

CHARACTERIZATION AND COMPARATIVE ASSESSMENT OF MONKIN AND KASSA CLAYS FROM TARABA STATE, NIGERIA FOR REFRACTORY AND CERAMIC APPLICATIONS

Mohammed Iliyasu Dawaki, Idu Hyacinth Kevin, *Gabriel Wirdzelii Joseph, Andeyangnde Danladi

Department of Physics, Taraba State University, Jalingo, Taraba State, Nigeria

*Corresponding Author Email Address: gabrielwjoseph@gmail.com

ABSTRACT

The Characterization of Monkin and Kassa clays from Zing and Yorro Local Government Areas in Taraba State, Nigeria, was investigated to evaluate their potential for refractory and ceramic applications. The clay deposits were analyzed to obtain physical and mineralogical properties for possible industrial application. Samples were fired at temperatures ranging from 1600°C to obtain modulus of rupture, refractoriness, thermal conductivity, thermal shock resistance, specific gravity, and cold crushing strength. Physical tests revealed that the clays were suitable for refractory applications. The mineralogical analysis shows that kaolinite was dominant in the clay sample, which suggests that it can be used in the bricks and the refractory industries. The results of X-Ray Diffraction analysis revealed that the clay sample obtained from Monkin area was composed mainly of halite, sylvine and sodian. The discovery of halite as the dominant mineral in Monkin clay-based sample M, along with sylvine and sodian, points to a saline depositional environment. The high content of soluble salts in the Monki clay sample limits its industrial utility without beneficiation. This is because halite's dominance in the clay sample deposit is unusual, as clays are typically rich in phyllosilicate minerals like kaolinite, illite, or smectite. The study, however, recommends that the Monkin clay (M), due to its superior mechanical strength (MOR and CCS) and thermal shock resistance, is suitable for the manufacture of refractory bricks, furnace linings, and structural ceramics.

Keywords: X-ray, Kaolinite, Halite, Ceramic Industry, Refractory Applications

INTRODUCTION

Nigeria's pressing need for sustainable development, coupled with its rich natural resources, underscores the need to promote the use of locally sourced materials through scientific advancements and improved technology. Technological advancements within the country have not only heightened awareness but also improved living standards for both urban and rural populations, resulting in increased demand for modern industrial applications (Cohen, 2004). As noted, sustaining industrial growth necessitates the expansion and support of Nigeria's iron and steel industries, which currently depend on furnaces lined with refractory bricks produced from kaolin and other clays—materials that are predominantly imported (Al-Tarazi et al., 2008; Nnuka & Agbo, 2000).

Clay is a fine-grained, naturally occurring substance formed through the gradual weathering and chemical degradation of rocks, particularly silicate rocks. It possesses a particle size of less than 2 µm, exhibits plasticity when mixed with water, contracts during drying, expands when wet, and solidifies upon firing (Idenyi &

Nwajagu, 2003; Guin *et al.*, 2025; Pang *et al.*, 2026). The versatility and distinctive properties of clay, including plasticity, cation exchange capacity, and adsorption capabilities, render it essential across various sectors such as ceramics, construction, paper manufacturing, and oil drilling (Birnin-Yauri *et al.*, 2014; Guin *et al.*, 2025; Vasić *et al.*, 2025). Chemically, clay is a complex aluminosilicate compound containing water molecules and originating from the disintegration of rocks like granite. It is commonly found in soils, sediments, sedimentary rocks, and hydrothermal deposits. A notable characteristic of clay is its ability to absorb water or other polar ions, a property referred to as swelling, which serves as the basis for its classification into swelling and non-swelling types, with smectites forming a primary group of swelling clays (Murray, 2006; Pang *et al.*, 2026; Wani *et al.*, 2025). Clays can be further categorized into mineral groups based on their composition and structure, with prominent examples including the kaolinite group ($\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$). This group features a one-to-one structure comprising alternating layers of silica and alumina and is characterized as non-swelling, allowing no water or ions between its layers, thus attributing its colloidal properties solely to external surfaces (Adeseko & Bolarinwa, 2021; Jongs *et al.*, 2018; Kumar & Mohan, 2021; Guin *et al.*, 2025). Kaolinite is recognized for its limited plasticity, cohesion, and swelling, making it suitable for applications that demand stability. Kaolin, which is refined from kaolinite, finds extensive use across numerous industries including paper coatings, paints, plastics, adhesives, inks, rubber, ceramics, and as a catalyst in petroleum cracking and automotive exhaust systems (Vasić *et al.*, 2025; Mohammed *et al.*, 2025).

Bentonite, another significant clay group, primarily consists of montmorillonite from the smectite group and often originates from weathered volcanic ash (Kaufhold, 2025). Its three-layer structure, which includes silica and aluminium sheets located in tetrahedral silica units, gives it its valuable elasticity. Bentonite types include sodium bentonite, calcium bentonite, and sodium-activated bentonite, all of which serve essential functions in drilling, binding, and absorption applications (Wani *et al.*, 2025; Kaufhold, 2025). Silica sand, commonly referred to as quartz, is a vital geological material for glass manufacturing due to its stable silicon dioxide (SiO_2) content, which remains unchanged under diverse transport and redeposition conditions. Quartz in its purest form, along with silica sand, which often results from weathering and erosion, is crucial for the production of sheet glass, bottles, mirrors, and optical instruments, although it may contain impurities such as hematite and dolomite (Mehboob *et al.*, 2025).

The unique properties of clay have led to its widespread application across various industries. Clay products are extensively utilized in ceramics, porcelain, glass, refractory bricks, architectural tiles, and even in the rubber industry, where their reinforcing abilities,

particularly in conjunction with silica, are highly esteemed (Vasić *et al.*, 2025; Guin *et al.*, 2025). The main properties affecting the industrial uses of clay are its plasticity, colour, strength and shrinkage during drying and firing. The specific oxide content of Fe₂O₃, MgO, CaO, and Na₂O in clay determines its suitability for uses such as bricks, tiles, and paper, while the presence of alkali metal oxides affects its application in ceramics (Vasić *et al.*, 2025). Nigeria is endowed with extensive clay deposits distributed throughout its regions, with material properties varying according to geological characteristics. Locally produced clay-based materials, such as ceramic wares, bricks, and tiles, offer cost-effective and durable alternatives to imported construction materials, particularly in light of the economic necessity to prioritize local sourcing. Regions such as Monkin and Kassa are noted for significant clay deposits; however, their industrial potential remains largely untapped due to insufficient research. Investigations in other areas have demonstrated that, with appropriate processing and characterization, local clay deposits can effectively substitute imported materials.

In light of Nigeria's rapid industrialization and the escalating demand for raw materials, it is imperative to explore and characterize local clay deposits, particularly those in Monkin and Kassa within the Yorro Local Government Area of Taraba State. This study aims to evaluate the mineralogical, physical, and chemical properties of these deposits to ascertain their potential for industrial applications, especially in ceramics, refractories, and construction. By emphasizing the ceramic potential and economic value of Nigeria's clay resources, this research endeavors to diminish reliance on imported materials and unlock new opportunities for local industrial development.

MATERIALS AND METHODS

The equipment utilized in this study includes the following: weighing balance or spring balance, measuring cylinder, buckets (or basins), scraper or hand trowel, presser, lubricant or separator (engine oil), wooden mold, brush, ruler, drier, sieve, mortar and pestle, and head pan.

Clay samples were obtained from Monkin coded M and Kassa coded K, within the Zing and Yorro Local Government Areas of Taraba State, Nigeria. The clay deposit sites were excavated to a depth of two meters using an iron digger, and samples were collected from the specified locations. Approximately 20 kg of clay samples from each site were gathered and subsequently transported to the testing location.

The clay samples underwent a beneficiation process that included washing, sieving, drying, and gravity separation. Additional beneficiation techniques involved screening the clay samples at a 120 mesh size and employing froth flotation to reduce silica content, thereby enhancing alumina levels.

Following this, the clay samples were sun-dried for three days and subsequently placed in an oven for further drying for eight hours at a temperature of 50°C. The dried clay was then pulverized into smaller particles and ground to finer sizes using a laboratory crusher and ball mills, respectively. The material was sieved and molded into various standard test geometries based on the specific testing requirements. The clay samples were subsequently mixed in varying proportions of 90:10, 80:20, 70:30, 60:40, and 50:50 for Monkin and Kassa clays, respectively.

All the experiments for this work were carried out at the Department of Metallurgical and Materials Engineering, Katsina State University, Katsina State, Nigeria. The proportioned clay blends

were subjected to firing in an electric furnace at temperatures of 1100°C to 600°C, at a predetermined firing rate of 5°C/minute. Thereafter, the samples were subjected to physicochemical properties determination using standard procedures as appropriate.

Fourier Transformed Infrared spectroscopy (FTIR)

This methodology was employed for the identification of clay minerals and poorly crystalline mineral phases, as well as for detecting potential adsorbed elements or functional groups. The samples were prepared utilizing the disc technique, which involved mixing 1 mg of clay sample with 200 mg of KBr, followed by placement in a mold. These intimate mixtures were subsequently pressed under extremely high pressure (10 tons per cm²) to produce a transparent disc, which was then positioned in the sample compartment. The spectra were recorded over the range of 4000 to 350 cm⁻¹ using a Fourier Transform Infrared Spectrophotometer.

Bulk Density

The bulk density of a refractory material is defined as the weight per unit volume, which encompasses the pore space. Test specimens were fabricated from the clay samples. Subsequently, the specimens were dried in an oven at a temperature of 1200 °C for a duration of 24 hours. The dried weight (W_d) of the specimen was recorded, after which they were fired in a furnace. Specimens were subsequently placed in a beaker of water within vacuum desiccators and evacuated until bubbling ceased. At this juncture, it was assumed that the air within the samples had been displaced by water. The specimens were then dried, and the soaked weight (W_s) was recorded. Following this, the specimens were individually suspended in a beaker of water, and the suspended weight (W_p) was recorded. The average bulk density was calculated using the following expression.

$$\text{Bulk density} = \frac{W_d}{W_s - W_p} \quad (1)$$

Moisture Content

A sample of 40 grams of the mixture was accurately measured to within 0.01 grams, spread in a thin layer on a sand glass, and dried at a temperature of 110 °C until a constant weight was achieved. Subsequently, the sample was cooled in a desiccator and reweighed. The weight difference was then calculated as a percentage of the dry weight, as demonstrated below:

$$\text{Moisture content (MC)} = \frac{M_w - M_D}{M_D} \times 100\% \quad (2)$$

Where MC = moisture content, M_w = mass of the wet sample, M_D = mass of the sample after drying.

Firing Shrinkages

Firing shrinkage denotes the irreversible alterations that refractory shapes experience during heating or re-heating under specified conditions. The test specimens were dried in an oven at 110 °C for 24 hours, followed by firing in a muffle furnace at 1100 °C and 1600 °C, with subsequent 20 °C intervals. The calculations for dried shrinkage (DS), fired shrinkage (FS), and total shrinkage (TS) will be performed using the following formulas:

$$\text{Dry shrinkage (D}_s\text{)} = \frac{O_L - D_L}{O_L} \times 100 \quad (3)$$

$$\text{Fired shrinkage}(F_S) = \frac{D_L - F_L}{F_L} \times 100$$

$$(4) \text{ Total shrinkage}(T_S) = \frac{O_L - F_L}{O_L} \times 100$$

(5) Where O_L = original length, D_L = dry length, F_L = fired length.

Water Absorption

The percentage of water absorption is a key indicator of the rate at which water is absorbed. This property is significant as it reflects the amount of moisture that the clay can absorb without compromising its structural integrity (Idenyi & Nwajagu, 2003).

The test specimens, crafted from the clay samples, were dried in an oven until a constant weight was achieved. Subsequently, the samples were immersed in boiling water sequentially, ensuring that they did not contact the bottom of the vessel. The evaporated water was replenished with boiling water, and after a designated boiling period, the vessel was allowed to cool to a specific temperature, measured in degrees Celsius ($^{\circ}\text{C}$).

Following the removal of excess water from the samples using a moist cloth, the specimens were weighed again. Both the dried and soaked weights were recorded. The percentage of water absorption was then calculated using the appropriate formula.

$$\text{Water Absorption}(WA) = \frac{W_S - D_W}{D_W} \quad (6)$$

Where W_S = weight of Soaked specimen suspended in air, D_W = Dried weight of specimen.

Apparent Porosity

Porosity is defined as the volume of all pores present within a material [10]. The specimens were subjected to drying in an oven at 110°C for a duration of 24 hours to ensure complete removal of moisture. Subsequently, they were fired at temperatures of 1100°C and 1600°C in a muffle furnace. The weights of the dried specimens were measured and recorded. The specimens were then suspended in distilled water, ensuring that they did not come into contact with the bottom or sides of the container. Following this, the specimens were boiled for two hours while remaining suspended in the water, allowed to cool to room temperature, and their weights were documented. Afterward, the specimens were removed from the water, and surface moisture was gently blotted away using a damp towel before weighing in air (W) [10].

The apparent porosity was then calculated by:

$$\text{Apparent porosity} = \frac{W - D}{W - S} \times 100 \quad (7)$$

Where D = weight of dry sample, S = weight of the sample suspended in water, W = weight of sample in air.

Cold crushing strength

Test specimens measuring $50 \times 50 \times 50$ mm were prepared and subjected to air drying for a duration of 24 hours. Following this, the specimens were transferred to a furnace, where they were heated for 6 hours at a temperature of 1200°C . Upon completion of the heating process, the samples were removed and allowed to cool to room temperature. Each specimen was subsequently placed in an Amsler Type Crusher. During the testing phase, the pressure application surface was meticulously aligned with the center of the spherical seat of the apparatus. An axial load was applied gradually until the specimen fractured. This procedure was repeated for additional test specimens, and the corresponding loads at which each specimen fractured were documented. The cold crushing strength (CCS) was then calculated using equation (2.8).

$$\text{Cold crushing strength}(CCS) = \frac{P}{A} \quad (8)$$

Where A = Area of test specimen, P = applied load

Thermal shock resistance

Specimens of predetermined dimensions were subjected to cyclic thermal shock testing. Each specimen was placed in a furnace preheated to 1600°C and held for 10 min. The specimen was then removed and allowed to cool in a desiccator for 10 min before being returned to the furnace at the same temperature for a further 10 min hold. This heating-cooling sequence was repeated until visible cracking or permanent deformation occurred under light mechanical loading. The number of complete cycles endured by each specimen was recorded. Thermal shock resistance was quantified as the number of cycles required to produce the first observable crack or deformation.

Modulus of rupture (MOR)

Various test specimens of clay bar with specified dimensions were prepared. The dry samples were subsequently moistened and blended to achieve a workable consistency. The wedged samples were cast in wooden molds, which were coated with a thin layer of machine engine oil. The bars were temperature-marked and then individually placed into an electric furnace, alongside American standard pyrometric cones with a refractoriness of 1600°C , and fired for approximately ten hours. Following this process, the bars were removed from the furnace and allowed to cool. Each batch of bars was subjected to a bending test at the center using a Denison strength testing machine with a 35 mm span, and the Modulus of Rupture (MOR) was calculated using the expression provided below.

$$\text{MOR} = \frac{3PL}{2bh} \quad (9)$$

where p = breaking Load in kgf, L = Distance between support b = Breadth, h = Height.

Modulus of plasticity (MOP)

The molded clay experienced deformation as a result of being struck from a predetermined height by a flat-headed plunger of known weight. The distance traveled will be recorded and measured using a graduated scale. The modulus of plasticity (MOP) for the clay sample was calculated using the following expression.

$$\text{MOP} = \frac{\text{Original Height}}{\text{Deformed Height}} \quad (10)$$

The percentage making moisture for the clay samples was obtained from the following expression:

$$\% \text{ Making Moisture} = \frac{\text{wet weight} - \text{Dry weight}}{\text{Net Weight}} \quad (11)$$

Loss of Ignition

The loss of ignition was determined by weighing, utilizing the Lechler and Desiletes method (Jongs et al., 2018). A thirty-gram pulverized sample was transferred into a clean, dry platinum crucible using an analytical balance. The sample was subsequently placed in an oven at 700°C for four hours to determine the loss on ignition. This procedure was repeated until a constant weight was achieved for the samples, in accordance with the specified formula.

$$\text{LOI} = \frac{\text{weight Loss}}{\text{Weight of sample}} \times 100 \quad (12)$$

X-ray diffraction

The identification of clay minerals in each clay sample was conducted using an X-ray diffractometer. All pulverized samples, sized at $2 \mu\text{m}$, were oven-dried, and approximately 1 g of each

sample was mounted for analysis. The analysis utilized copper (Cu) target radiation at 45 kV and 20 mA, with a specified scan speed.

Scanning Electron Microscope (SEM)

The microstructures of the clay samples were analyzed using a Scanning Electron Microscope (Model Pro X) equipped with an energy-dispersive X-ray spectrometer, as described by Triaki et al. (. (2009)

RESULTS AND DISCUSSION

This study provides a comprehensive characterization of the physical and chemical properties of Monkin and Kassa clay located in the Zing and Yorro local government areas of Taraba State, with the objective of evaluating their potential for industrial applications. The X-Ray Diffraction analysis (fig 1 and 2) of the clay sample from the Monkin area revealed a mineral composition predominantly consisting of halite, sylvine, and sodian. The presence of halite as the principal mineral in the Monkin clay sample (M), alongside sylvine and sodian, suggests a saline depositional environment. The significant concentration of soluble salts within the Monkin clay sample restricts its industrial applicability without further beneficiation, as the predominance of halite is typical for clay deposits, which usually contain phyllosilicate minerals such as kaolinite, illite, or smectite. Consequently, the properties of Monkin clay indicate its unsuitability for ceramic or refractory applications.

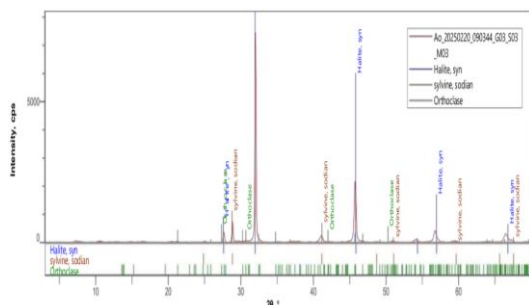


Figure 1: X-ray diffractograph for Samples

In contrast, the X-Ray Diffraction mineralogical analysis of clay

sample K indicated that the primary minerals are kaolinite ($\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$) and quartz (SiO_2), with minor constituents of muscovite and orthoclase. This mineral assemblage implies a richness in aluminum silicates, consistent with the findings of (Kumari & Mohan, 2021), which suggest that such minerals are primarily formed through weathering processes in a siliceous environment. The mineralogical profile of sample K is favorable for industrial applications, characterized by a dominance of kaolinite and quartz, supplemented by accessory minerals of muscovite and orthoclase. The presence of both clay and non-clay minerals in this area indicates a formation resulting from mature weathering processes and mixed sedimentary origins.

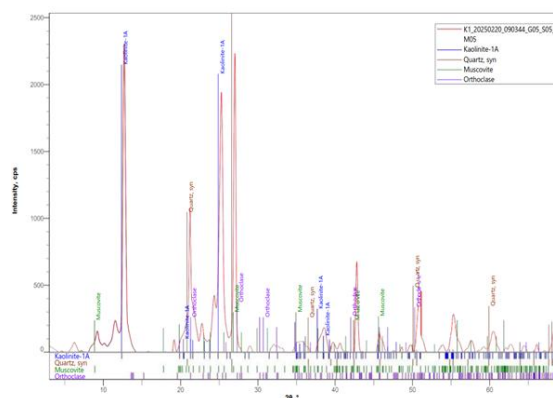


Figure 2: XRD pattern for Monkin and Kassa Clay Sample

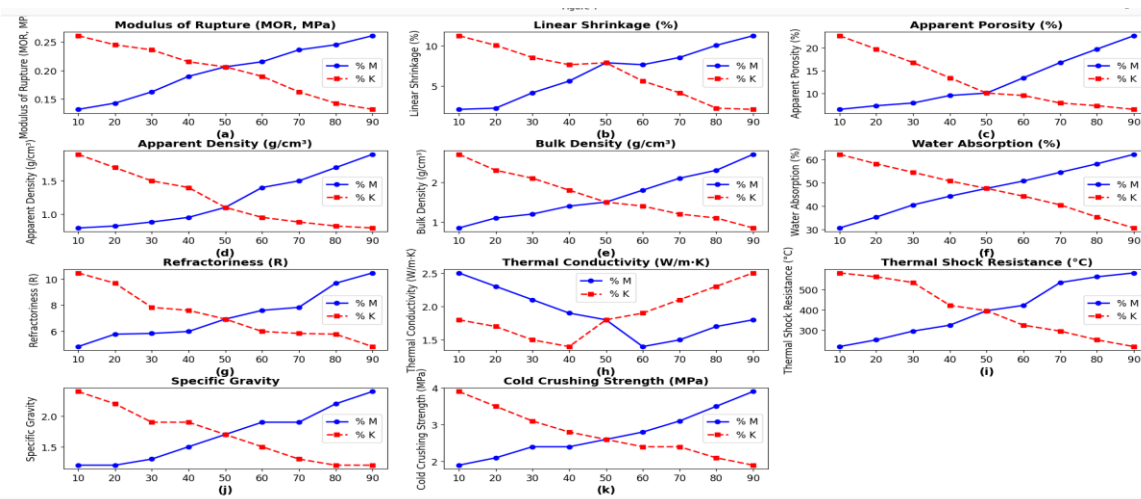


Figure 3: Physical and Mechanical Properties of Mixed Samples M and K

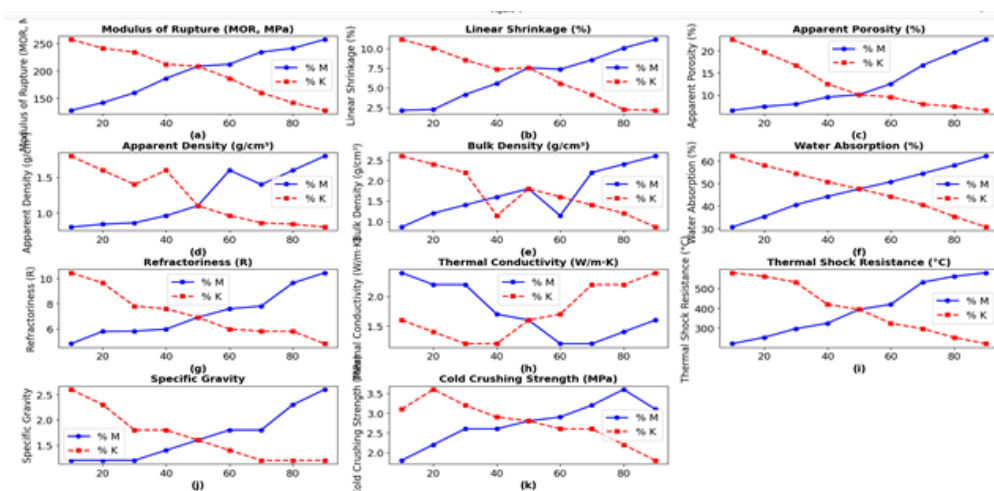


Figure 4: Physical and mechanical properties of the samples M and K sintered at 1200°C

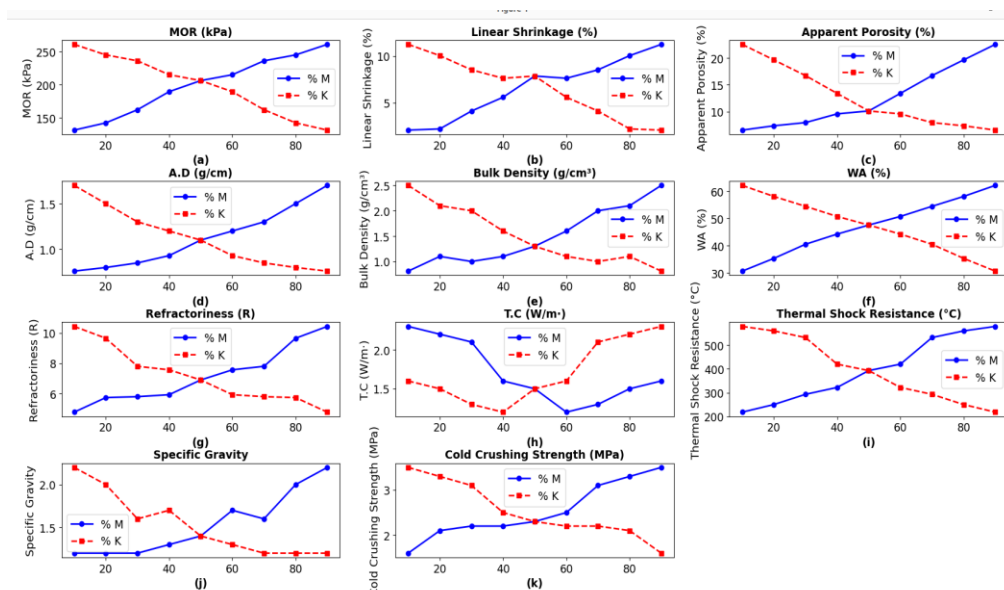


Figure 5: Physical and mechanical properties of the samples M and K sintered at 1300°C

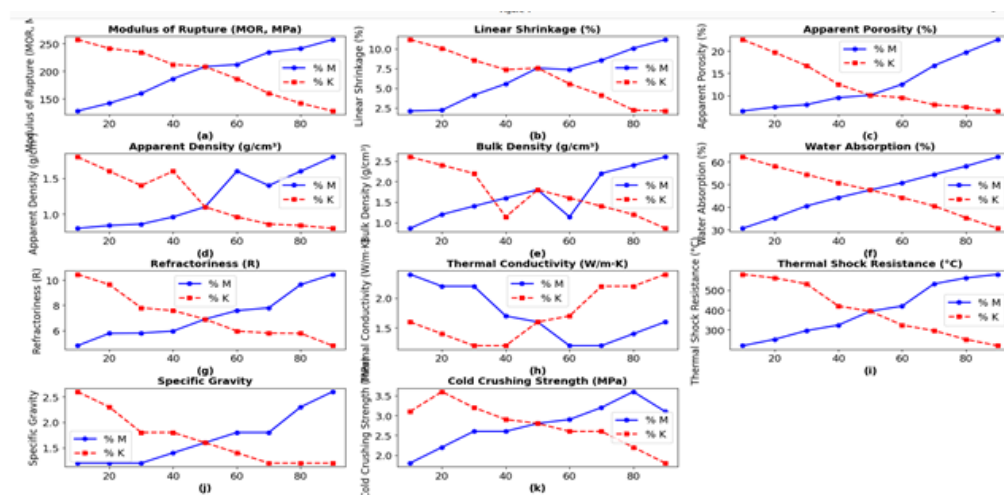


Figure 6: Physical and mechanical properties of the samples M and K sintered at 1400°C

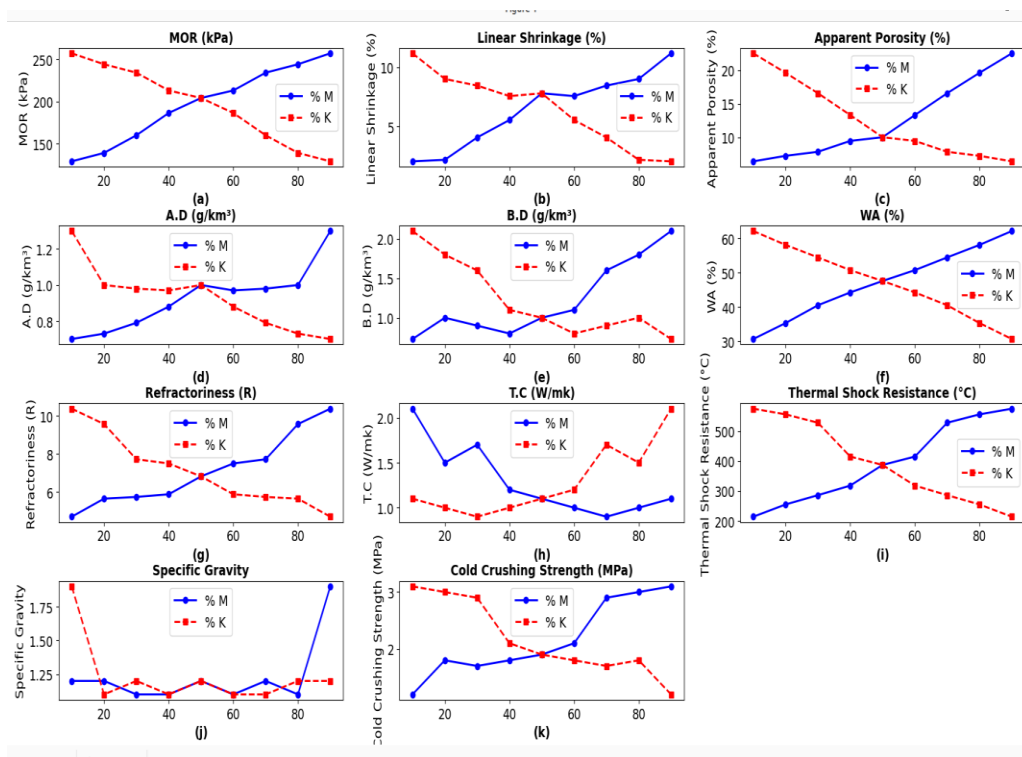


Figure 7: Physical and mechanical properties of the samples M and K sintered at 1600°C

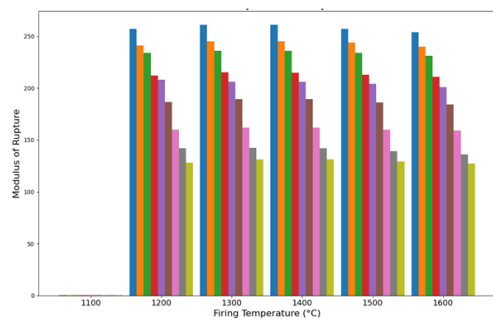


Figure 8: Modulus of rupture as a function of temperature

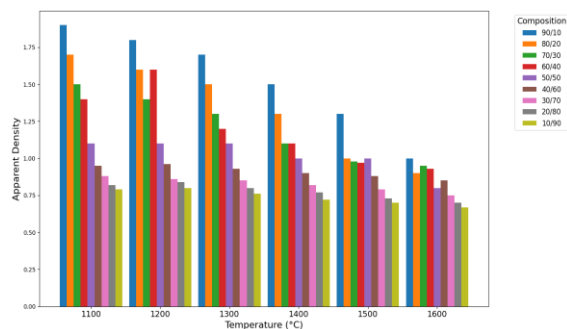


Figure 9: Apparent density as a function of temperature

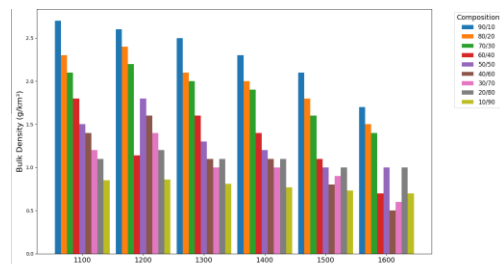


Figure 10: Bulk Density as a function of temperature

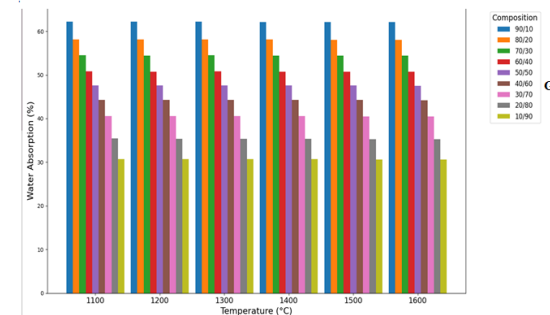


Figure 11: Water Absorption as a function of temperature

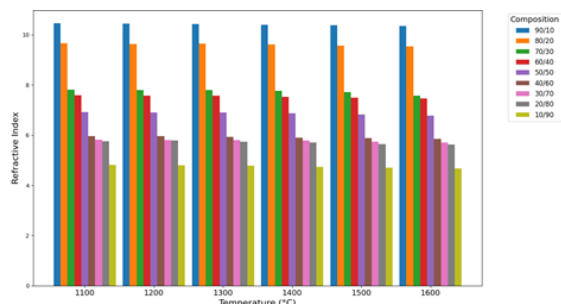


Figure 12: Refractive index as a function of temperature

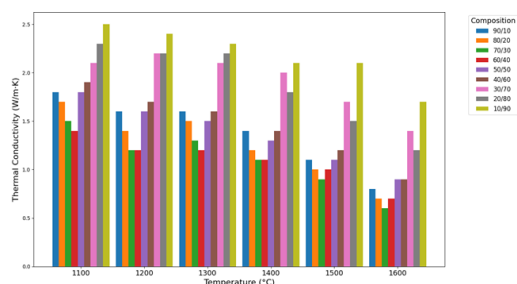


Figure 13: Thermal Conductivity as a function of Temperature

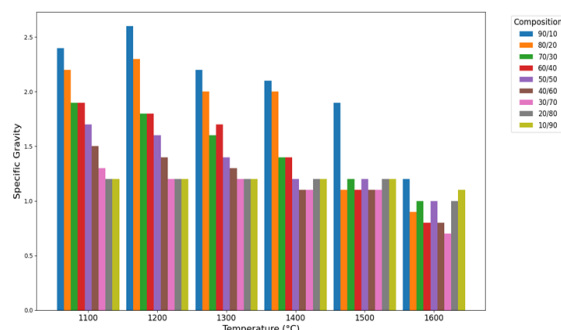


Figure 14: Thermal Shock Resistance as a function of Temperature

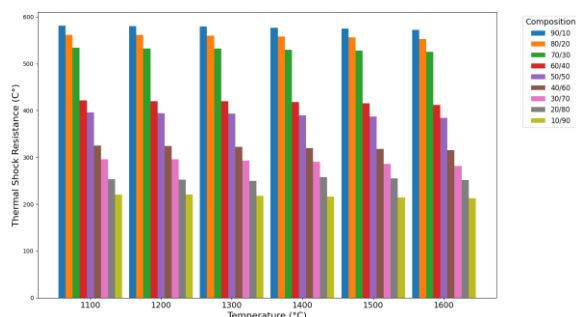


Figure 15: Specific Gravity as a function of Temperature

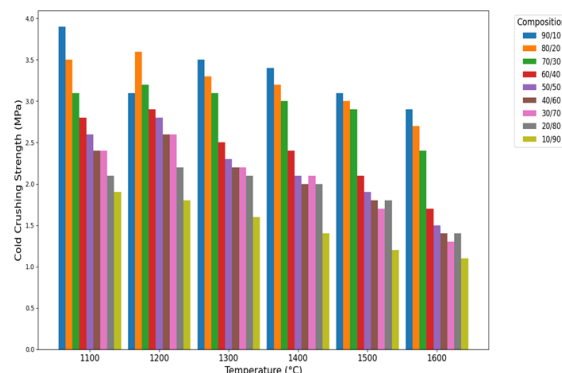


Figure 16: Cold Crushing Strength

From the analysis of the physical properties of the Monkin and Kassa clay samples, it can be deduced that Sample M exhibited superior modulus of rupture (MOR) and cold crushing strength (CCS) across all firing temperatures when compared to Sample K, indicating that the Monkin clay sample possesses enhanced mechanical strength and durability. The MOR and CCS values demonstrated a progressive decline with increased K content in the mixed samples M and K, thereby confirming Monkin clay as the principal contributor to the mechanical robustness of the composites.

The Monkin clay sample M displayed greater linear shrinkage than the Kassa clay sample K, suggesting enhanced plasticity and densification upon firing. The linear shrinkage values for mixed samples decreased progressively from ID2 to ID10, remaining within acceptable limits (7-10%) for aluminosilicate and kaolin-based fireclays, which affirms good firing efficiency and dimensional stability. Sample M also demonstrated higher apparent porosity and water absorption, indicating a greater number of open pores within its structure. However, the mixed samples M and K exhibited a reduction in porosity and water absorption as the percentage of K increased, suggesting pore closure and densification with higher K content, albeit at the expense of mechanical strength.

Furthermore, the Monkin clay demonstrated higher apparent density (AD) and bulk density (BD), signifying better consolidation and compaction. The mixed samples exhibited a declining trend in both AD and BD as the proportion of K increased, correlating with diminished mechanical strength and increased fragility.

The results of thermal conductivity (TC) analysis for sample K indicated an increase, suggesting that samples with higher K content possess improved heat conduction due to denser matrices and reduced air gaps. However, thermal conductivity did not correlate with mechanical strength, indicating that mineralogical changes during sintering exerted a distinct influence on thermal behavior.

The sample M exhibited a higher thermal shock resistance (TSR), indicating greater resilience to rapid temperature changes. The interplay between thermal expansion mismatch, elastic modulus, fracture toughness, and thermal conductivity of the material governs the observed trends in thermal shock resistance (TSR) with temperature. Rapid temperature changes generate transient tensile stresses at the surface during cooling. When these stresses

exceed the local fracture strength, microcracks initiate and propagate. Materials with lower thermal expansion coefficients, higher thermal conductivity, and greater fracture toughness typically endure more cycles before failure. Microstructural features such as porosity, grain size, and the presence of secondary phases further modulate stress relaxation and crack deflection, thereby controlling the number of cycles to failure. TSR values were observed to decline, consistent with the trends in MOR and CCS, confirming that samples with a higher K content are less resistant to thermal shock. Analysis of specific gravity values revealed a decrease across all temperatures, indicating a transition of the samples from denser to lighter phases, which correlates with increased porosity and reduced strength.

Overall, the results indicate that both Monkin and Kassa clays exhibit commendable refractoriness, with no failure observed at firing temperatures ranging from 1100 to 1600°C. The measured refractoriness values (up to approximately 10.4) and sintering behavior suggest that both clays meet international standards (1580 to 1750°C) and are suitable for high-temperature applications in the refractory and ceramics industries.

Conclusion

In this study, it is established that Monkin and Kassa clays have significant applications in areas of ceramics and refractories due to their mechanical behaviors, thermal stability and mineralogical properties. As demonstrated in fig 8 and fig 14, Monkin clay has exceptional mechanical and thermal resistance but requires beneficiation to mitigate its salt content. From fig 2 and fig 14, Kassa clay is dominated by kaolinite and quartz and exhibits favorable mineralogical purity and thermal conductivity, hence good materials for conventional processes. The complementary properties of these clays support their use in blended formulations for target industrial applications. The findings in this work contribute to Nigeria's database on clay resources, providing a foundation for advancing local materials utilization in support of the nation's industrial growth and development.

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