JMME, Vol.14, April, 2024
Pp 13 – 28

ISSN: 2006 - 1919

INVESTIGATION OF THE REFRACTORY PROPERTIES OF KANKARA CLAY FOR ENGINEERING AND INDUSTRIAL APPLICATIONS

[1]Adidi O. D., [2]Ocheri C., [3]Oyibo A. O. and [4]Eneh C.
[1,3]Dept. of Welding and Fabrication Engineering & Department of Mechanical Engineering Delta State Polytechnic, Ogwashi-Uku, Delta State
[2]Dept. of Metallurgical and Materials Engineering, University of Nigeria, Nsukka, Enugu State
+Dept. of Metallurgical and Materials Engineering, Enugu State University of Science and Technology, Enugu
Corresponding author: Email: adididavid123@gmail.com, Phone no: +2348030814419

Abstract

The refractory properties of Kankara clay have been investigated with a view to understanding its suitability for various engineering and industrial applications. The experimental procedures include thermal shock resistance, thermal conductivity, shrinkage, apparent porosity, refractoriness under load with rising temperature mode, and refractoriness under load-maintained temperature mode. The results obtained from the research work showed the clay has good refractory properties that can be used for both Engineering and industrial applications. The value obtained through the thermal conductivity test 0.48W/m℃ , as compared with 0.35- 0.45 W/m^{o}C for insulating fire brick and 1.05- 1.45W/m℃ for dense fire brick. 2kg/cm^2 of the sample was further subjected to refractoriness test where the sample was heated to 1405^{o}C as compared to 1750^{o}C for the production of fire bricks. Further investigation indicated that a glassy surface structure was formed when the samples was heated above 1400℃ . The value obtained as regard the porosity level was 25% which fell between 20-30% as the acceptable standard. The sample was also subjected to apparent porosity and a value of 38% was obtained. Kankara clay formed a glassy and surfaces when heated above 1400^{o}C. In this research, these bricks porous with an apparent porosity of 38.07%. Attempts to produce these bricks with acceptable porosity level of 20-30% were not successful. Kankara clay exhibits moderate thermal shock resistance, moderate thermal conductivity, moderate shrinkage, high apparent porosity, and high refractoriness under load in both rising temperature mode and maintained temperature mode. "Based on these results, Kankara clay appears to be well-suited for use in applications where moderate levels of thermal shock resistance, thermal conductivity, and shrinkage are acceptable, such as in the manufacture of low-temperature bricks, but less suited for high-temperature applications, such as furnace linings, due to its high apparent porosity and susceptibility to deformation under load. Further research could be conducted to explore strategies for reducing the porosity and improving the refractoriness of this clay for broader applications.

Keywords: *Applications, refractory, properties, Kankara, clay*

1.0 Introduction

Refractories are materials made of minerals and chemicals that have extremely high heat-resistance qualities. As a result, they are perfect for use in the construction of walls, ceilings, and other components of blast furnaces, glass-making tanks, cement kilns, hot stoves, ceramic kilns, open hearth furnaces, nonferrous metallurgical furnaces, and steam boilers in the iron and steel industry [1]. Both clay and non-clay refractory can be used to create refractory materials. In addition to fire clay, non-clay refractory can be manufactured of less common materials such as alumina, zirconia, silicon carbide, chromia, magnesite, and graphite, although their cost is significantly greater [2]. Refractory clay can also be shaped into unique shapes, such the T-sections of refractory pipes or the little supports that hold ceramic items while they are fired in a kiln [3]. Bricks are the most common form that clay refractory products are produced in. Since the 1960s, refractories have been a crucial component of thermal engineering plants, where they have been effectively utilized to increase output and energy efficiency. Refractories are stable both physically and chemically at high temperatures, which explains why. Refractories must be chemically inert and resistant to heat shock, depending on the operating environment [4]. A good fireclay refractory should always have a plasticity of between 24 and 26%, and its maximum shrinkage after burning should be between 6 and 8%.

Additionally, a high-quality fireclay refractory shouldn't include more than 25% Fe_2O_3. The most popular and widely utilized refractory bricks in all heat-generating locations are those produced of fireclay due to its plentiful supply and relative affordability [5]. The main application for fireclay bricks is in furnace construction, where they are utilized to contain heated environments and protect structural elements from high temperatures [4]. Strength is typically not a major factor for fireclay brick because it is not normally needed to support structural loads. Usually, some control is retained over the final product's dimensional stability and precision.

Fireclay is the name for a class of refractory clays that can withstand temperatures higher than Pyrometric Cone Equivalent (PCE) 19. What is not classified as refractory is clay that fuses below PCE 19. The composition of fireclay is similar to that of china-clay and is basically composed of kaolinite. The typical composition of this material in nature is 24–32% Al_2O_3, 50–60% SiO_2, and 9–12% LOI. White, grey, or black coloration is caused by impurities such as alkalies and oxides of calcium, iron, titanium, and magnesium [6]. Indeed, fireclay is primarily found in coal measures as bedded deposits and is strictly speaking of sedimentary origin [2]. An item classified as refractory is one that is not harmed or deformed by high heat. High temperatures can refer to temperatures over roughly 1000℃ (1830 °F) or to those at which ordinary metals cannot be used due to oxidation or melting. Refractory materials are often non-metallic and are used in the production of furnaces, especially metallurgical furnaces, insulation, incinerators, and crucibles. Thus, a refractory is a substance that, under high temperature situations, will maintain its strength, form, and chemical identity. It is utilized in applications like furnace linings that call for a high degree of heat resistance [7].

A blend of naturally occurring minerals that can withstand modest loads at high temperatures is typically used as a refractory material. They are oxides in their pure state, such as alumina (Al_2O_3) and magnesium (MgO). Several common refractory materials utilized in the metallurgical industry are magnesium chromite, silica, carbon, chrome-magnestite, dolomite, fosterite, aluminum silicate, etc. A few non-oxide refractory minerals are also included, such as graphite. The most prevalent kind is the alumino-silicate kind, which is used to make fire bricks. [12-15].

Granite and feldspathic rocks weather and disintegrate to provide a plentiful supply of fine earthy powders known as clays [8]. These are complex compounds made of alumina (Al_2O_3) and silica (S_iO_3) that are anhydrous and exist in different ratios. They also contain different levels of iron impurities, organic materials, and leftover minerals [9]. These materials made of clay can be found in both plain and riverine regions [8]. The word "clay" describes a naturally occurring substance that is mainly made up of fine-grained minerals. It is typically pliable at the right water content and can harden when heated to a high degree [10].

Clay typically contains phyllosilicates, but it can also contain additional substances that, when wet, give it fluidity and, when burnt, harden it. However, organic stuff and substances that do not impart plasticity may be found in clay's related phases [11, 16-18]. Clays are the least expensive raw materials used to make refractory bricks. Alumina, silicates, and water make up the majority of the crystalline minerals that make up clay. Silica terrahedron and alumina octahedron cells are ionized and arranged in parallel layers that make up the structure of clay. The way these sheets are arranged defines the type of clay; for example, (a) Kaolinite minerals are Al_2O_3. $SiO_2.2H_2O$; (b) Montmorillonite minerals are Al_2O_3. $4SiO_2.nH_2O$; and (c) Illinitemineral [19-21].

These clay minerals vary in composition, but they all have the same characteristics: Moisture-induced plasticity, which allows for deformation and shaping; (b) Rigidity when dried but capable of regaining plasticity when wet; and (c) Rigidity when fired but incapable of regaining plasticity when wet. Both the metallurgical and non-metallurgical sectors need refractories, some of which are found in kilns, reheating furnaces, and metal melting furnaces. In addition to crucibles, refractory clay can be used to create ceramic items, bricks, and tiles. [22-23] All these industries require a significant amount of refractory; when added together, the overall requirement is in the millions of tons. At the moment, only the ceramics industries use clay from the area; the metallurgical industries import almost all of their refractory clay. Because of this, a large portion of the nation's foreign exchange is used to import clays and other minerals. [24-27].

1.1 Properties requirement of Refractory Bricks

Refractory bricks must have certain qualities depending on the functions they are anticipated to carry out in the furnace. Based on the tasks to be completed on the materials, the procedures might be evaluated. The clays' refractoriness needs to meet specific requirements. (a) Sturdiness and power to bear the operation temperature while retaining form and dimensions. (b) The capacity to tolerate heat shock, as is frequently achieved during a furnace's rapid heating and cooling process, (c) Resistance to chemical attacks from gasses, slag, or liquid metal that may come into contact with it. (d) Resistance to deterioration that could arise from solid-solid contact. Additional characteristics like thermal conductivity and thermal expansion refractoriness offer appropriate ways to access these attributes and, consequently, determine whether the refractory is appropriate for the intended use.

1.2 Nigerian Refractory Clay Deposits

Table 1: Refractory clay deposits in Nigeria

S/N	Clay Deposits / site	Al_2O_3 (kg)
1	Giru (Sokoto)	37.5- 42.42
2	Oshiele (Ogun)	36.0-37.45
3	Kankara (Katsina)	31.45-38.54
4	Nsu (Imo)	30.5-32.42
5	Onibode (Ogun)	26.9-39.52
6	Ozubulu (Anambra)	26.0-36.30
7	Barkin- Ladi (Plateau)	20.3- 30.2
8	Bauchi (Bauchi)	11.98-25.0
9	Ekulu (Enugu)	10.95-11.83
10	Ogbete (Enugu)	8.6-9.13
11	Werem (Plateau)	Not Available
12	Isheri (Lagos)	Not Available
13	Lokoja (Kogi)	Not Available

Source: Moses et al [14]

It appears from the literature that not much research has been done on these deposits. The Onibode deposit has undergone extensive geological processing, which has provided information regarding the deposit's quality and distribution [15]. On the Oshiele deposit, some preliminary research has been done. Regarding the other deposits, not much is known aside from them.

2.0 Experimental Procedure

2.1 Thermal shock resistance

Five standard samples were produced with a circular shape of diameter 25.4 mm and thickness of 6.4 mm. The prepared samples were dried at a temperature of 80°C until it reaches a constant weight. The samples were immersed in a water bath at a temperature of 20°C for 24 hours. The samples were removed from the water bath and were placed in a furnace. The furnace was heated to 1000°C, and was held at this temperature for 1 hour. After the samples were heated in the furnace they were subsequently removed from the furnace and were immediately immersed in the water bath for a second that has been prepared at a temperature of 20°C. All the samples were allowed to cool for 30 minutes, and were then removed from the water bath. The samples were inspected for any signs of cracking, flaking, or other damage. The degree of thermal shock resistance was determined by comparing the number of cracks in the samples before and after the test.

The thermal shock resistance of a clay sample was calculated using the following formula:

$$TSR = \frac{A}{(B + C)}$$

where:
A = the number of cracks in the clay sample before thermal shock testing
B = the number of cracks in the clay sample after thermal shock testing
C = the number of original pieces in the clay sample

2.2 Thermal Conductivity on clay samples.

Five cylindrical samples of diameter 25.4 mm and length of 25.4 mm were prepared for the tests. The sample were placed between two metal plates that had been pre-heated to a constant temperature. The plates were separated by an air gap. The temperature was monitored with the use of thermocouples. The thermocouples were inserted into the samples in such a way that they cannot be in contact with the metal plates. The temperature of the samples was measured for 30 minutes.[28]

The thermal conductivity of clay samples was calculated using the following formula:

$$\lambda = \frac{\mathrm{m} * \mathrm{C} * \Delta\mathrm{T}}{\mathrm{k} * \mathrm{A} * \Delta\mathrm{t}}$$

where:
λ = the thermal conductivity of the clay sample
m = the mass of the clay sample
C = the specific heat capacity of the clay sample
ΔT = the temperature difference between the metal plates.

2.3 Shrinkage property on clay sample.

Five cylindrical samples of diameter 25.4 mm and length of 25.4 mm were prepared for the tests. The clay samples were dried in an oven at a temperature of around 125°C for a period of 24 hours. The samples were weighed before and after drying were the weight loss was determined due to moisture evaporation. The dried samples fired to a temperature of 1000°C. This formula was used to calculate the shrinkage of clay samples using the "ring" method is as follows:

$$S = \frac{\mathrm{D} - \mathrm{D}_f}{D}$$

where:

S = the shrinkage of the clay sample
D=the inner diameter of the ring before firing
D_f = the inner diameter of the ring after firing

This formula assumes that the clay sample shrinks uniformly and that the ring remains unchanged after firing.

2.4 Apparent porosity (%) of the clay samples

The unit of apparent porosity is typically expressed as a percentage (%) of the total volume of the sample. For example, if a sample has an apparent porosity of 30%, this means that 30% of the sample's total volume is composed of pores. This value can be used to assess the ability of a material to absorb water, as well as its thermal and mechanical properties. The higher the apparent porosity, the more porous the material, and the more likely it is to absorb water and exhibit weaker mechanical properties. Five cylindrical samples of diameter 25.4 mm and length of 25.4 mm were prepared for the tests. The samples were dried in an oven at a temperature 125°C for 24 hours. The samples were weighed before and after the drying process where the weight loss was determined due to moisture evaporation. The samples were dried, they were saturated in water for 24 hours. [29].

The formula for calculating the apparent porosity of a clay sample is as follows:

$$P = \frac{(\mathrm{W} - \mathrm{Wf})}{W}$$

where:
P = the apparent porosity of the clay sample
W = the weight of the sample before saturation
Wf = the weight of the sample after saturation

This formula was used since the clay was completely saturated with water where the water completely filled all of the pores in the sample.

2.5 Cold crushing strength measurement on clay samples.

1. Five cylindrical samples of diameter 25.4 mm and length of 25.4 mm were prepared for the tests. The samples were dried and were freed from defects. The samples were placed in a compression testing machine; the samples were had been oriented so that the direction of applied force was perpendicular to the direction of the clay layers. A compressive load was applied to the samples at approximate rate of 2 mm/min until the sample fails. The maximum load was applied to the samples before failure. The formula below was used to calculate the cold crushing strength of a clay sample is:

$$CCS = \frac{F}{A}$$

Where:

F= Force (kg)

A= Cross sectional Area.

CCS = the cold crushing strength of the clay sample. (kg/cm^2)

2.6 Linear shrinkage

Linear shrinkage is a measure of the degree to which a clay sample shrinks in a particular direction during drying and firing. It is usually expressed as a percentage, with higher values indicating greater shrinkage. To measure linear shrinkage, you typically mark a line on the surface of a clay sample before drying and firing, and then measure the distance between the marks after drying and firing to calculate the percentage of shrinkage. Linear shrinkage can be an important property to consider when designing ceramic products, as it can affect the size and shape of the final product.

Five cylindrical samples of diameter 25.4 mm and length of 25.4 mm were prepared for the tests. The samples were dried and were freed from defects. The samples were placed a compression testing machine; the samples were had been oriented so that the direction of applied force was perpendicular to the direction of the clay layers. A compressive load was applied to the samples at approximate rate of 2 mm/min until the sample fails. The maximum load was applied to the samples before failure. The formula below was used to determine the calculation of linear shrinkage in a clay sample is as follows:

$$LS = \frac{(\mathrm{L} - \mathrm{Lf})}{\mathrm{L}} X\ 100\%$$

Where:
LS = the linear shrinkage of the clay sample
L = the length of the sample before drying and firing
Lf = the length of the sample after drying and firing

This formula was utilized since the samples had shrunk uniformly in the direction of the marked line. But where the samples shrinkage was non-uniform, then the samples must be averaged, so that the shrinkage measurements could be performed from multiple lines.

2.7 Sieve Analysis on the clay Samples

1) 150 g of the ground clay samples were used for these experiments. This process was achieved through the grinding of the sample using a mortar and pestle until it is a fine powder. The ground powdered samples were placed a stack of sieves (usually with increasing size of the sieve holes from top to bottom). The Sieve analyzer was automatically operated by shaking the stack of sieves for 15 minutes which allowed for different sized particles to fall through the holes in the sieves.

5) The contents of the sample were weighed on each sieve, where the amount of clay size range was determined. The formula below was used to calculate the particle size distribution from sieve analysis:

$$\%\ \text{Retained} = \frac{(\text{Weight of particles retained on each sieve})}{\text{Weight of sample}} x100\%$$

To calculate the average particle size, use this formula:
Average Particle Size (µm) = (Cumulative % Retained) / 100
70% was used as the retained samples on a sieve with a 250 µm opening.

2.8 Refractoriness under load

Refractoriness under load is a measure of how well a material can withstand high temperatures under load (pressure). It's an important property to consider when designing and using ceramics in high-temperature applications, such as furnaces. The process involves heating a clay sample in a kiln under load, typically for 1 hour. During this time, the temperature of the sample was increased gradually. The temperature at which the sample begins to deform or crack was then recorded. This temperature is known as the refractoriness under load. Five cylindrical samples of diameter 25.4 mm and length of 25.4 mm were prepared for the tests. The samples were placed in a heating furnace with a pressure plate on top of the sample. The temperature of the furnace was increased gradually at a rate of 5°C per minute, while the temperature and the shape of the samples were monitored. The necessary record on the temperature were taken as the samples begins to deform or crack, record the temperature.

2.8.1Refractoriness under load with rising temperature mode

Refractoriness under load with rising temperature mode is a variant of the traditional refractoriness under load test. Instead of using a constant temperature, this method increases the temperature of the sample gradually, usually by 5°C per minute, until the sample begins to deform or crack. This method allows a close observation on how the sample behaves at different temperatures and under different levels of stress, providing a more detailed understanding of its behavior under high-temperature conditions. It's particularly useful when working with materials that have a wide range of melting points, such as ceramic composites. The samples for this experiment was prepared. Five cylindrical samples of diameter 25.4 mm and length of 25.4 mm were prepared for the tests. The prepared samples were allowed to dry in the furnace, with a pressure plate on top of the sample. The temperature of the starting of furnace was operated at a low temperature at room temperature, and this was gradually increased at a rate of 5°C per minute. The process was monitored as the temperature increases, the samples were observed for any changes in shape or cracking.

The formula for refractoriness under load with rising temperature mode is:

Refractoriness under load (°C) = Final temperature before failure (°C) - Initial temperature (°C).

This formula was used to calculate the temperature range over which the sample was able to maintain its shape and structure under load before failure occurred. It's important to note that this formula is only applicable when the temperature is increased gradually, at a constant rate.

2.8.2The refractoriness under load maintained temperature mode.

Refractoriness under load-maintained temperature mode is yet another way to measure a material's refractoriness under load. In this method, the sample was heated to a specific temperature, usually a temperature just below the sample's softening temperature, and held at that temperature for 30minutes. The temperature and the length of time at which the sample begins to deform or crack was then recorded. This method allows the observation on how the samples behaves at a specific temperature, providing insight into how the samples behaved when they were subjected to prolonged high-temperature conditions.

The refractoriness under load-maintained temperature mode. Five cylindrical samples of diameter 25.4 mm and length of 25.4 mm were prepared for the tests. The samples were placed in the furnace with a pressure plate on top of the sample. The samples placed in the furnace were heated to a temperature of 1200°C usually just below the sample's softening temperature. The formula below was used to calculate the refractoriness under load in maintained temperature mode:

Refractoriness under load (hours) = Time until failure (hours) at specified temperature.

2.8.3. X-ray fluorescence (XRF) is a widely used technique for the analysis of clay content in soil and other materials. Here's how the XRF technique works: - An X-ray source emits a beam of X-rays which interact with the atoms in the sample, exciting them to emit X-ray fluorescence (XRF) at specific energies. The emitted X-ray fluorescence is analyzed using a detector and processed to produce a spectrum, which provides information on the elemental composition of the sample.

3.0 Materials and Methods

3.1 Materials

The materials used for this investigation was sourced from the Kankara Clay deposit in Katsina State of Nigeria.

3.2 Methods

3.2.1 Thermal shock resistance

The resistance to thermal shock was measured by heating a refractory brick size 75mm x 50 mm x 50mm at 1100^{o}C for minutes. The specimen was removed from the furnace and allowed to cool for 16 mins after which it was adjusted to a specified load in a stranded rig for testing spalling resistance, If the specified did not fracture under this load, was returned into the furnace and heated for 15 minutes at the temperature of 1050^{o}C. The specimen was again cooled for 10 minutes and tested under load. The recycle process was performed by heating the samples until fracture occurred at 39 cycles.

3.2.2 Thermal Conductivity on clay samples.

A refractory brick, 50 mm x 50mm x 18 mm was used for these measurements. Heat was conducted through the 50mm x 50mm surface into a water calorimeter, at steady state, the rate of heat conduction was measured. A material's ability to transfer heat through conduction is measured by its thermal conductivity. Its SI unit is W/m. K^3, and it is represented in terms of power per unit length and temperature differential. The equation Q / t = kAT / d can be used to calculate thermal conductivity. In this equation, Q represents heat transfer, t is the time, k is thermal conductivity, A is cross-sectional area, and d is material thickness. Another method is to utilise the formula C = kA / L, in which L is the material's length and C is its thermal conductance. This formula was used to obtain the thermal conductivity value obtained 0.48W/m^{o}C. Typical thermal conductivity values of certain types of firebricks are as follows:

Dense firebricks and silica brick 1.00 - 1.45W/m ^{o}C and Insulating Firebricks = 0.15- 0.45 W/m ^{o}C

3.2.4 Apparent porosity (%) on the clay samples

A dry refractory brick of 40 mm cube, was weighed in air, heated in an oven for 1hour at 110^{o}C, and transferred into boiling water, Boiling was continued for 10 more minutes after which it was discontinued. The hot water was slowly displaced by cold water until room temperature was attained, the weight of the brick in cold water was noted. The brick was then removed from the water, and weighed in air. The apparent porosity was calculated using the formula.

$$Pa=\frac{W_c-W_a}{W_c-W_b}$$

Where W_a = Weight of dry brick in air

W_b = Weight of brick in water

W_c = Weight of brick impregnated with water but suspended in air

The apparent porosity values for three bricks were determined, and an average value of 38.07% was obtained [29] . The data obtained was used to plot the graph shown in Fig 1.

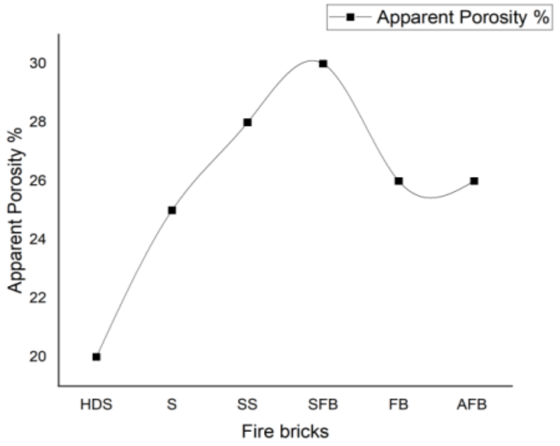

Fig 1: Apparent Porosity (%) vs Fire Bricks

3.2.5. Cold crushing strength measurement on clay samples.

Five refractory bricks, each 40 mm cube, were tested in compression to fracture. Three of them were tested in the direction transverse to the direction of pressing. The average cold crushing strengths are as follows:

Strength in the direction of press = 15, 517 kN/m^2 and Strength in the transverse direction = 8, 645kN/m^2.

The cold crushing strength was plotted against Fire bricks as shown in Fig 2

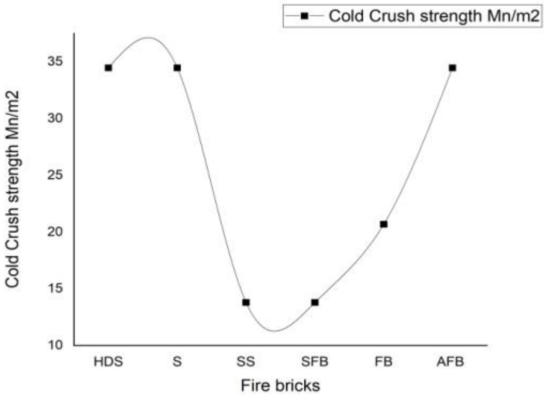

Fig 2: Cold Crush Strength Mn/m^2

3.2.6 Linear shrinkage measurement

The shrinkage of the brick was measured by comparing the as-fired and the green dimensions. The green dimensions of the bricks tested were: 100 mm x 80 mm x 50 mm. Four bricks were tested, and the average linear shrinkage was obtained to be 5.8%.

3.2.7 Determination of Optimum Water Level

Bricks were made with water content ranging from 12 to 22%. It was found that bricks with water level between 16 and 22% gave bricks with well-formed dimensions and were easy to form. With water level above 22%, the plastic clay was getting too wet and forming at the above pressure was not possible. Also, the required green dimensions could not be achieved. The 18% water level was found to be ideal. When the water level was less than 16% mould was too dry for good bounding to be achieved.

3.2.8 Sieve Analysis on the clay Samples

The sieve analysis of the clay was performed in order to ensure that the clay had the required particle distribution for it to be used for the manufacture of refractory bricks. The results are shown in Table 2.

Table 2: Sieve Analysis of Kankara Clay

Particle size	Weight of particles (g)	%
+1000	0.3	0.6
+710	0.2	0.4
+500	0.1	0.2
+250	0.4	0.8
+150	0.6	1.2
+106	1.1	2.2
+75	1.8	3.6
+53	1.5	3.0
-53	3.8	7.6
-20	40.2	80.4

3.2.8 Refractoriness under load (R.U.L)

There were two tests in this category; the refractoriness under load in the rising temperature mode, and the other in the maintained temperature mode.

(a) Refractoriness Under load (Rising Temperature mode)

Both R.U.L. modes were carried out using a dilatometer. In the rinsing temperature mode, a cylindrical refractory brick, 27 .6 mm in diameter and 63.5 mm high was subjected to an axial load of 2 kg / cm^2 inside the dilatometer. The temperature of the brick was slowly raised (at the rate of about 10^{o}C/ min). As the temperature was increased to 1405℃ there was an indication of contraction that occurred at 5% Table 3 shows the typical value for fire bricks Fig 3 and 4 show the R.UL^{o}C vs Fire Bricks and Refractoriness ^{o}C vs Fire bricks respectively.

Table 3: Typical values for fire bricks

Fire Brick	Apparent Porosity %	Cold Crush strength Mn/m^2	Refractoriness ^{o}C	U.L ^{o}C
High duty Silica (HDS	20	34.47	1730	1600
Silica	25	34.47	1710	1600
Semi- silica (SS)	28	13.79	1450	50
Siliceous Fire bricks (SFB)	30	13.79	1550	1300
Fire bricks (FB)	26	20.68	1700	1500
Aluminous Fire bricks (AFB)	26	34.47	1750	1550

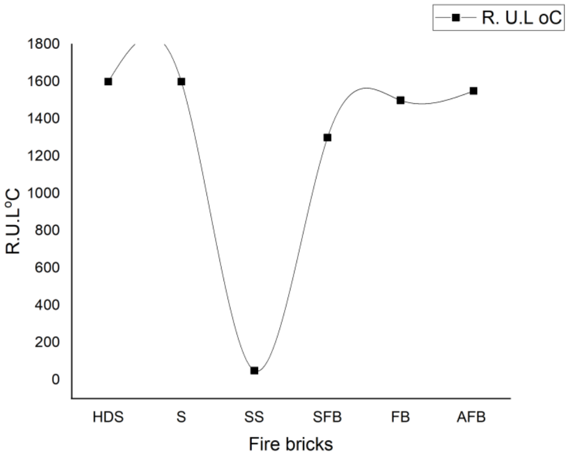

Fig 4: R.UL^{o}C vs Fire Bricks

(b) Refractoriness Under Load (Maintained temperature Mode)

In the maintained temperature mode, the same specimen was maintained at a temperature of 1200^{o}C under the same load of 2kg/cm^2 for some time. The subsidy at the end of 2 hours was found to be 0.42%. The refractoriness of the fire bricks is shown in Fig 5.

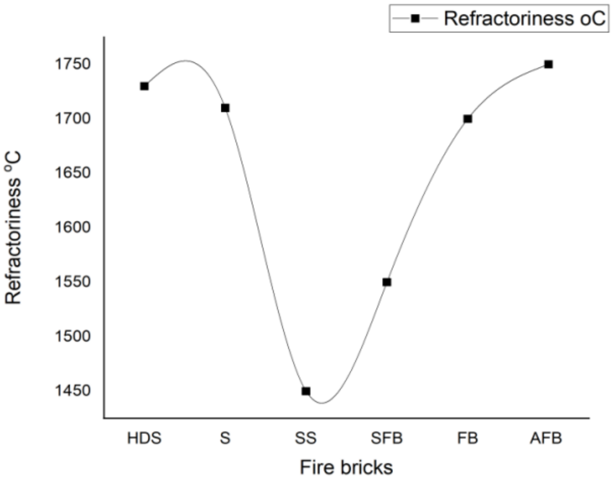

Fig 5: Refractoriness ^{o}C vs Fire bricks

3.3 Production of Bricks

The as-mined clay was washed in water and was dried in the sun. It was then ground and sieved through an aperture of 250µm. The required water level was then added to the clay. The aggregate was thoroughly mixed and worked to give a smooth plastic paste. The correct quantity of this plastic clay was placed in a mould of 75mm x 50mm x75mm with approximate weigh of 2kg and pressed under a pressure of $10kg/cm^2$. The formed wet brick was then removed from the mould and left on the laboratory floor to dry slowly for a minimum of 12 hours, followed by oven drying at 110^oC for 12 hours. The bricks were fired in an electric furnace by heating them up at the rate of 7^oC/min and soaking at the following temperatures:

(a) 300^oC for 4 hours
(b) 600^oC for 4 hours
(c) 900^oc for 3 hours
(d) 1250^oC for 2 hours

The bricks were finally cooled to room temperature.

3.4 Determination of chemical composition of Kankara Clay Deposit using XRF

The refractory clay deposit in Kankara, a town in Katsina State is fairly extensive. The exact geological maps are still not available despite the fact that it has been under investigation for many years back. It has been used for many years for ceramics application [6]. Also, it has been found suitable for preparing synthetic foundry sands. In the as mined condition, Kankara clay is white in appearance and is in the powder form. Though it contained small lumps, these are easily ground to less than 250-micron size. X-Ray fluorescence (XRF) technique was used to determine the chemical compositions as indicated in Table 4. Judging from its silica and alunmina contents, Kankara clay can be said to contain mostly kaolinite, minerals. This is because the kaolin forming clay, with a structural formula of $(OH)_8$. $Si_4.Al_2O_{10}$ have a theoretical composition: 46.54% SiO_2, 39.50% Al_2O_3 and 13. 96% H_2O. However, the natural kaolin forming clay contain 40-48%. The differences in this area are dependent on the location of the site taken for analysis.

Table 4: Chemical analysis of Kankara clay

Elements	% composition (wt. %)
SiO_2	44.55
Al_2O_3	31.45
H_2O	18.09
Fe	1.07
MgO	0.87
TiO	0.41

The obtained chemical compositions from the XRF shown above can be inferred that the clay has the following characteristics:

i. High Al_2O_3 content (31.45%) suggests that the sample contains a significant amount of clay minerals such as kaolinite, halloysite, or montmorillonite.
ii. High SiO_2 content (44.55%) suggests that the sample also contains significant amounts of quartz.
iii. High water content (18.09%) could indicate that the clay content is relatively high, as clay minerals tend to absorb and retain water.
iv. The presence of kaolinite and halloysite is typically associated with high Al_2O_3 content. The high SiO_2 content could be due to the presence of kaolinite and quartz, both of which are Si-rich minerals.

4.0 Discussion

Kankara clay is a type of clay found in the Kankara region of Nigeria. It is rich in silica and alumina, which are essential components of refractory materials. Refractory materials are used in high-temperature applications, such as furnaces, kilns, and incinerators. They must be able to withstand high temperatures without significant thermal expansion, chemical attack, or spalling. The refractoriness of a material is measured by its fusion temperature, which is the temperature at which a material starts to soften and melt.

Kankara clay has a high fusion temperature, making it a suitable refractory material. The high silica and alumina content of Kankara clay contributes to its refractory properties by creating a strong, dense matrix with excellent resistance to thermal shock and chemical attack. Kankara clay is a relatively low-cost clay with moderate thermal shock resistance, moderate thermal conductivity, moderate shrinkage, high apparent porosity, and limited refractoriness under load. It may be a suitable choice for certain applications where its properties are acceptable, such as in the production of pottery or low-temperature bricks. However, for applications requiring high-temperature stability or low shrinkage, other clay types with more suitable properties may be preferred. Further research into methods of improving the refractoriness under load and reducing the apparent porosity of Kankara clay could also be explored. Bricks made using Kankara clay showed fairly good properties with respect to linear shrinkage cold crushing strength, resistance to thermal shock.

However, they had not so good properties with respect to refractoriness and apparent porosity. Comparison of the refractory properties the Kankara fire clay bricks were considered to have properties very well with those for the siliceous firebrick, expect for the high apparent porosity value. It may then be necessary to effect densification of these bricks in order to improve the properties for the dense brick applications. This will then reduce the apparent porosity value. The thermal conductivity value of 0.48W/m.^{o}C obtained for Kankara clay means that it is a relatively poor conductor of heat, which makes it potentially useful as a refractory material because refractory materials must be able to resist heat. Apparent Porosity: Apparent porosity of 38.07% indicates that Kankara clay has a relatively high level of void spaces, which may contribute to its refractory properties. High porosity can increase the refractory material's thermal insulation and resistance to thermal shock.

The resistance to thermal shock + 30 cycle obtained for Kankara clay means that the clay was able to withstand being subjected to rapid changes in temperature (i.e. thermal shock) a total of 30 times without suffering significant damage. This is an important property for refractory materials, as they are often exposed to extreme temperature changes during industrial processes. The fact that Kankara clay was able to withstand these repeated thermal shocks suggests that it could be a suitable refractory material.

Linear shrinkage is the percentage reduction in length of a material during thermal processing. A linear shrinkage of 5.8% for Kankara clay is relatively high, which may be a concern for some refractory applications where dimensional stability is important. However, for refractory materials that do not require strict dimensional control, high linear shrinkage is not necessarily a drawback. In fact, some high-alumina refractory materials, such as fireclay, have high linear shrinkage but are still commonly used for their excellent refractory properties.

The cold crushing strength is a measure of the compressive strength of a material at room temperature. A high cold crushing strength indicates a material that is strong and less likely to crack under compression. In the case of Kankara clay, the cold crushing strength of 15.52 MN/m^2 (Megapascals per square meter) in the direction of forming suggests that the material is reasonably strong and unlikely to fracture under moderate compression. This is a desirable property for refractory materials, as they must often support loads or withstand compressive forces in industrial applications. The cold crushing strength of 8.65 MN/m^2 in the transverse direction indicates that Kankara clay is weaker in this direction compared to the direction of forming. This is not uncommon for ceramics, as their strength is anisotropic (direction-dependent).

However, it's important to note that the transverse strength of Kankara clay is still relatively high, which suggests that it has good mechanical strength in all directions. The refractoriness under load value of 1405°C is an important indicator of Kankara clay's ability to withstand high temperatures without significant loss of strength. The maintained temperature value of 0.42% for Kankara clay means that the material suffered only a small loss of strength after being heated to a temperature of 1405°C and then maintained at that temperature for a specific time interval (usually 24 hours). This is a good indication of the material's thermal stability, as it suggests that Kankara clay is unlikely to weaken or deform significantly at high temperatures. This is a critical property for refractory materials, as they must often function at extreme temperatures in industrial applications.

4.1 Attempts to Produce dense Kankara Firebricks

Attempts were made to produce dense bricks using the Kankara clay, and these include: (a) additions of grogs, (b) variation of water level and (c) using higher moulding pressure

Table 4 indicate the effect of changing of water level and the formed pressure. Figure 5 shows the level of porosity (%) and the level of changing water level used.

Table 5: Effect of changing water level and forming pressure on porosity

Water level 1 (%)	Porosity	
No	$10kg/cm^2$	$214Kg/cm^2$
10	47.43	40.63
12	46.75	41.18
14	45.83	40.91
16	45.07	41.79
18	44.29	41.27

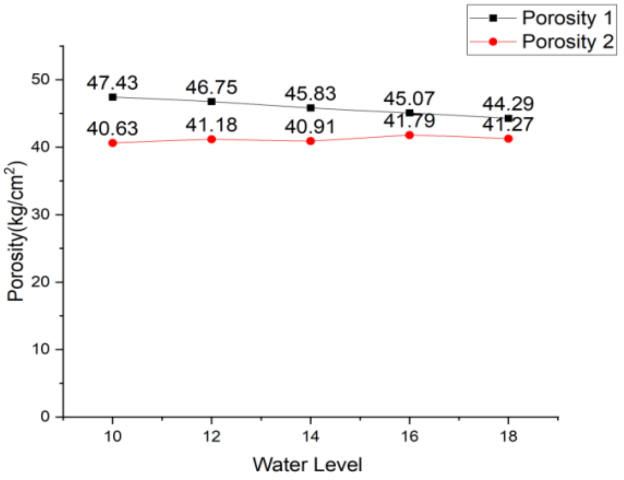

Fig 5 Porosity vs. water level

The addition of grog in the preparation of dense refractory bricks from the Kankara clay was not realized. In fact, the addition of grog caused a slight increase in the porosity values. This is the case irrespective of the particle's distribution in the grog. Also varying the moisture content of the refractory clay mix did not result in any porosity of the bricks. There was also no significant change in porosity when the forming pressure was increased from 10kg/ cm^2 to 214 kg/ cm^2. However, for the higher pressure, slight denser bricks were achieved due to reduction in porosity.

6.0 Conclusion

Kankara clay can be used to produce refractory fire bricks with good cold crushing strength, linear shrinkage and excellent resistance to thermal shock. However, it has a fairly low refractoriness, which limits its applications to temperature below 1200^{o}C. In addition, the fire clay formed porous bricks with porosity value well above the recommended values for dense bricks. The thermal conductivity of the Kankara refractory bricks is intermediate between those for regular dense brick and those for insulating bricks.

The results obtained in all the data indicate that High duty Silica (HDS) has the highest values of the properties that were determined, followed by Silica, and then theFire bricks (FB), and the Siliceous Fire bricks (SFB) respectively while the Semi-silica (SS) has the lowest values for all the properties determined. All these properties of the bricks are indicated in table.

Further work will be required to find ways of producing dense brick using this clay material. Preliminary study and attempts to densify the brick by grog addition variation in water content and increase of the moulding pressure did not result in any significant results.

Based on the information obtained from the research work it can be concluded as follows: that the clay material is likely to be kaolinite-rich and halloysite-rich, with some quartz present. The conclusion was drawn:

1. 1 The high Al_2O_3 content indicates the presence of aluminum-rich clay minerals. Kaolinite and halloysite are both aluminum-rich clay minerals.
2. 2.The presence of SiO_2 at relatively high levels supports the presence of quartz and kaolinite, which are both silicate minerals.
3. 3 Ceramics and Refractories: Kaolinite and halloysite are both widely used in ceramics and refractory applications due to their high alumina content, low iron content, and good plasticity.
4. Paper Industry: Kaolinite and halloysite are used in the paper industry as a filler and a sizing agent, which improves the paper's surface finish and printability.
5. Petroleum Industry: Kaolinite and halloysite can be used as drilling muds and acidizing agents in the oil and gas industry, which helps in stabilizing boreholes and removing drilling mud during well completion.
6. Cosmetics and Healthcare: Due to its fine particle size, kaolinite is used in cosmetics as an absorbent, and as a mild abrasive in toothpastes.
7. Construction Industry: Kaolinite is used in building materials such as bricks, tiles, and cements due to its low shrinkage and high plasticity.
8. Water Treatment: Kaolinite can be used in water treatment to remove heavy metals and other contaminants from water. It is also used as a filter media in water filtration systems.

References

[1] Wikepedia (2009) 'Clay' http://en.wikipedia. org/wiki/Clay

[2] Bricks (2004) 'Bricks' Http://www.bricks. com/documents

[3] Campbell, J. W. P., and Pryce.W (2003), 'Bricks: a world history', Thanes & Hudson, New York.

[4] Atanda, P. O., and Imasogie, B. I. (2009) Development of an Integrated Salt Bath Isothermal Heat Furnace unit for Austempering of Ductile Iron. Ph.D. Thesis Submitted to the Department of Materials Science and Engineering, Obafemi Awolowo University, Ile-Ife. Nigeria.

[5] Scaffer E. and James, P. (1995), The Science and Design of International Journal of Materials and Chemistry 2012, 2(5): 185-191 191 Engineering Materials, 1st ed., Longman, London.

[6] Azom.com (2007) 'The A to Z of Materials' http://www. azom.com

[7] Markov, B. and Krivandin, V. (1980), Metallurgical Furnaces, 1st Ed. Mir. Publisher, Moscow

[8] E.S. Nweke and E.I. Ugwu,Analysis and Characterization of Clay Soil in Abakaliki, Nigeria, The Pacific Journal of Science and Technology, v. 8, n.2, 2007, 190-193.

[9] J. F. Akinfolarin and O. O. Awopetu (2014). The Effect of Sawdust on the Insulating Effect of Ikere Clay as Refractory Lining, AU J.T. 17(3),143-147.

[10] C. P. Dogan, K. S.Kwong and J. P.Bennet,(2002) "Improved refractory materials for Slagging coal Gasifiers, "in proceedings from the 27th International conference on coal utilization and fuel systems, Clearwater, Florida.

[11] W.T. Bakker (1993), "Refractories for present and future electric power plants", Key Engineering Materials, Trans Tech Publications, Vol. 88, 41-70

[12] Odo, J.U., Okeke, S.I. and Obiorah, S.O. (2005) "Effect of Agricultural Waste Additives on the Refractory Properties of Two Blended Nigerian Clays" The Nigerian Metallurgical Society Annual Conference Proceedings.

[13] Daniel, C.C. (2004) "Investigation into the Refractory Properties of Ogulogu-Olo Clay". B.Eng Project, NnamdiAzikiwe University.

[14] Moses Oghenenyoreme Eyankware, (2021) Christopher Ogwah1 Joy Chiaka Ike (2021) A Synoptic Review of Mineralogical and Chemical Characteristics of Clays in the Southern Part of Nigeria Research in Ecology | Volume 03 | Issue 02 Distributed under creative commons license 4.0 DOI: https://doi.org/10.30564/re.v3i2.3057

[15] Obiorah, S.O., Odo, J.U. and Daniel, C.C. (2005) "Characterization of Ogulogu-Olo Clay Deposits for Industrial Applications" 2nd International Conference on Engineering

[16] Ihom, P.A., Jatau, J. and Muhammad, H (2004). The use of LP Simplex Method in the Determination of the Minimized Cost of a Newly Developed Core Binder.

[17] Obikwelu, D.O.N (2008). “A Novel Insulating Ceramic Powder Developed for Application in the Materials Industry” International Journal of Engineering. Vol. 2, No. 3, Pp 201- 211

[18] http://en.wikipedia.org/wiki/refractory (2008)

[19] Obikwelu, D.O.N. (2004) An introduction to Engineering Science. Warri: Amdi-Niel.

[20] Gupta, C.K(2003. Chemical Metallurgy. Moscow: Mir Publishers.

[21] Perepelitsyn, V. and Grishenkov, E. (2004) “A Classification of Refractories and Industrial Ceramics” Springer volume 45 No. 5.

[22] Jongs, L.S. (2008), “The importance of Clays in Industrial Development” A paper presented at an in-house Seminar at National Metallurgical Development Centre, Jos.

[23]. Odo, J.U. and Nwajagu, C.O. (2002) “Investigation into the Possible Use of Non-Cement Refractory Castables in the Metallurgical Industries” The Nigerian Metallurgical Society Annual Conference Proceedings.

[24] Odo, J. U., Obiorah, S. O. &Okeke, S. 1(2006). Production of Fire Clay Insulating Bricks from a Blend of Two Nigerian Clays, 5th Nigerian Materials Congress (NIMCON) Abuja. Nov. 16th_18th. P 113-115. 2006.

[25] Omotoyinbo, J.A. and Oluwole, O.O. (2008) “Working Properties of Some Selected Refractory Clay Deposits in South Western Nigeria”. Journal of Minerals &Materials Characterization & Engineering, Vol. 7, No.3, pp 233-245, 2008

[26] Mohd Sarat et al. (2202)“Properties and Applications of Clay Minerals: A Comprehensive Ceramics International

[27] Ibrahim A. Amin et al (2012)" Assessment of the Refractory Potential of Nigerian Clay Deposits “Journal of Earth Sciences and Environmental Management,

[28] Youcef Nachef et al. (2012) "Thermal Conductivity and Thermal Shock Resistance of Clay-Graphite Composites" by (Materials Science and Engineering.

[29] Mari Beall and Michaela Binder (2014) "Apparent Porosity and Density of Bricks and Tiles: An Experimental Study" by (In: Ceramic Materials and Components for Energy and Environmental Applications, Springer Netherlands.