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(Research Article)

Innovative Processing of Refractory Bricks Using Locally Sourced Clay in Southwestern Nigeria

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Abstract

This research investigates the utilization of indigenous clay deposits from Ipokia, Ogun State, Nigeria, for the fabrication of refractory bricks as a sustainable replacement for imported refractory products. Clay samples obtained at a depth of 1.5 m were characterized chemically and found to possess suitable refractory oxides, with Ipokia I containing 34.50% Al_2O_3 and 51.30% SiO_2, and Ipokia II containing 27.30% Al_2O_3 and 58.75% SiO_2, satisfying established refractory composition requirements. The clays were processed into bricks and tested for key performance indicators, including cold crushing strength, porosity, bulk density, linear shrinkage, thermal shock resistance, and refractoriness. Ipokia I exhibited superior mechanical and thermal performance, recording a cold crushing strength of 16.8 MPa, porosity of 24.6%, bulk density of 2.20 g/cm^3, and refractoriness of 1500 °C, while Ipokia II produced 12.4 MPa, 28.3%, 2.08 g/cm^3, and 1450 °C respectively. Both materials demonstrated dimensional stability and durability under repeated thermal cycling, indicating their suitability for medium- and high-temperature furnace applications. Although industrial-scale validation was not conducted, the findings confirm the potential of Ipokia clays as viable raw materials for refractory brick production. The study recommends their adoption for commercial manufacturing to reduce dependence on imported refractories, promote local content utilization, and support economic development.

Keywords: Refractory Bricks; Indigenous clay; Cold Crushing Strength; Thermal performance; Industrial Applications

1. Introduction

Refractory materials are essential components in high-temperature industrial applications such as metal smelting, cement production, glass manufacturing, and petrochemical processing, where they act as thermal barriers and structural supports under severe heat and chemical stress [1, 2]. These materials are broadly categorized into clay-based and non-clay refractories. Non-clay refractories include expensive engineered ceramics like alumina, zirconia, silicon carbide, and magnetite, whereas fireclay refractories remain cost-effective and widely used in industry. Standard fireclay refractories are expected to maintain plasticity within 24–26%, exhibit firing shrinkage of 6–8%, and withstand temperatures of at least 1500 °C without structural failure [3]. Despite a growing demand for refractory products in Nigeria, the nation's capacity to manufacture them locally is limited, resulting in a strong dependence on imported products. Between 1999 and 2012, import expenditure increased from ₦2.27 billion to ₦36.2 billion, indicating a significant economic outflow and reliance on foreign supply [4, 5]. This situation persists even though abundant clay deposits with proven refractory potential exist within the country [5].

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Clay deposits in Southwestern Nigeria, particularly in the Ipokia axis of Ogun State, represent an untapped resource for the innovative processing of low-cost refractory bricks that could replace imported alternatives. However, limited scientific data exist on the mineralogical composition and thermo-mechanical performance of these clays. This research explores the processing and characterization of refractory bricks derived from locally sourced Ipokia clay, focusing on evaluating its suitability for industrial furnace linings. The study assesses the viability of the clay for refractory brick development, determines its chemical constituents, and examines critical performance indicators such as porosity, density, shrinkage, thermal resistance, and mechanical strength. Outcomes are benchmarked against international refractory standards to establish its application potential.

The relevance of this work lies in reducing reliance on foreign refractory products, conserving national revenue, and promoting industrial independence through the strategic use of domestic raw materials. By demonstrating viable innovative processing of refractory bricks from local clay, the research supports sustainable industrial growth, encourages job creation, and contributes to economic advancement in Nigeria.

2. Theoretical framework

2.1. Refractory Materials

Refractory materials constitute a vital class of industrial engineering materials valued for their exceptional thermal endurance and resistance to degradation under extreme temperature conditions. They play an essential role in high-temperature operations in steel production, cement processing, ceramics manufacturing, petrochemical refining, and glass melting industries [6]. The primary function of these materials is to retain mechanical strength and structural stability while resisting thermal shock, chemical attack, and mechanical wear. The term "refractory" originates from the Latin word *refractarius*, meaning *resistant or stubborn*, a term that aptly reflects their capability to withstand severe heat without deformation or failure [8]. ASTM C71 defines refractory materials as "non-metallic substances possessing chemical and physical properties that make them suitable for environments exceeding 538 °C" [3]. In industrial systems, refractories act as protective linings in furnaces, kilns, incinerators, reactors, boilers, and other thermal equipment, providing thermal insulation and ensuring safe containment of heat-intensive processes [9].

Refractories are generally grouped into clay-based and non–clay-based categories. The non–clay-based category includes advanced ceramics such as alumina (Al_2O_3), zirconia (ZrO_2), magnesia (MgO), silicon carbide (SiC), and graphite, which possess superior heat-resisting capabilities but are often expensive and not easily accessible in developing nations [10]. Clay-based refractories, particularly those derived from naturally occurring fireclays alumino-silicate minerals—are more economical and widely applied due to their availability, plasticity during shaping, and sufficiently high melting temperatures [11]. In countries such as Nigeria, the high market price and import dependence associated with non–clay-based refractories have intensified efforts to explore local clay deposits for industrial refractory fabrication. Although numerous clay reserves are found across the country, only a limited number have been rigorously tested or characterized for high-temperature applications [12]. The inadequate level of local research and commercialization has driven continued dependence on imported refractory products. For instance, in 2012 alone, Nigeria spent over ₦36.2 billion on refractory imports to sustain operations in metallurgical and petrochemical facilities [4], revealing significant capital flight and underutilization of abundant local resources. Fireclay refractories, when appropriately processed, can achieve refractoriness values above 1500 °C, demonstrate thermal shock resistance, and exhibit satisfactory strength, but their performance depends largely on clay mineralogy, processing method, and firing temperature [13]. Therefore, scientific evaluation of locally available clays such as those in Ipokia, Ogun State is essential to determine their suitability for industrial high-temperature applications.

This study is anchored on the proposition that innovative processing and optimization of refractory bricks from locally sourced clay deposits such as Ipokia clay can serve as a cost-effective and sustainable pathway toward reducing import dependence. Accordingly, this theoretical review synthesizes global and regional research on refractory material composition, properties, and performance, focusing specifically on clay-based alternatives for furnace lining and other high-temperature engineering systems.

2.2. Test for moisture content of molding mass

The determination of moisture content in the molded clay mass follows the ASTM C72-76 standard, which outlines the procedure for water content and sieve analysis of refractory materials. Approximately 50 g of clay sample is used, and care is taken to obtain the sample quickly to prevent moisture loss before measurement. The sample mass is recorded to the nearest 0.1 g and subsequently dried in an oven at 105–110 °C for about three hours. After drying, the final mass is recorded, and the moisture content is computed as a percentage to the nearest 0.1%, as described by [14] using Equation (1).

Thus,

$$\text{Moisture content} = \frac{M_w - M_d}{M_w} X\ 100 \quad (1)$$

2.3. Test for apparent porosity

Apparent porosity is determined in accordance with ASTM C20-80a, the standard test method used to evaluate apparent porosity, water absorption, bulk density, and apparent specific gravity of refractory bricks by boiling water saturation. An alternative approach involves evacuating the samples in a vacuum desiccator followed by impregnation with paraffin [15]. After recording the dry mass of the brick (W_d), the saturated mass after soaking (W_s), and the suspended mass when immersed in water (W_a), apparent porosity (Pa) is evaluated using Equation (2).

$$\text{Apparent Porosity (Pa)} = \frac{W_a - W_d}{W_a - W_s} X\ 100 \quad (2)$$

2.4. Bulk density test

Bulk density is evaluated alongside the apparent porosity using the same mass measurements obtained in the previous test, following ASTM C20 procedures. Bulk density is directly related to the processing technique and compactness of the refractory sample [28]. The bulk density (BD) of the bricks is computed using Equation (3).

$$BD = \frac{W_d}{W_a - W_s} \quad (3)$$

2.5. Test for cold crushing strength

The cold crushing strength (CCS) test is conducted following ASTM C-93-67 (reapproved in 1977) and ASTM C133-97 [16]. The test utilizes a compressive strength testing machine—either mechanical or hydraulic—with a minimum sensitivity of 89 N, capable of loading up to 67 kN. A dial-type micrometer is used to measure the deformation of the sample during loading. The cold crushing strength is computed using Equation (4).

$$CCS = \frac{W}{A} \quad (4)$$

2.6. Test for linear shrinkage

Linear shrinkage is assessed by comparing the dimensions of the unfired (green) bricks with those of the fired bricks after thermal treatment [17]. It is expressed as a percentage, indicating dimensional reduction due to firing and sintering effects, and calculated using Equation (5).

$$\text{Linear shrinkage} = \frac{l_g - l_f}{l_g} X\ 100 \quad (5)$$

2.7. Application of Refractory Bricks

Refractory bricks serve as primary protective linings in high-temperature industrial equipment such as steel and iron furnaces, cement kilns, glass melting units, ceramic kilns, chemical reactors, waste incinerators, sugar refinery furnaces, and power generation facilities [18]. They are applied in thermal containment structures, insulation units, recuperators, regenerator chambers, and heat-treatment systems to ensure thermal efficiency and protect structural components from direct heat exposure. Refractory clays typically possess desirable characteristics such as low thermal conductivity, low thermal expansion, moderate density, and limited slag penetration [19]. Owing to the difficulty in producing closed-cell pore structures within ceramics containing high void fractions, these materials inherently remain open-porous systems [20]. Thus, refractory bricks are essential for confining hot combustion zones, providing thermal insulation, and shielding furnace walls and mechanical assemblies from excessive temperature loads [21].

3. Materials and method

The primary material utilized in this study was locally sourced clay collected from three different sites within Ipokia Local Government Area of Ogun State, Southwestern Nigeria. The clay was excavated at a depth of approximately 1.5

meters, consistent with established sampling depth recommendations [22]. Distilled water obtained locally was used during mixing and specimen preparation (see Figures 2 and 3). Experimental work was carried out using equipment accessed from the Nigerian Building and Road Research Institute (NBRRI) Jos Zonal Office, Abubakar Tafawa Balewa University, Bauchi, and Ahmadu Bello University, Zaria. Major equipment included a Universal Testing Machine (Model S12V02, 1000 kN capacity), an X-Ray Spectrometer (XRS) for elemental analysis, an electric oven (Model 10-D1390/10, max. 300 °C), a kerosene-fired kiln (max. 1700 °C), a precision digital balance, 50 × 50 × 50 mm brick moulds, and a manual hydraulic press (Carver Inc., Model 4751-3, 400 kN capacity).

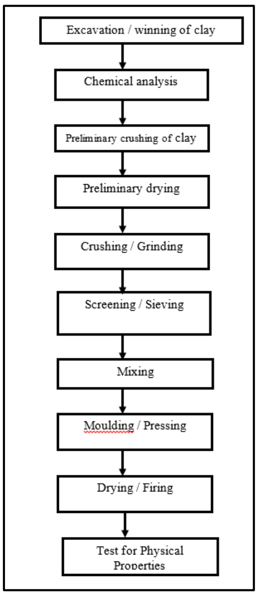

Figure 1: Production Flow Chart of the bricks

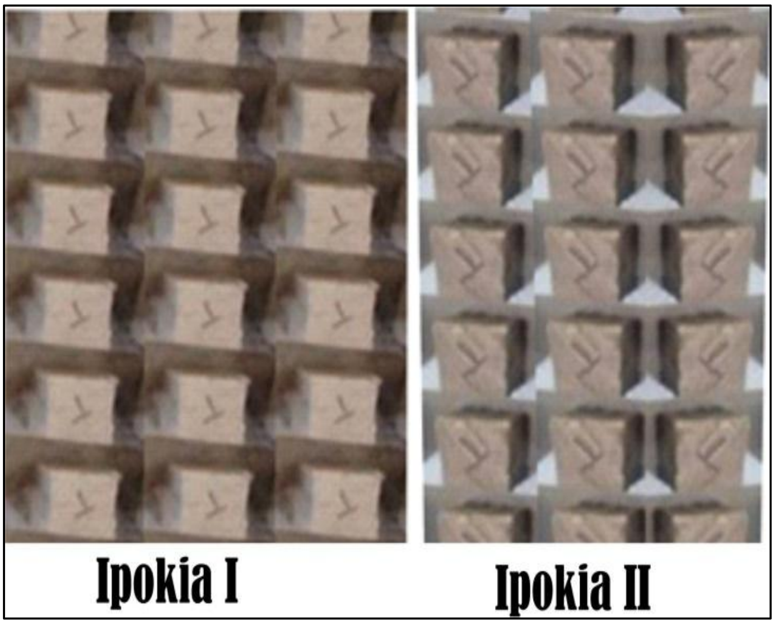

Figure 2: Cured Developed Bricks used for Test

Figure 3: Mould used in production of bricks (50mm x 50mm**)**

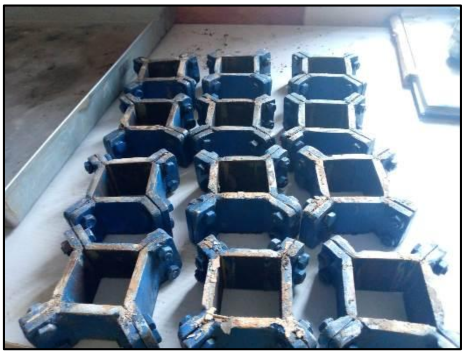

Figure 4: Developed Brick from Ipokia I and Ipokia

The clay samples were sun-dried, crushed manually, pulverized, and sieved through a 425 µm mesh. Chemical composition was determined using an X-ray spectrometer following the procedure outlined in [23]. Moisture content determination followed the method specified in [24]. Refractory bricks of dimensions 50 × 50 × 50 mm (Figure 4) were compacted using a hydraulic press (1000 kN capacity), air-dried, oven-dried at 110 °C, and subsequently fired in a kerosene kiln at a maximum temperature of 1700 °C. The produced specimens were then subjected to standard characterization tests, including apparent porosity and bulk density [25], fired linear shrinkage [26], loss on ignition [27], and cold crushing strength [16]. Thermal shock resistance was evaluated through multiple heating and quenching cycles [28], while refractoriness was determined using the pyrometric cone equivalent method [29]. These procedures provided a comprehensive assessment of the chemical, thermal, and mechanical suitability of Ipokia clay for refractory brick production, as summarized in the flow chart (Figure 1).

Figure 5: Lumps of Ipokia I Clay

Figure 6 Lumps of Ipokia II Clay

4. Results and discussion

The chemical composition analysis presented in Figure 7 shows that the clays obtained from Ipokia I and Ipokia II contain appreciable amounts of alumina (33.85% and 29.0%) and silica (57.89% and 62.46%), which fall within the acceptable range specified by ASTM standards for clay-based refractory materials. These oxides are responsible for conferring thermal stability, refractoriness, and load-bearing strength. Iron oxide contents (1.42% and 1.43%) also meet recommended limits, contributing to improved structural strength and heat tolerance. The level of calcium oxide observed in Ipokia I (1.08%) is within the classification for high-melting clays, while that of Ipokia II (0.055%)—although lower—is still suitable for clay refractory production. Magnesium oxide contents (0.50% and 0.04%) categorize both samples as refractory-grade clays, and potassium oxide contents (0.80% and 0.70%) remain within permissible limits. Collectively, the chemical profiles confirm that Ipokia clays possess attributes required for producing refractory bricks used in furnaces, kilns, and other high-temperature facilities.

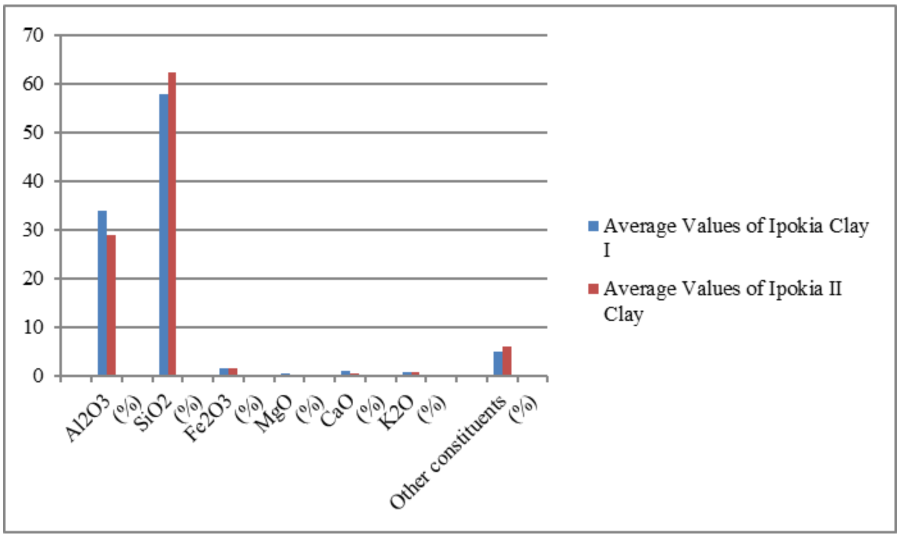

Figure 7 Chemical composition of clay samples from Ipokia I and Ipokia

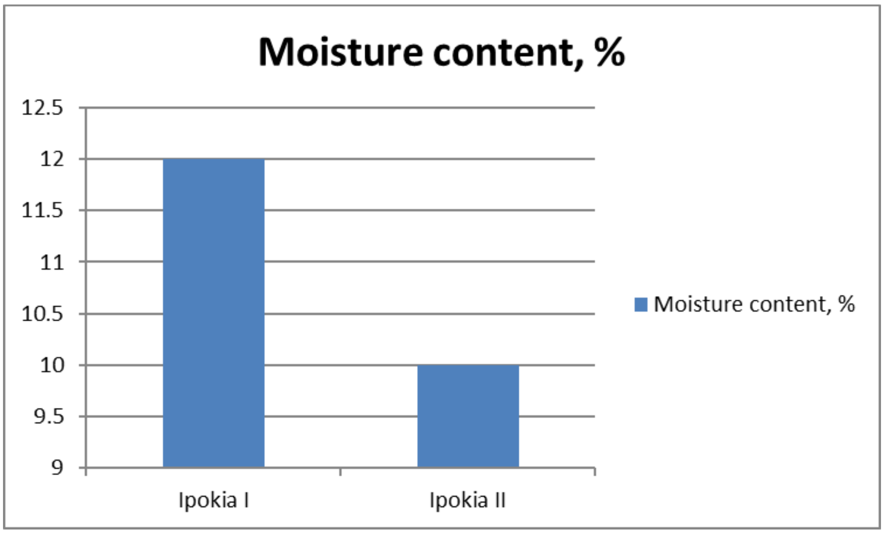

Figure 8 The moisture content in bricks moulded from Ipokia I and Ipokia II clay samples

Moisture content results (Ipokia I: 12%; Ipokia II: 10%), presented in Figure 8, lie within the ASTM C20 (2015) recommended moisture range (1–13%) for clay-based refractories and are consistent with values reported in literature [30]. Moisture content influences molding behavior and affects porosity and shrinkage since increased moisture enhances plasticity and contributes to the formation of pores during firing [31]. Suitable moisture levels improve the molding process and working properties of the clay [32, 37], which aligns with research establishing moisture as a key factor in developing sufficient green strength and shaping stability [15]. The recorded moisture content values therefore validate that Ipokia clays can be efficiently processed into refractory bricks while maintaining acceptable forming and performance characteristics.

Fired linear shrinkage data (Figure 9) shows shrinkage values of 6.40% for Ipokia I and 4.60% for Ipokia II, both within the internationally accepted 2–10% range and compliant with ASTM C179 [35]. Shrinkage reflects the dimensional stability of clay during firing and determines resistance to cracking and warping [34]. Values within this interval are considered optimal for maintaining shape consistency and minimizing thermal expansion-related cracking [17]. Shrinkage is closely related to moisture levels and pore formation during firing [31, 33]. The recorded shrinkage values confirm that both clay samples have stable firing behavior, reinforcing their reliability for refractory brick production.

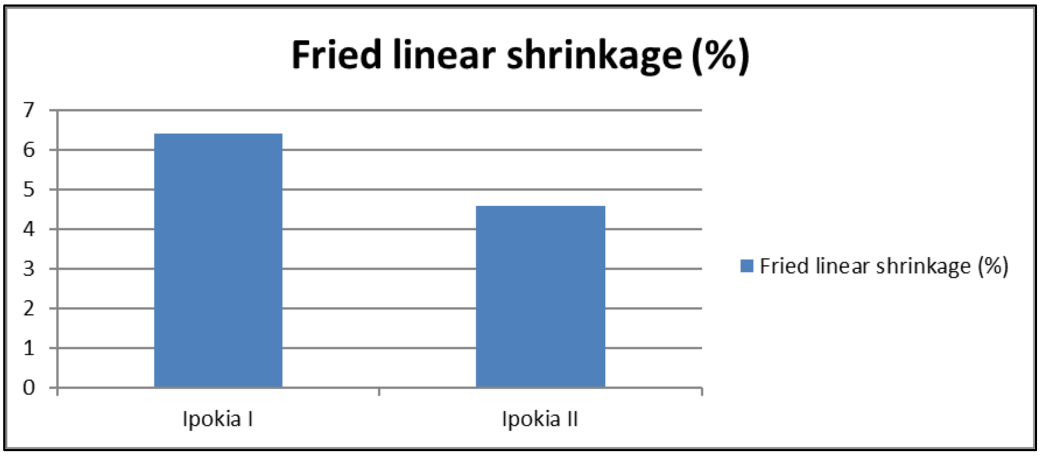

Figure 9 The fired linear shrinkage of bricks moulded from Ipokia I and Ipokia II clay samples

The apparent porosity of Ipokia I (24%) and Ipokia II (22%), illustrated in Figure 10, falls within the acceptable international range of 20–30% for refractory materials [30, 31]. Porosity determines the ability of molten slag or gases to penetrate refractory bricks and affects their durability. Lower porosity improves service life, whereas moderate porosity improves thermal insulation [33, 36]. Since porosity also affects water absorption and shrinkage, the obtained results aligned with ASTM C20 [25] demonstrate that Ipokia clays yield refractory bricks with balanced permeability, insulation, and mechanical stability.

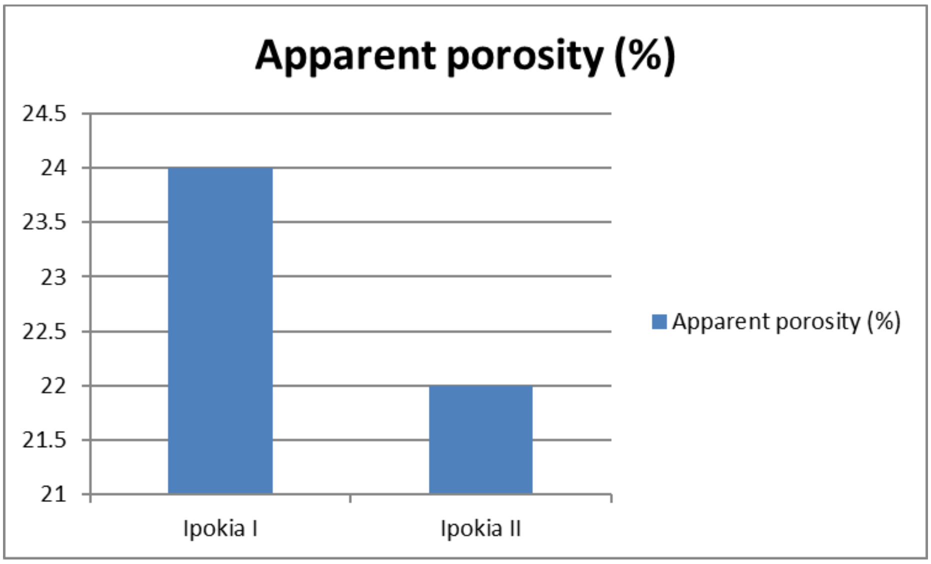

Figure 10 The Apparent porosity of bricks moulded from Ipokia I and Ipokia II clay samples

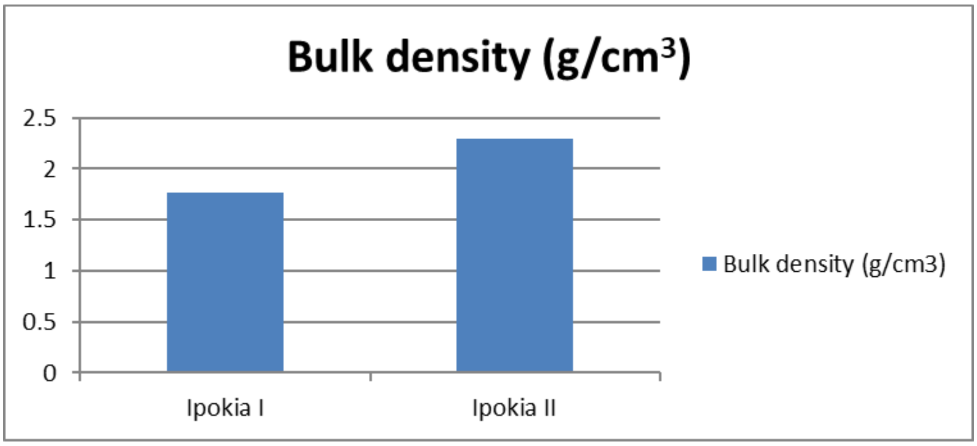

Figure 11 The Bulk density of bricks moulded from Ipokia I and Ipokia II clay samples

Bulk density values obtained (Ipokia I: 1.76 g/cm^3; Ipokia II: 2.30 g/cm^3), presented in Figure 11, compare favorably with the recommended density range for refractory clays (1.71–2.80 g/cm^3) [31]. Ipokia II meets the ASTM C134 [27] standard (2.20–2.80 g/cm^3), making it ideal for heavy-duty service environments, whereas Ipokia I though slightly lower, is better suited for insulation applications due to its higher porosity. These results suggest that Ipokia I may serve as an insulating refractory, while Ipokia II is suitable for high-load and high-temperature processes.

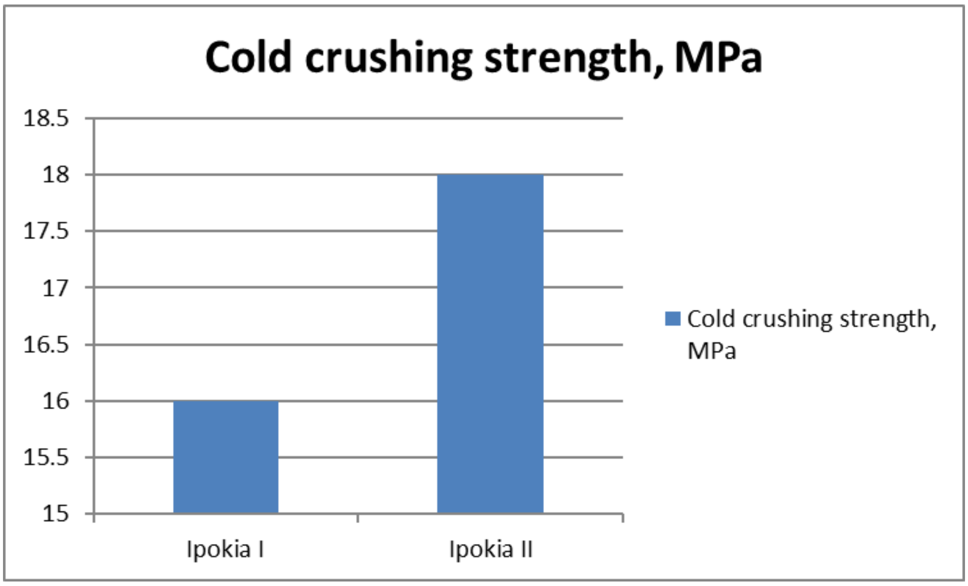

Figure 12 The cold crushing strength of bricks moulded from Ipokia I and Ipokia II clay samples

Cold crushing strength (CCS) values of 16 MPa and 18 MPa for Ipokia I and Ipokia II, respectively (Figure 12), exceed the ASTM C133-97 [16] minimum requirement of 15 MPa. The impressive CCS values may be attributed to the significant silica content, which improves mechanical resistance [30]. Proper firing cycles also contribute to enhanced integrity and handling durability [31]. Both clay types therefore meet industrial strength requirements, confirming their usability in high-temperature refractory systems.

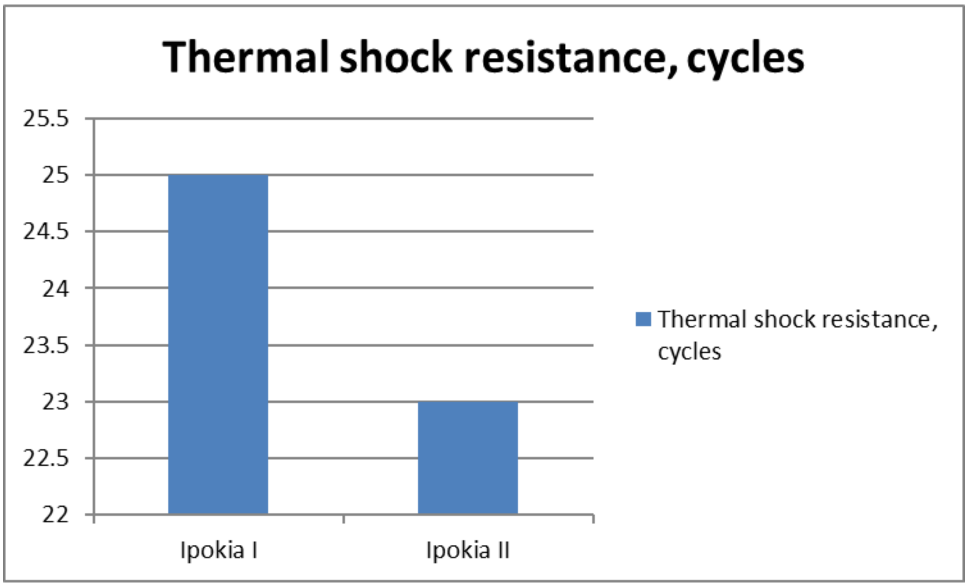

Figure 13 The thermal shock resistance of bricks moulded from Ipokia I and Ipokia II clay samples

Thermal shock resistance values (Ipokia I: 25 cycles; Ipokia II: 23 cycles), within the acceptable standard of 20–30 cycles [31], satisfy ASTM C1171 [25]. Materials in this category are rated as having *good* thermal shock resistance [30]. The results agree with studies such as [39, 40], indicating that the bricks can maintain structure despite rapid temperature fluctuations—an essential quality for furnace linings and high-temperature equipment.

The loss on ignition (LOI) values (Figure 14) for Ipokia I (15%) and Ipokia II (13%) fall within the recommended 12–15% range [41] and comply with ASTM C24 [28]. LOI reflects the removal of volatile materials during firing and indicates structural stability and appropriate clay composition for high-temperature use.

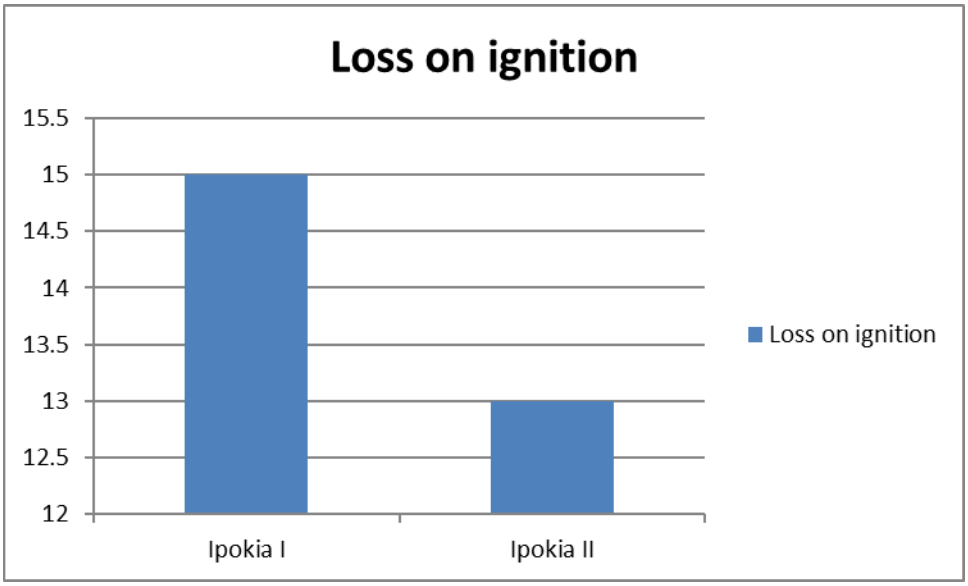

Figure 14 The loss on ignition of bricks moulded from Ipokia I and Ipokia II clay samples

Refractoriness results in Figure 15 show that Ipokia I withstands temperatures up to 1500 °C, meeting the ASTM C71 [3] fireclay refractory standard (1500–1750 °C). Ipokia II records refractoriness of 1200 °C, making it suitable for moderate-temperature environments. The reduced refractoriness of Ipokia II may be linked to its slightly higher silica content, which affects melting behavior. Ipokia I is therefore appropriate for furnace and thermal unit linings, while Ipokia II is best suited for moderate-temperature applications such as kiln walls.

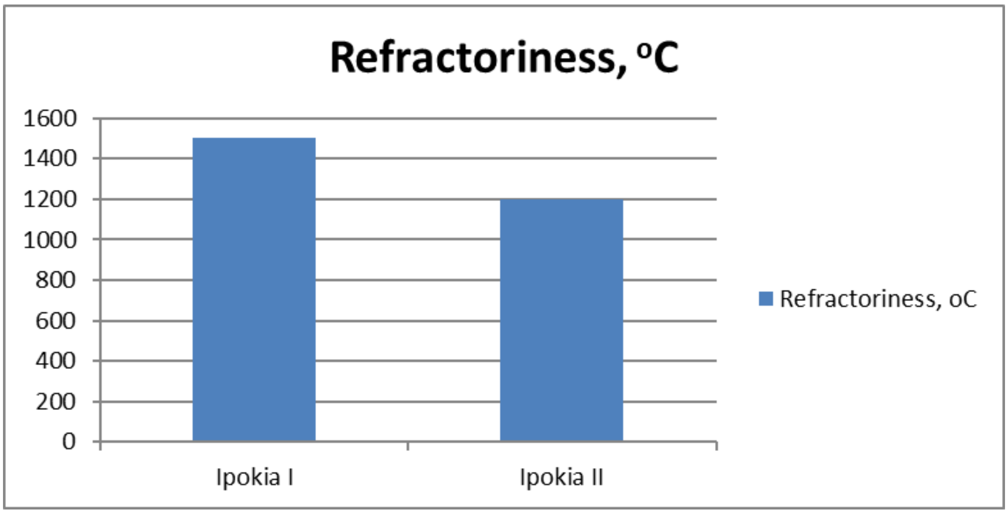

Figure 15 The refractoriness of bricks molded from Ipokia I and Ipokia II clay samples

Table 1 International standard for physical properties with Ipokia average values

Properties	Standard Value	Value	
		Ipokia I	Ipokia II
Fried linear shrinkage (%)	2-10	6.4	4.6
Apparent porosity (%)	20-30	24	22
Bulk density (g/cm^3)	2.2-2.80	1.76	2.3
Cold crushing strength, MPa	15.0 min	16	18
Thermal shock 6resistance, cycles	20-30	25	23
Refractoriness, ^{o}C	1500-1750	1500	1200
Moisture content, %	1-13	12	10
Loss on ignition	12-15	15	13

5. Conclusion

This study successfully established the potential of locally sourced clays from Southwestern Nigeria for the innovative processing of refractory bricks suitable for industrial furnace lining and other high-temperature applications. Among the tested samples, the clay with higher alumina composition (33.85%) exhibited excellent thermal endurance, maintaining structural integrity up to 1500 °C, and was therefore classified as suitable for high-temperature furnaces. Conversely, the clay with slightly lower alumina content (29%) demonstrated effective performance up to 1200 °C, making it ideal for moderate-heat applications such as kiln and furnace wall linings. Both clay types satisfied international benchmark standards for critical refractory parameters such as apparent porosity, linear shrinkage, cold crushing strength, and thermal shock resistance. However, minor adjustments are recommended to improve bulk density in specific formulations for enhanced mechanical strength. Overall, the findings underscore the viability of utilizing indigenous clays in Southwestern Nigeria to produce durable, high-quality refractory bricks—offering a sustainable, cost-efficient substitute for imported materials while fostering industrial self-reliance and economic development through local resource utilization.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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