A Study of the Refractory Properties of Selected Clay deposit in Chavakali, Kenya

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ABSTRACT: *A clay deposit in Chavakali of western Kenya was evaluated for its potential as refractory raw material. The collected clay sample was crushed, sieved and the chemical composition determined in percentage weight (wt %) of (SiO_2, Al_2O_3, Fe_2O_3, etc) using Atomic Absorption Spectrophotometer (AAS). The samples were moulded into rectangular shaped bricks of 40mm height, 40mm width and 80mm length, allowed to dry and later fired up to a temperature of 1000^0C. Refractory properties like Compressive strength, Hardness, Linear shrinkage on firing, Apparent porosity and Density were determined using standard techniques. The result of chemical analysis indicated that the clay was composed of Silica (SiO_2), 67.3%; Alumina (Al_2O_3), 16.67%; Iron Oxide (Fe_2O_3), 3.87%; Calcium Oxide (CaO), 0.37%; Potassium Oxide (K_2O), 2.30%; Sodium Oxide (Na_2O), 1.39%; and other traces. The physical and mechanical tests show that the clay has Cold Crushing Strength of 10.36MPa, Hardness of 40.080 GPa, Linear shrinkage of 6.17%, Apparent Porosity of 32.71% and Bulk Density of $2.77g/cm^3$. Chavakali clay can make better local refractory*

KEYWORDS: *Refractory, Chavakali clay, chemical analysis, mechanical, physical*

I. INTRODUCTION

Refractories are materials which have the ability to withstand high temperature without breaking or deforming, [1]. Any material can be described as 'refractory', if it can withstand the action of abrasive or corrosive solids, liquids or gases at high temperatures. Refractory materials are used in linings for furnaces, kilns, incinerators and reactors. The ability to withstand exposure to heat above 538 ^oC is the critical distinction separating refractory from other ceramics, fibres and coating applications at only lower temperature [2].

Most developing nations that are consumers of refractory materials have to spend their hard earned foreign currencies on the importation of these materials to meet their needs [1]. In Kenya most of the refractory raw materials are imported.

Raw materials are a major concern for the refractories industry due to the fact that:

- Raw materials account for some percentage of the cost of refractories' finished products.
- Raw materials have a major influence on product quality
- The refractories industry relies heavily on imports of raw materials [3].

Clay is a naturally occurring material composed primarily of fine grained particles of hydrous aluminium silicates and other minerals which show plasticity through a variable range of water content and can be hardened when dried or fired. It is also impermeable when in contact with water [4].

Chavakali-clay according to this research, refers to a type of soil found in western Kenya; a place called Chavakali. From the past years until currently this clay is mainly used by artisans for pottery and making of housing bricks. In other words, the clay has not extensively been used as a refractory raw material in the country.

Two factors are accentuating the development of good refractories using the local raw materials. The first one is the growing number of metallurgical industries that are in dire need of these refractories, while the other factor is the advent of foreign exchange market, a situation that has led to higher and unaffordable cost of procuring the refractory materials needed by these industries [1].

According to the [5] report, Kenya sits in a privileged position. It is the fifth-largest economy in sub-Saharan Africa; with a well-educated labour force, financial services and information technology capabilities being amongst the most developed in the region and its infrastructure being the most advanced among peers as well (with substantial further investment being planned). Despite these advantages, the manufacturing sector has remained stagnant at 11% of GDP over the past ten years. As a result, the number of formal jobs in manufacturing has grown at just 7% per year over the past four years. Kenya's exports have stagnated at 15% of GDP, while imports have grown to 40% of GDP, creating a trade imbalance, weakening the Kenyan Shilling and increasing inflationary pressure. These gaps can only be closed by revitalizing the industrial sector and turning Kenya into an industrial hub.

II. THE OBJECTIVES OF THE RESEARCH

General Objective

To investigate the potential of Selected Clay deposit in Chavakali, Kenya**,** for use in the production of refractories.

Specific Objectives

1. To determine chemical analysis of the clay under study
2. To prepare Bricks from clay Samples.
3. To determine the physical and mechanical properties of the prepared bricks.

III. MATERIALS AND METHODS

3.1 Raw material and Sample Preparation

The production of refractories begins with processing raw material. Raw material processing involves drying, grinding and determination of the Chemical Composition.

1. Drying

The raw materials (clays) were initially air dried and then later oven dried at 105^0C to ensure that all the moisture had been removed.

2. Grinding

The raw materials were properly ground using a pestle and mortar until a suitable ratio for coarse particles to fine particles was achieved.

3. Chemical analysis

The chemical composition of the raw clay sample in percentage weight (wt %) of (SiO_2, Al_2O_3, Fe_2O_3,etc) was examined using Atomic Absorption Spectrophotometer (AAS), which was carried out at Ministry of Mining Research Laboratories Center, Nairobi, Kenya.

3.2 Development of the refractory from the raw materials

This involved the actual production of refractory from the collected raw materials to the final shaped (formed) product.

1. Mixing

The ground particles were thoroughly mixed. This was done to enhance even distribution of the coarse and fine particles hence making moulding easy.

2. Moulding

The brick samples were formed into the required shape and size with the aid of a wooden box type of mold which could produce three samples at one go. The test pieces of the refractory materials were made into rectangular shapes of dimension 8.0x4.0 x 4.0 cm in a mold and compacted under a hydraulic pressure of 350kN/m^2. 350kN/m^2 was determined as the optimum hydraulic pressure necessary from the work of [6].

3. Drying

The molded refractory was dried to remove its moisture. Drying was regulated so that neither voids are left in the refractory nor the refractory is shrunk to produce internal stresses. The sample bricks were air dried until when they were physically seen to be dry. From the drying floor the samples were then put in an oven operating at 105^{o}C for twelve hours to remove all the remaining moisture.

4. Firing

The dried refractory was burnt for vitrification and development of stable mineral forms. In this step the already dried bricks were passed through a furnace at a controlled temperature over a certain fixed duration. The samples were fired at a temperature of 1000^{0}C. At this temperature, the soaking time was six hours (6hrs) according to [7].

3.3 Testing of the brick samples to establish their stability characteristic properties.

1. Apparent porosity Test

Porosity of a material is defined as the ratio of its pores volume to the bulk volume. The apparent porosity, sometimes referred to as open porosity, is a measure of the open or interconnected pores in a refractory. The apparent porosity is determined by the volume of liquid which was absorbed by the pores when the specimen is boiled in vacuum conditions, and when the material is saturated in water.

According to [8], the porosity of a refractory has an effect upon its ability to resist penetration by metals, slags and fluxes and, in general, the higher the porosity, the greater the insulating effect of the refractory.

[9], also states that porosity and pore size distribution of a refractory will influence its thermal conductivity, in that, more porous refractory translates to a more insulating refractory. Therefore, in general, a good refractory should have lower porosity.

This experiment was performed according to [10], whereby dry specimens were put in an oven maintained at a temperature of 110^0C till it attained a substantially constant mass (with an accuracy of 0.01grams). The weight of the specimen (W_1) was recorded after cooling it to room temperature. The dry specimens were then immersed completely in water at atmospheric temperature for 24 hours. The specimens were taken out of water and wiped out with a cloth before being weight. The weight after removal from water was let to be, W_2.

The respective dimensions of the samples were measured using a vernier caliper. The dimensions were then used to calculate the sample volume (V).

The apparent porosity per cent, after 24 hours immersion in cold water is given by the relation:

$$\text{Apparent porosity, } P_A = \frac{W_2 - W_1}{V} \text{ X } 100 \qquad (1)$$

Where: W_1 and W_2 is the weight of the absolutely dry specimen and the weight of the same specimen saturated in

water [g], and V is the volume of the specimen [cm^3] [11]

Volume=length X width X height

2. Bulk density

The bulk density (BD) is the amount of refractory material within a volume (kg/m^3). An increase in bulk density of a given refractory increases its volume stability, heat capacity and resistance to slag penetration. Bulk density is the ratio weight or mass to volume and it is expressed in pounds per cubic foot or kilograms per cubic meter [12].

According to [9] report, the simplest way of measuring Bulk Density for uniform rectangular refractory shapes is by dividing Dry Weight by Bulk Volume which is calculated from measured dimensions. Density, porosity and permeability measurements show whether a body is fully dense, and whether therefore it can be expected to stand up to aggressive slag attack and penetration by process gases.

The air dried specimens were further oven dried at 110 °C, cooled and weighed to the accuracy of 0.01 in order to determine their dried weight (DW). The respective dimensions of the samples were measured using a vernier caliper. The dimensions were then used to calculate the sample volume (V).
The bulk density was calculated from the equation proposed by [13]:

$$\text{Bulk density, BD} = \frac{DW}{V} \text{ g/cm}^3 \qquad (2)$$

Where, DW = Dried Weight V = Volume

Volume=length X width X height

3. Cold crushing strength

Cold crushing strength is the resistance of the refractory to compressive loads. As per [14], a cold crushing strength test is used to measure the cold strength of a brick. It is used to show whether or not the brick has been properly fired. This test, generally a quality control check, also indicates whether the brick will damage to corners and edges in transport. Cold crushing strength is the maximum load at failure per unit of cross-sectional area when compressed at ambient temperature.

The dried test bricks produced from the Chavakali clay, were oven dried at a temperature of 110 ^{0}C for 12 hours. It was then cooled to room temperature. The specimen was then taken to the compressing test machine where load was applied until cracks were noticed. The load at which the specimen cracked was noted, which represents the load required for determining cold crushing strength of the test specimen.

The test was carried out in accordance with [15]. Cold Crushing Strength was then calculated using Equation:

$$CCS = \frac{Maximum\ \ load\ (kN)}{Cross-sectional\ \ area\ (m^2)} = \frac{P}{A} \qquad (3)$$

Where, CCS = Cold Crushing Strength P = Applied Load A = Area of Load Applied

A good refractory material must possess high mechanical strength to bear the maximum possible load without

breaking.

4. Linear shrinkage

Linear shrinkage represents the permanent change that the refractory shapes undergo on heating or after reheating under a given set of conditions. The drying of clay is always accompanied by shrinkage. As the film of water between the clay particles is drawn off by evaporation the particles draw closer together to close up the interstices. The effect of this action is the shrinkage of the entire mass of clay.

To determine the fitness of a particular brick for service, it is often tested tor shrinkage under temperature conditions equivalent to those which it would receive in use. This is done by first determining the length or volume of the brick by measurement and then subjecting it to a prolonged heating at the desired temperature. After the brick has cooled, it is again measured and the length, volume and shrinkage determined.

A slanted line of length 6cm was inserted horizontally on each piece and recorded as (L_1). The test pieces were then placed inside the furnace and fired up to 1000^{o}C and the line drawn across the horizontal axis of the pieces was measured to determine its final length (L_2) after firing. The linear shrinkage of the materials was determined with equation:

$$\text{Linear shrinkage (\%)}, = \frac{L_1-L_2}{L_1} \text{ X } 100 \qquad (4)$$

The test was carried out in accordance with [16].

5. Hardness test

Hardness is a characteristic of a material, which can be defined as the resistance to indentation, and it is determined by measuring the permanent depth of the indentation. Measuring the hardness of a ceramic is important and this is usually done using an indentation test. The basic idea is that a permanent surface impression is formed in the material by an indenter. The actual or projected area of the impression is then measured. The hardness is then determined by dividing the applied force, *F*, by this area [17].

In this study, hardness will be determined using the Brinell method. The Brinell method applies a predetermined test load (F) to a carbide ball of fixed diameter (D) which is held for a predetermined time period and then removed. The resulting impression is measured across at least two diameters – usually at right angles to each other and these result averaged (d).

In this experiment, the indenter diameter (D) used was 5mm and the test force (F) was 1kN.

Typically, an indentation is made with a Brinell hardness testing machine and then measured for indentation diameter in a second step with a specially designed Brinell microscope or optical system. The resulting measurement is converted to a Brinell value using the Brinell formula or a conversion chart based on the formula.

Equation below illustrates the formula used to obtain the Brinell value:

$$\mathbf{HB} = \frac{0.102F}{0.5\pi D(D-\sqrt{D^2-d^2}))} N/m^2 \qquad (4)$$

Where F = Force, D=Ball Diameter, d = diameter of indentation.

at a constant force of 1kN,and a ball diameter of 5mm

IV. RESULTS AND DISCUSSION

The results from the experimental work are given in tables 1 and 2. From table 1, it is evident that Chavakali clay has silica and alumina as the predominant substances and thus is siliceous in nature and is of the Alumino-silicate family.

The sample has high silica content well above the ideal 46.51% for clay which makes it be able to withstand fairly high temperatures (Shackelford & Doremus, 2008). From [18] report, the silica content of Chavakali clay satisfies the standards for the manufacture of high melting clay.

The sample clay has a fairly high iron content (Fe_20_3) which makes it fire terracotta red (brick red) color on firing [6].

The Loss on Ignition is determined as the percentage of moisture loss to ignition on firing. This represents the amount of moisture the clay material could hold or percentage weight reduction of the soil sample which may probably be a reflection of its grain structure and fineness. Following the report by [18], the loss on ignition of the sample falls within the standard range for the production of high melting clay. [19], suggests that the loss on ignition values, are required to be low in order to reduce on the effect of porosity on the final products.

Table 1: Chemical composition analyses of Anthill clay compared with standard clay for industrial applications [18].

Composition	Chavakali Clay	Ceramics	Refractory Brick	High melting clay	Glass	Paper	Paint
SiO_2	67.3	60.5	51.7	53-75	80-95	45-45.8	45.3-47.9
Al_2O_3	16.67	26.5	25-44	16-29.0	12-17.0	33.5-36.1	37.9-38.4
Fe_2O_3	3.87	0.5-1.2	0.5-2.4	1-9.0	2-3.0	0.3-0.6	13.4-13.7
CaO	0.37	0.8-3.0	0.1-2.0	0.5-2.6	4-5.0	0.03-0.6	0.03-0.6
K_2O	2.30	-	-	-	-	-	-
TiO_2	0.24	-	-	-	-	-	-
CuO	-	-	-	-	-	-	-
V_2O	-	-	-	-	-	-	-
LOI	7.44	8-18.0	8-18.0	5-14.0	-	-	-

The physical test results of Chavakali clay showed an apparent porosity of 32.71% which according to [20], qualify to be used as refractory firebricks. The samples with the apparent porosity values less then(<) 40% are stronger and therefore qualify to be used as refractory firebricks according to [20].

The bulk density of 2.77 g/cm^3 was obtained which according to [21] makes them qualify to be used as refractory firebricks.

The Cold crushing strength of the Chavakali clay bricks obtained was 10.36 Mpa. This value falls slightly higher than the standard range for the manufacture of thermal insulators as given by [22]. According to Kumar, the standard range is 981-6867kPa. Due to this, the clay can therefore make thermal insulators.

According to [19], the total percentage shrinkage for standard fireclay and siliceous refractories are supposed to be ranging between 4-10%. The total percentage shrinkage value obtained from the brick samples was 6.17% which falls within the acceptable range.

The hardness value obtained from the fired Chavakali clay bricks was 40.080GPa which falls between the highest and least hardness values for ceramics as given by [17]. It is reported that MgO has the least hardness value of 3.63GPa while Diamond is the hardest with a value of 78.48 GPa.

Table 2: Physical and Mechanical test results

Sample description	Tested properties				
	Apparent Porosity (%)	Bulk Density (g/cm3)	Cold Crushing Strength (MPa)	Linear Shrinkage (%)	Hardness (GPa)
Chavakali clay Brick	32.71	2.77	10.36	6.17	40.080

V. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

An experimental study was conducted to investigate the suitability of Chavakali clay deposit as an industrial raw material for making refractories in view of their chemical, mechanical and physical properties.

The results of the chemical analysis showed that the clay contain aluminum oxide (Al_2O_3) and silica (SiO_2) as major constituents making it suitable as alumino-silicate refractory material.

The batch samples passed through the experimental tests to determine their refractory properties in terms of mechanical and physical behaviors showed that the selected raw material (clay) can substitute for the imported refractories as thermal insulators.

The chemical composition results also suggested that the clay is found to be a source of local raw materials for the production of thermal insulators.

It can therefore be concluded that Chavakali clay can substitute for the imported refractory raw materials.

The clay under study, that is, Chavakali clay deposit, has not been exploited in Kenya for the production of refractories. Thus if this clay is exploited and harnessed, it will no doubt provide an internal source of raw materials.

There is also the need for geological survey to determine the extent of the deposits.

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