. Generally, refractory materials are made in different combinations and shapes depending on the required application area. The major chemical compositions that determine the critical properties of refractory materials are alumina (Al_2O_3) and silica (SiO_2). Clay is a soil part that passes the 75-µm U.S. standard sieve size. Clay has good plastic behaviour during the moulding process and has appreciable refractory properties when fired at the required temperature. In most cases, termite mound clay contains 20% more clay than the surrounding soil, making it an appropriate raw material used for producing refractories.Accordingly, the chemical composition and different refractory properties of termite mound clay are different from place to place. Hence, it is important to study this kind of clay in our country and find out the possibilities of using it as a refractory material.

4. Materials and Methods

The materials used in this thesis were termite mound clay and Aluminum oxide. Representative samples were collected from three identified potential areas of termite mound clay resources found in Temben-Tigray-Ethiopia. This study was mainly intended to study the possibility of using the local termite mound clay for the applications of insulations and other refectory materials. First, termite mound clay was Mined and stored in a container.

According to (Folorunso, 2015), three to eight days is the recommended range for completely drying a clay in the sun to be easily crushed. In this research, the samples were sun- dried for 8 days, and then hand hammering was used for size reduction. Aluminium oxide is formed by the chemical reaction of aluminium and oxygen, and it is the most commonly occurring oxide called alumina (Al_2O_3). For this research, fused alumina was used from the market. The proportional mixture was in such a way that TC+ 10 wt. % Al_2O_3, TC+15 wt. % Al_2O_3, and TC+20 Wt. % Al_2O_3 were used.

4.1. Equipment, tools, and machines used in the experimentation

The different types of equipment used were an X-ray fluoresce (XRF) machine for chemical composition analysis, Jaw crusher, and a hammer to made fine termite clay. Amount, and electrostatically controlled oven for drying the clay sample, and different sieve sizes for determining of grain size were used. A Casagrande device with its accessories was used to determine the Atterberg limit (liquid limit and plastic limit) of the sample clay, and an electrical muffle furnace was used for firing the prepared samples. A Digital Venire caliper was used for measuring the initial and final dimensions of a sample to determine the fired shrinkage property. A Specific gravity test setup was used for determining the suspended weight of samples. A Compressive strength testing was used for the CCS test of the samples, and mold made of wood was used for producing the samples. Termite mound clay was collected from Temben-Tigray - Ethiopia. It was then washed in water to remove the deleterious particles. The water was drained from the clay slurry. The recovered clay was dried in the sun for eight days and again in the electric oven at 110 °C for 8 hours. The dried clay was finally jaw crushed and sieved to 90 µm for chemical composition analysis and 150 µm for the remaining other properties determination (Folorunso, 2015). Finally, a mixture of termite clay and aluminum oxide under the varied proportion of Al2O3 (10-20) % by 5% step was molded based on the required size of the sample for different properties analysis.

4.2. Chemical composition analysis of termite mound clay

A Malvern Analytical Energy Dispersive X-ray Fluorescence (ED X-RF) machine was used for determining the chemical composition of termite mound clay. The basic concept of using spectrometers is a radiation source, sample, and a detection system. The working principle of ED X-RF is by irradiating a ray to a sample directly from an X-ray tube and detecting the reflected radiation from sample and the detector is able to measure the different energies of the radiation coming from the sample. The detector has the ability to separate the radiation from the sample into the radiation from the different elements present in the sample. TMC was collected from three different places in

Temben. Termite clay was jaw crushed, grinded and sieved to a 90-micron size. Finally, the fine termite clay was punched to a sample holder and put into the ED X-RF spectrometer machine (Çadırlı, 2012).

4.3. Graduation /sieve analysis of termite mound clay

Wet sieve analysis is carried out because small particles of the clay are stacked against another large particle. The main purpose of the wet sieve analysis is to separate small particles by washing and allow them to pass through a 75-micron sieve. The procedure was done according to the standard for wet sieve analysis, (ASTM international D 2217-85, 1998). Firstly, the termite clay sample was dried in an oven for 100 hours, and out of the dried sample clay, one kg by weight was taken. After that, it was completely immersed in water and waited for 24 hours for slowly dissociate the stacked particle. On the third day, it allowed passing through a 75 µm sieve carefully. Following that, a particle smaller than 75 microns was passed, and the remainder was collected and dried for 24 hours.

1st 2nd 3rd 4th

Figure 2

Procedures for separating sand portion and clay portion of the termite mound soil

Finally, a dry sieve analysis was carried out using the following procedure: After being dried again in the oven, the amount of sand returned above 0.075 mm during the wet sieve procedure was 110.09 grams. This indicates that almost 89% of the termite soil is clay and silt. It was then performed using a dry sieve analysis according to (ASTM international D421-85, 1998) to classify sand into fine, medium, and coarse Arrange a sequence of sieves as shown below and measure each sieve weight, then put the termite clay sample at the top of the series sieves. After that, shake for 10 minutes in a mechanical shaker. Finally, weigh the returned clay in each sieve.

4.4. Atterberg limits (Liquid and Plastic limits)

Soil engineering properties vary with the amount of water present. In 1911, a scientist called Atterberg said that limiting the water content was a more important key for engineer's physical states of interest. Such as determining the liquid limit, plastic limit, and shrinkage limit values of a fine grain soil are water contents (expressed as percentages) where the soil behaviour change (ASTM international D 4318, 2000). According to guidelines (ASTM international D 48, 2000), the liquid limit was determined by the following procedures: First, the dried TMC samples were crushed and sieved by 425µm; then, they were soaked for 24 hours. 24 hrs.

Finally, the liquid limit is carried out by using a Casagrande as follows: The soaked sample was mixed with distilled water in the evaporating dish. In the cup of the liquid limit device, a portion of the mud was placed and levelled to a maximum depth of 1 cm.

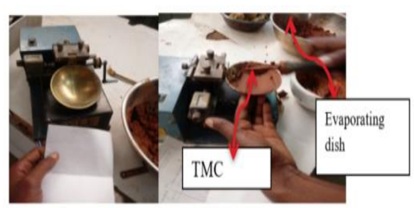

Figure 3

Liquid limit device (Casagrande) with its accessories

Then draw the grooving tool through the sample along the symmetrical axis of the cup by holding the tool perpendicular to the cup. The handle of the device then rotated until the two parts of the clay particle came into contact at the bottom of the groove.

Figure 4
Grooving and blowing the sample on Casagrande

Count the number of blows at the time when the two parts of clay come into contact. Then take a small amount of mud from the sample perpendicular to the groove axis, as shown above. Determination of the water content at 25 numbers of blows using a single sample is difficult.

The procedure involved putting in Excel the different values of water content at the corresponding number of blows and drawing a graph to show the relationship among them. Right-click on any point on the graph and click on trend line then trend line option polynomial. Finally, get the interpolation equation with the greatest R-value that approaches one and calculate the value of water content at 25 blows. The plastic limit of the termite mound clay carried out was according to (ASTM international D 4318, 2000) by taking a small sample from the 24-hour-soaked clay. It was performed by hand rolling on a pure glass to approximately 3 mm in diameter until it showed a small crack or discontinuity, then weighing the wet clay. Finally, it was dried in an oven for 24 hours and weighted.

Figure 5
Plastic limit determination

Therefore, the method used was the polynomial interpolatio technique on Microsoft Excel to determine to liquid limit at 25 blows.

The range of water content over which a soil exhibits plasticity called plastic index. Numerically, it is the difference between the liquid limit and the plastic limit (ASTM international D D 4318, 2000). According to (ASTM international D 2216, 1999) water existing in soil can be completely removed to get the mass of the sample by heating up in an oven at110+-5℃ for 12 hours.
(ASTM international D 2216, 1998). The TMC samples were weighed first and then heated in an oven for 12 hours at a constant temperature of 110℃. Finally, it was cooled in a desiccator and weighed.
To get the moisture content (ASTM international D 2216 , 1999).

$$M.C = \frac{WBD-WAD}{WBD} x100\% \qquad (1)$$

Where: M.C= moisture content
WBD=weight before dried by subtracting the weight of the container
WAD=weight after dried

4.5. Preparation of samples for determining physical and thermal properties

The samples were prepared in such a way that termite mound clay alone and termite mound clay mixed with aluminium oxide in varied proportions were taken as follows: The mixture was one kilogram of fine termite mound clay that passed through a 150-micrometre sieve and 100, 150, and 200 gram of aluminum oxide for each kilogram of the clay respectively. The reason for adding 10–20% of aluminum oxide to a sample of termite mound clay was because the

Recommended range of aluminum oxide for possible refractory material made from siliceous clay is 25 - 39%. However, the chemical composition of the selected termite mound clay has an average of 14.19% aluminum oxide.

Hence, to overcome the chemical composition of termite mound clay and to determine the properties within the range, aluminum oxide was added and bought from the market.

Table 1

Termite mound clay alone, a mixture of termite mound clay and aluminium oxide

Sample code	Termite clay (%)	Al_2O_3 (%)
TC	100	0
TCA10	90	10
TCA15	85	15
TCA20	80	20

There are different types of stirring machines for making a uniform mixture. However, due to the small number of samples taken, it is not suitable to use a large mixer. So, the new setup was developed for this purpose. The equipment used for making the set-up was portable hand drilling, a round solid bar welded to form a T-shape, a flat plate with a hole at the center, and a circular cup.

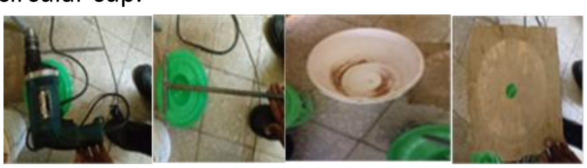

Figure 6

(a) Portable hand drilling, (b) welded T-shaped round bar, (c) container, and (d) flat plate with a hole at the center

After preparing, all the above facilities were then arranged as shown to develop the setup. Before the T-shaped bar is connected to the portable hand drill, first pass the bar through a flat plate hole from the bottom, and then connect it to the hand drill. Since the hand drill has a high capacity of

Revelation per minute, the mixing was efficient.

The plastic clay was formed into a mold according to the standard sample size required for different property exterminations. For preparing the mold, a flat plate, a handsaw, a Venire caliper, and C CN-43 general-purpose plaster was used.

Figure 7

Produced samples

The method used was hand ramming to produce the required samples according to the determined size for different experimental tests. The mould was covered with plastic (LDPE) first for easy removal of the sample from the mound.

Figure 8

Firing of the samples, testing for reheat change after fired and cold, as well as temperature capacity test in furnace

Some of the critical properties of the produced samples, like apparent porosity, bulk density, and water absorption, compressive strength, firing shrinkage, and refractoriness or fusion temperature, were determined based on ASTM international standard test methods.

4.6. Physical property testing

Samples were prepared with dimensions of 50 x 50 x 50 mm and fired at 900℃. Then the fired and dried samples were cooled in desiccators. The dried weight of the sample was measured (D). The weighed samples were transferred into a beaker, soaked with distilled water, and heated for 30 minutes to release the trapped air in the sample. After boiling, keep the specimens immersed in water for 12 hours before weighing. The samples were then cooled and measured for saturated weight (W) (ASTM international C20, 2005). To determine the suspended weight, Archimedes immersion technique was used. According to the Greek mathematician Archimedes (Berger, 2010), the buoyant force on a submerged object is equal to the weight of the fluid that is displaced by the object. Therefore, based on the Archimedes principle, the specimens transferred were into a basket that was connected to a balance and immersed in water until an equal depth of the basket. Each specimen placed was in the basket inside the water, and the weights of each specimen were measured when suspended in water (S).

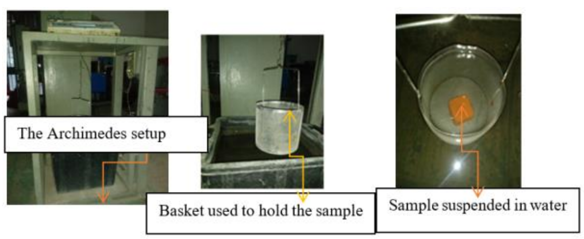

Figure 9

Laboratory Archimedes setup for measuring the Suspended weight of samples

Apparent porosity: Apparent porosity is a proportion of the volume of the open pores into which a fluid can infiltrate, as a level of the complete volume. This is a significant property in situations where the unmanageable is in contact with liquid charge and slag. High porosity materials are exceptionally protected because of the high volume of air they trap, since air is a poor thermal conductor.

The apparent porosities were calculated by using Eq-2 (ASTM international C20, 2005).

$$\text{Apparent porosity (\%)} = \frac{W-D}{W-S} x100\% \qquad (2)$$

Bulk density: a property of refractory materials that characterizes the material present in a given volume. A refractory material with a high bulk density value has good volume stability, heat resistance, and resistance to slag penetration. The bulk densities of the samples were determined using the relationship determined in Eq -3.

NOTE-1—this assumes that 1 cm^3 of water weighs 1 g. This is true within about 3 parts in 1000 for water at room temperature(ASTM international C20, 2005).

$$\text{Bulk Density} = (\frac{g}{cm3}) = \frac{D}{W-S} \qquad (3)$$

Water absorption: This property determines how much the refractory material can penetrate liquid or slag. The water absorption, A, expresses as a percentage the relationship of the weight of water absorbed to the weight of the dry specimen.

Calculate 'A' as follows (ASTM international C20, 2005),:

$$A\% = \frac{W-D}{D} x100 \qquad (4)$$

The technique used to determine the compressive strength of the refractory material system was as follows: The samples were prepared from the termite mound clay and mixed with aluminum oxide, which was then molded into a cube shape measuring 51 x 51 x 51 mm. The specimens were fired at 900 ^oC for 2 hours in a furnace. Then the specimens were cooled at room temperature for 24 hours.

The compressive strengths of the cooled specimens were determined by the compressive testing machine (ASTM international C 133, 2008).

$$\text{Cold compressive strength (CCS)} = \frac{Force}{Area} \qquad (5)$$

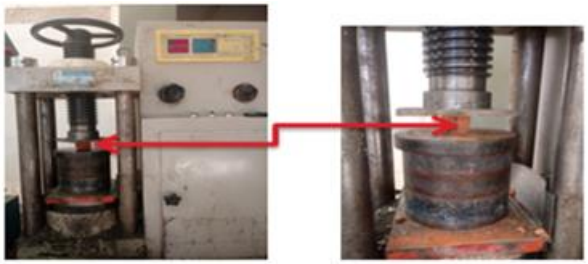

Figure 10

Compressive strength testing machine (Capacity the machine is up to 2000 kN)

4.7. Thermal property testing

Specimens with a half-scale dimension of 32 x 57 x 114 mm were prepared according to (ASTM international C210, 2007). The specimens were then dried in the air for 24 hours, fired at 900 oC in a furnace for 2 hours, and allowed to cool to room temperature. The dried length, width, and height of the specimens were recorded. After that, all specimens were heated in a furnace at 845 oC for 2 hours. Finally, take the samples from a furnace and measure the final dimensions (ASTM international C 210, 2007). The position of the specimens inside the furnace was rested by 114 x 32 mm according to the standard test of refractory materials for reheat change.

The fired shrinkage of the specimens was determined using the relationship in Eq-6. (ASTM international C 210, 2007). The linear change can be calculated using relationships.

$$L\% = \frac{Lo-Lf}{Lo}x100 \quad (6)$$

Where; L- length, W= width, H=height

$$W\% = \frac{Wo-Wf}{Wo}x100 \quad (7)$$

$$Q = \frac{KA\Delta T}{L},\ k = \frac{QL}{A\Delta T} \quad (9)$$

$$H\% = \frac{Ho-Hf}{Ho}x100 \quad (8)$$

Where, Q- heat in (W/m k)

5. Results and Discussions

Termite mound clay's (TMC) potential applications in ceramics and construction are determined by its chemical structure. X-ray fluorescence (XRF) spectroscopy is used in this investigation to investigate three TMC samples (TMC-01, TMC-02, and TMC-03) (Table 2). SiO_2 (55.89% avg.), AlO_3 (14.19% avg.), FeO_3 (6.58% avg.), and CaO (10.14%) avg.) are the main constituents. The null hypothesis (H_0) that the means are statistically equal was tested using a single-factor ANOVA to evaluate compositional variations. This establishes if the observed variations are significant or the result of inherent variability.

Table 2

Experimental test results of the chemical composition of three different termite mound clays by XRF.

Chemical composition	Sample locations			
	TMC-01	TMC-02	TMC-03	Average
SiO_2	57.7	53.58	56.39	55.89
Al_2O_3	15.13	14.95	12.48	14.19
Fe_2O_3	5.39	7.5	6.85	6.58
Cao	9.83	9.61	10.99	10.14
Mgo	0.64	1.29	1.11	1.01
H_2O	1.2	1.1	0.3	0.87
LOI	8.42	8.96	9.85	9.08
Remark	LST	LST	LST	

Results inTable-2 showed that termite clay samples are high-silicate clays. The average percentage of silicon oxide falls averagely within the standard range of 46–62% that is required for the production of good refractory fireclay materials (Umaru et al, 2012). Therefore, they can find applications as lining for heat treatment furnaces, melting furnaces for low-melting-temperature materials, and other insulation applications.The average percentage of aluminium oxide value was less than the recommended range value of 5–39%, as reported by Nnuka and Agbo for typical low-duty refractory materials[Aliyu S et al., 2014]. Generally, the amount of aluminium oxide that exists within the studied termite mound clay may not be suitable for producing any type of refractory material. Hence, this was the main reason to add a percentage of aluminium oxide to the samples. In addition, the recommended range for both magnesium oxide and calcium oxide is 0.2–1.0% (Umaru et al., 2014). The magnesium oxide values of the samples fall within the recommended range needed for refractory materials, but the calcium oxide exceeds the recommended value. However, more Cao indicated the limeness of the clay. The value of Fe_2O_3 found in this study was 6.588% on average. However, the recommended values for low-duty refractory materials are 0.4–2.7% and 1-9% for high-melting clay (Umaru et al., 2014). The main effect of increasing the percentage of Fe_2O_3 is decreasing the fusion temperature of refractory materials. Generally, it can be used as an insulator, as a basic refractory material for laboratory crucibles, and as a principal fireproofing ingredient in construction materials. But it is not safe to use for the melting of aluminium and its processing because rich iron oxide has an effect on contacting aluminium at high temperatures (Umaru M et al., 2014).

Table 1

Experimental test results of Graduation/sieve analysis of TMC

S(mm)	W_s	W_{s+c}	$W_C = W_{s+c} - W_S$	% R= $P \frac{Wi}{WT}$x100	%C	% finer
4.75	534.31	534.31	0	0	0	**100**
2.36	441.35	444.52	3.17	0.317	0.317	**99.683**
1.18	491.62	499.08	7.46	0.746	1.063	**98.937**
0.6	389.93	397.31	7.38	0.738	1.801	**98.199**
0.3	363.14	375.57	12.43	1.243	3.044	**96.956**
0.15	348.91	367.61	18.7	1.87	4.914	**95.086**
0.075	90.99	151.42	60.43	6.043	10.957	**89.043**

Where, W=wight Wc = wight of con Ws= wight of sample %c=cummulative WT =totlal

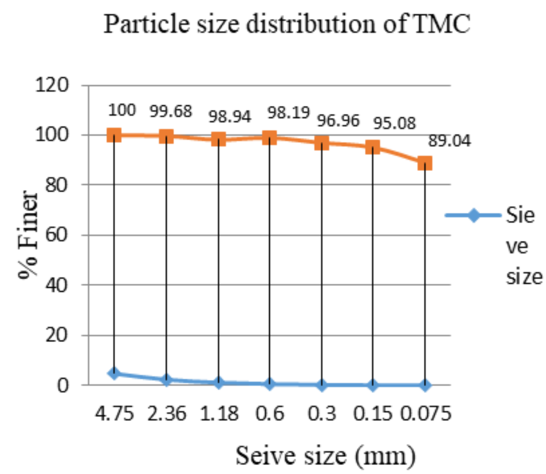

Figure 11

Percentage of finer vs. sieve size

Figure-11 showed that around 89.043 % of the sample contains clay + silt (particles that passed 0.075 mm sieve), and Also, 9.156 % of the sample contains fine sand (particles between 0.075 -0.6 mm). The remaining 1.484% and 0.317% of the sample are medium and coarse sand, respectively (particles between 0.6-2.36 and 2.36 - 4.75 mm, respectively). Therefore, termite mound clay has a sufficient amount of clay that can be used for refractory materials. This kind of analysis helps to determine the amount of sand that exists in the material as a binder without affecting other refractory properties.

Table 2

Experimental test results of Liquid limit of TMC

T	C	(M_1)	(M_2)	(N)	(M_3)	M $= \frac{M2-M3}{M3-M1}$	% w
1	Y_{M2}	0.01	0.06	29	0.04	0.35483	35.48
2	H_2	0.01	0.05	34	0.04	0.36666	36.67
3	10	0.01	0.04	17	0.03	0.3333	33.33
4	Y_1	0.01	0.05	23	0.04	0.34615	34.62

Whrere **T** = test no. **C**=cones **M1**=con mass **M2**= Con mass + mass of wet clay, **M3**=Con mass + mass of dry clay **M**=moisture content **%W**= water content

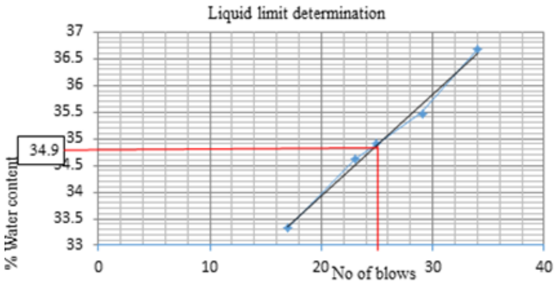

Figure12

Percentage of water content vs. No. of blows to get the amount of liquid limit at 25 Number of blows (Polynomial interpolation technique was used)

According to (Chukwudi, 2008), determining the water content of clay is an important factor during soaking to get good plastic clay for the production of samples. From Figure-12 the maximum limit of water added to the clay has to be less than 34.9% by weight. Adding water to the clay beyond the limit may result in a liquid, rather than plastic, kind of clay. If different materials are needed to mix with clay, the minimum value of each will be the possible value.

Table 3

Experimental results for Plastic limit of TMC

T	C	M_1	M_2	M_3	% Water = $\frac{M2-M3}{M3-M1}X100$
1	T_{12}	0.01	0.0407	0.03707	19.11
2	A	0.01175	0.03369	0.03019	18.98

According to (Chukwudi, 2008), the plastic limit is also an important factor that determines the limit of water content needed to make highly plastic clay. Most of the time, such kinds of factors are needed according to the suitability of the manufacturing process, type, and system required. Two trials were taken, and the average value of the water contents is the plastic limit value of the termite mound clay, which is 19.045%.

Table- 4: Plastic index result of TMC

Average liquid limit of TMC (LL) %	Average plastic limit of TMC (PL)%	Plastic Index (PI) PI= LL-PL
34.9	19.045	15.855

The difference between the liquid limit and the plastic limit is called the plastic index. According to (Chukwudi, 2008), the recommended plastic index value for general ceramic and refractory materials is 10-30%. Hence, the plastic index value of the studied termite mound clay is 15.85% (Table-6) and it is within the recommended range. (Chukwudi, 2008) said that the finer the clay, the higher the plasticity index. Most of the time, the plastic index is used to classify and group any kind of fine-grained soil. Accordingly, the studied termite mound cay is classified under inorganic clay and lean clay with sand according to (ASTM international D2487, 2000). If the liquid limit of the clay is less than 50% and the plastic index value PI > 7, then it is called inorganic clay. If the liquid limit value of clay after oven drying is less than 75% of its liquid limit value before oven drying, then it is called organic clay. The dry weight, saturated weight, and suspended weights of each sample required for the determination of apparent porosity, water absorption, and bulk density are listed in Table 7 below.

Table 5

Experimental results of the apparent porosity, water absorption, and bulk density of the prepared samples

S	N	AP	BD	%A
TC	1	30.59	1.460	20.95
	2	28.96	1.471	19.70
	3	29.81	1.462	20.40
	Average	29.79	1.464	20.35
TCA10	1	26.99	1.613	16.74
	2	27.23	1.624	16.77
	3	27.46	1.613	17.03
	Average	27.23	1.617	16.84
TCA15	1	24.72	1.750	14.13
	2	25.11	1.747	14.37
	3	25.42	1.746	14.55
	Average	25.08	1.748	14.35
TCA20	1	20.22	1.768	11.44
	2	20.05	1.769	11.33
	3	20.62	1.779	11.66
	Average	20.30	1.769	11.47

Where, ***S****=samples ,* ***N****=number of tests* ***Ap****%=apparent porosity* ***AP %*** $=\frac{W-D}{W-S}$*,* ***BD****=Bulk density* ***BD*** $(\frac{g}{cm3})=\frac{D}{W-S}$*, A%=water absorption* ***%A*** $=\frac{W-D}{D}$

Table-7 showed that apparent porosity values decreased as 10–20% alumina was added to termite mound clay. The main reason for decreasing the apparent porosity is that pores are blocked or filled because of the binding effect of alumina, which reduces the inter-particle distances between the grains. Since the particle size of termite mound clay was 150 µm, which is greater than the particle size of alumina 100 µm, in addition, after alumina fills the gap between the particles of the clay, it cannot burn off during firing like other organic matter or dust particles. Therefore, it had the effect of decreasing the apparent porosity value of the samples.

Table 6

Experimental results of the dry, saturated, and suspended weights of the samples

S	S N	D (g)	SW (g)	SP (g)
TC	1	152.06	183.91	79.8
	2	152.89	183.01	79.01
	3	151.98	182.99	78.98
	Average	152.31	183.30	79.26
TCA10	1	154.41	180.25	84.5
	2	154.03	179.86	85.01
	3	153.88	180.08	84.68
	Average	154.11	180.06	84.73
TCA15	1	173.98	198.56	99.13
	2	173.12	197.99	98.89
	3	172.87	198.03	99.07
	Average	173.32	198.19	99.03
TCA20	1	178.98	199.45	98.23
	2	178.53	198.76	97.85
	3	177.86	198.59	98.04
	Average	178.46	198.93	98.04

Where, ***S****=samples* ***SN****=sample number* ***D****=dry weight,* ***SW****=saturated weight,* ***SP****=suspended weight*

The bulk density of termite mound clay was found to be 1.464 g/c^3, as shown inTable-8 above, and the density of alumina used in this research was 3.94 g/c^3 according to the manufacturer's specification.

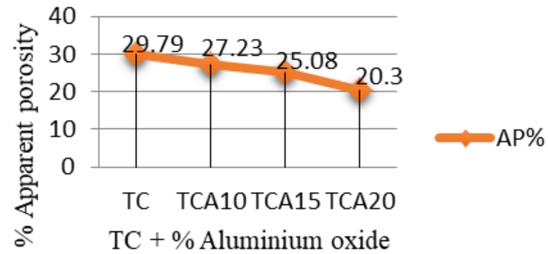

Figure 13

Effect of adding aluminium oxide to termite mound clay on apparent porosity

Factors that affect the apparent porosity of a given refractory material are the size and shapes of particles, chemical composition, ramming pressure, and firing conditions (Karim,2016). Two kinds of porosities are available: open and closed porosities. Apparent porosity, as its name indicates, considers only the open pores. The maximum and minimum apparent porosity recorded were 29.79% and 20.3% for TC (termite mound clay alone) and TC + 20% of Al_2O_3 respectively (Figure- 13). The values meet the recommended range of apparent porosity values for fire clay refractory materials of 20–30% (Umaru et al. 007). The main reason for recording a high apparent porosity value for TC alone was due to the fact that coarse grains used to have the ability to form voids during pressing (manual ramming) and burn off some organic matter during firing. Generally, it was shown that the addition of aluminium oxide to termite mound clay results in a decrease in the apparent porosity value. This is due to the fact that aluminium oxide closes the spaces within the sample during moulding and cannot burn off during firing. For high insulation purposes, the apparent porosity should increase to 68% (Energy Efficiency, 2005). Pore formers such as sawdust or rice husk can be used to produce good insulation materials with high apparent porosity.

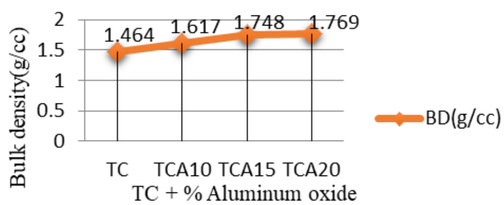

Figure14

Effect of adding aluminium oxide to termite mound clay on bulk density

The property of bulk density considers all the open and closed porosity as a whole and relates to its mass. The addition of aluminium oxide to termite mound clay results in an increase in bulk density value, as shown in Figure-14. Bulk density is inversely proportional to apparent porosity. The reason for increasing bulk density by adding aluminium oxide is due to the filling of the results of the free space with an increase in the mass of the material system at constant volume. Hence, bulk density is the ratio of mass to volume in the material system. The recommended value of bulk density for fire clay is 2.3 g/c3 (Umaru et al., 2012), and for insulating materials is around 0.56 g/cc (Energy Efficiency, 2005). The maximum and minimum bulk density recorded were 1.769 and 1.464 g/cc, respectively.

Therefore, the studied termite mound clay is more suitable for fireclay than for insulation applications.

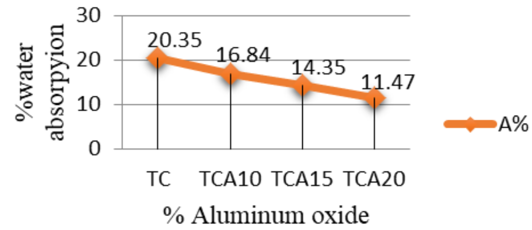

Figure 15

Effect of adding aluminium oxide to termite mound clay on water absorption

Grain size affects lowering the bulk density value of the refractory material system with an increment in fines. Apparent porosity has an inverse relationship with water absorption. Water absorption determines the ability of the refractory materials to resist the penetration of molten metals and slags during service time. A refractory material with low apparent porosity is desirable in areas where contact with molten charge and slag occurs. Due to, it prevents the easy penetration of molten metals or slag. Figure-16 shows that adding aluminium oxide to TMC results in decreasing the water absorption of the refractory material system. The maximum water absorption observed was at termite clay alone, which is 20.35%, and the minimum water absorption observed was at termite mound clay mixed with 20% aluminium oxide, which is 11.47%. Therefore, the reason for decreasing water absorption with increasing percentages of aluminium oxide is because Al2O3 fills the gaps and free spaces that can penetrate water.

Table 9

Experimental results of the CCS of the samples

Sample code	Sample No.	Area (m^2)	Applied force (kN)	CCS(cold compressive strength) (MPa)
TC	1	0.0025	18.75	7.500
	2	0.0025	17.56	7.024
	3	0.0025	17.06	6.824
	Average		17.79	7.116
TCA10	1	0.0025	27.56	11.024
	2	0.0025	28.04	11.216
	3	0.0025	27.31	10.924
	Average		27.67	11.155
TCA15	1	0.0025	28.48	11.392
	2	0.0025	29.25	11.700
	3	0.0025	29.07	11.628
	Average		28.93	11.573
TCA20	1	0.0025	30.76	12.304
	2	0.0025	31.27	12.508
	3	0.0025	31.85	12.740
	Average		31.29	12.517

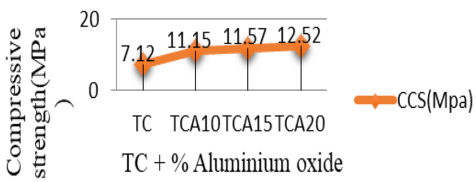

Figure 16

Effect of adding aluminium oxide to termite mound clay on CCS (cold compressive strength

The CCS increased with the increasing addition of aluminum oxide to termite mound clay. The maximum CCS was recorded at TCA20 (termite mound clay mixed with 20% aluminum oxide) samples, equal to 12.52 MPa, and the minimum at TC (termite mound clay alone) samples, equal to 7.12 MPa (Figure 16). The main reason for increasing the compressive strength is the decrease in pore spaces in the sample's results, which increase the area of the sample exposed to an applied load. Because of the pores inside the material, stress increases, especially in brittle clays. The recommended range of CCS for fire clay is >=15 MPa(Umaru et al., 2012). However, the value recorded falls short of meeting the requirement. Hence, it needs an enhancement that may be in the production process.

Table 7

Experimental results for reheat change during the firing of the samples

Samples	initial dried dimension			Final fired Dimensions		
	Length (L_i)	Width (W_i)	Height (H)	Length (L_f)	Width (W_f)	Height (H)
TC	114	57	32	111	54.0	30.05
TCA10	114	57	32	112	54.5	30.34
TCA15	114	57	32	112	54.7	30.62
TCA20	114	57	32	112	56.4	32.09

Table 8

Experimental results of % shrinkage during the firing of the samples

$$\% \text{ Shrinkage} = \frac{\text{Dried dimension} - \text{Fired dimension}}{\text{Dried dimension}}$$

samples	% shrinkage along length	% Shrinkage along the width	% Shrinkage along the height
TC	2.42	5.16	6.09
TCA10	1.21	4.29	5.19
TCA15	1.39	3.95	4.31
TCA20	1.02	1.02	0.01

The linear fired shrinkage values along all sides of the samples were recorded, as shown in Table-11 above. The highest value of shrinkage was observed at termite clay alone, and the minimum value was observed at termite clay mixed with 20% aluminum oxide samples. It is also observed that among all sides of the samples, the highest shrinkage value occurred at the height of the samples, and this was due to the placement of the samples. Because the lower face of the sample carries the overall weight during firing.

Table 9

list of refractory properties of TMC compared with existing one

RP		TC	TC A10	TC A15	TC A20	Refer
C	SiO2	55.89%	-	-	-	42-62%
	Al2O3	14.19%	-	-	-	25-39%
	Others	29.92%	-	-	-	10-29%
P	AP (%)	29.79	27.2	25.0	20.3	20-30
	BD(g/cm3)	1.464	1.61	1.74	1.769	1-2.3
T	RC (%)	6.09	5.19	4.51	0.01	4-10
M	CCS (MPa)	7.11	11.1	11.5	12.52	15

Note: RP=refractory properties; C=chemical composition; P=physical properties; T=thermal properties; M=mechanical properties; AP=apparent porosity; BD=bulk density; RC=reheat change

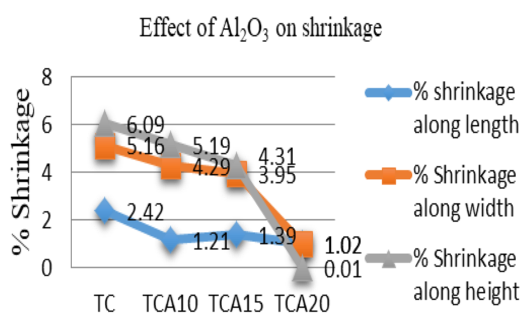

Figure 17

Addition of aluminum oxide to TMC vs fired shrinkage next page

The shrinkage value decreases with an increase in the addition of aluminium oxide to termite mound clay (Figure-17). The reason is that decreasing the amount of volatile material within the system lowered the shrinkage value. Volatile material means either very fine particles or something that has lower melting point materials inside the system, and those burn off during firing and cause high fired shrinkage.

The chemical composition and physical properties of both the TMC alone and the customized one are good enough compared to the existing ones (Table-12). However, the thermal properties of TMC and the customized one did not satisfy the requirements, excluding reheat changes. This indicates that termite mound clay still needs enhancement strategies for its thermal properties.

Conclusions

The significant discovery was that a percentage of chemical compositions existing within the termite mound clay have a great value on the physical and thermal properties of refractory materials. This study was conducted to determine the suitability of termite mound clay as a source of material for making different refractories in view of its physical and thermal properties. The effect of adding aluminum oxide to termite mound clay was also studied in this research. The values of apparent porosity and bulk density fall within the required range for making refractory materials. The compressive strength also increased from 7.11 to 12.52 MPa with the addition of Al_2O_3. The main reason for increasing the compressive strength was decreasing the pore spaces within the sample's results, increasing the cross-sectional area exposed to the applied load, and the pore area acting as a stress riser. The percentage of linear fired shrinkage of the samples at 900 along the length, width, and height were decreased from 2.42-1.02%, 5.16-1.02%, and 6.09-0.01%, respectively, with the increasing addition of Al_2O_3. Generally, the locally available termite mound clay can replace the refractory materials that are being imported from abroad with some improvement in their thermal properties.

Data Availability

Every piece of data used in this article is available from the corresponding author upon request.

Conflicts of Interest

The authors confirm that they have no financial or personal ties to any parties that might influence the results of this study.

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