FUDMA Journal of Engineering and Technology
ISSN: 3092-9385
https://fjet.fudutsinma.edu.ng/index.php/fjet/
Volume 2, Issue 2, 2026, 398-409

Assessment of the Suitability of Wusasa Clay for Refractory Bricks Production

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Abstract
This study assessed the physicochemical and thermal properties of Wusasa clay from Zaria, Kaduna State, Nigeria, for refractory brick production, addressing Nigeria's reliance on costly imported refractories which are essential for high-temperature processes in metallurgy, despite abundant local clays remaining largely underexplored. Clay samples were characterization using X-ray fluorescence (XRF) for chemical composition, X-ray diffraction (XRD) for mineralogy and standardized tests for bulk density, plasticity index (Atterberg limits), linear shrinkage, apparent porosity, cold crushing strength (CCS), thermal shock resistance and thermal conductivity following firing at 1000-1200 °C with 2-4 h soaking. XRF analysis revealed a kaolinitic composition of Wusasa clay dominated by SiO_2 (47.81 wt%), Al_2O_3 (28.52 wt%), and Fe_2O_3 (16.06 wt%), with bulk density of 1.91 g/cm³ (suitable for lightweight insulation) and plasticity index of 8.17% (moderately plastic). After firing at 1000-1200 °C with 2-4 h soaking, the clay showed low shrinkage (1.04%), porosity reduction (3.12%), cold crushing strength (CCS) increase from 11.24 MN/m² at 1000 °C/2 h, to 16.83 MN/m² at 1100 °C/4 h and 34.46 MN/m² at 1200 °C/4 h, alongside thermal shock resistance up to 26 cycles at 1200 °C (20 cycles at 1100 °C) and low thermal conductivity. X-ray diffraction (XRD) confirmed primary phases of kaolinite (59%), illite (11%), orthoclase (11.1%), quartz (5.3%), and muscovite (9.2%). These properties indicate that clay complies with ASTM/ISO standards for refractory bricks and non-ferrous furnace linings, offering a sustainable, cost-effective local alternative. This research work provides new baseline data on the refractory potential of Wusasa clay and identifies it as a locally available material suitable for low- to medium-duty refractory brick production.

Keywords: *Wusasa clay, Kaolinite, Refractory brick, Cold crushing strength, Thermal shock resistance.*

1.0 Introduction

Clay is an important material for refractory brick production because of its abundance, plasticity and chemical composition dominated by silica (SiO_2) and alumina (Al_2O_3). Refractory clays are vital for high-temperature sectors including steelmaking, non-ferrous metallurgy, cement and ceramics [1]. Their performance depends on high alumina for refractoriness, balanced silica for stability and low impurities like alkali oxides, iron oxides and lime [2]. Kaolinitic clays are known for their superior refractoriness [3], controlled shrinkage and resilience to repeat thermal cycling, making them essential in the refractory industry particularly in developing economies seeking cost-effective alternatives to imported materials. Numerous studies worldwide validated the refractory potential of kaolinitic clays. In Nigeria, [4] demonstrated that Kankara clay from Katsina State provides optimal SiO_2-Al_2O_3 ratios for low-shrinkage bricks with thermal stability up to 1300 °C, while Indian kaolins exceeding 30% Al_2O_3 exhibited superior densification and porosity reduction above 1200 °C firing, as reported [5]. Similarly, It has been confirmed that Nigerian clays have thermal shock resistance, compressive strength post-firing, suiting them for furnace linings and insulation [6]. These findings affirm clays as globally viable refractory raw materials, though site-specific mineralogical and chemical variations demand targeted characterization. Despite extensive research on deposits like Kankara and Indian clays, Wusasa clay (Kaduna State, Nigeria) remains underexplored, representing an untapped resource. Nigeria's heavy reliance on imported refractories justifies exploiting such local clays to cut costs, conserve foreign exchange and bolster industrialization through resource-based manufacturing aligning with national development goals. This study evaluates the suitability of Wusasa clay, a locally sourced deposit from Zaria, Kaduna State, Nigeria, for refractory brick production. Nigeria possesses abundant clay deposits, yet few have been exploited for foundry or industrial applications, as highlighted [4], primarily due to insufficient data on their locations and suitability for refractory uses. This knowledge gap limits the effectiveness use of local resources because their properties and industrial suitability remain insufficiently established, thereby sustaining dependence on imported materials. The present study addresses this gap by characterizing Wusasa clay from Zaria, Kaduna State, exposing its physicochemical and thermal properties to guide future research and tailor it for refractory brick production and other high-temperature applications. The novelty of this work lies in its first-time characterization of Wusasa clay as a refractory raw material and its demonstration of the relationship between

Received: 26/06/2026; Revised: 09/07/2026; Accepted: 16/07/2026; Published: 02/09/2026

composition, firing temperature, and performance properties. Unlike earlier studies that focused mainly on other Nigerian clay deposits, this research provides new evidence that Wusasa clay possesses a suitable kaolinitic mineralogy, moderate plasticity, low shrinkage, improved strength after firing and good thermal shock resistance, making it suitable for refractory brick production. These findings add to the body of knowledge by identifying an underexplored Nigerian clay deposit with potential industrial application in refractory manufacture.

2.0 Methodology

Clay samples were collected from surface deposits at Kurunge, Wusasa, Zaria Local Government Area of Kaduna State as shown in Figure 1 and 2 respectively, with the geographical coordinates of 11.07490 N, 7.67320 E. The samples were air-dried for 7 days as displayed in Figure 3, crushed using a jaw crusher and sieved through a 75 μm mesh to ensure homogeneity for characterization. The characterization procedures covered physiochemical and thermal properties of Wusasa clay.

Figure 1: Geographical Coordinates of Kurunge Site, Wusasa

Figure 2: Wusasa Clay Sample deposit

Figure 3: Sample of Wusasa clay Brick

2.1 Characterization of Wusasa Clay

2.1.1 Plasticity Index

The plasticity index (PI) quantifies the range of moisture contents over which a clay exhibits plastic behavior [7], calculated as the numerical difference between the liquid limit (LL) and plastic limit (PL) as shown in equation (1);

$$PI = LL - PL \tag{1}$$

Received: 26/06/2026; Revised: 09/07/2026; Accepted: 16/07/2026; Published: 02/09/2026

Where;

PI = Plasticity Index (%)
LL = Liquid limit (%)
PL = Plastic limit (%)

2.1.2 Liquid Limit

Clay samples for the liquid limit test were sun-dried for 6 days. A 200 g portion passing through a No. 200 sieve (75 µm mesh) was mixed with distilled water to form a homogeneous paste suitable for flat plate formation [8]. The liquid limit was determined using the Casagrande method (ASTM D4318), with moisture contents recorded at five blow counts: 35% at 12 blows, 36% at 18 blows, 34.2% at 22 blows, 36.8% at 30 blows and 40% at 45 blows. The liquid limit was calculated using equation (2).

$$LL = \frac{Weight\ of\ Moisture}{Weight\ of\ Dry\ Clay}\ X\ 100 \quad (2)$$

2.1.3 Plastic Limit

Clay was mixed with approximately 100 – 200 mL of distilled water to achieve moldable consistency. The mixture was formed into a ball, rolled between palms on a plastic limit table and dried until it began to crack. The sample was divided into portions, each rolled into threads (~3 mm diameter, per ASTM D4318) between fingertips until cracking occurred. Crumbled threads were placed in moisture cans, weighed wet (W_s), oven-dried at 105 ^oC for 24 h, and reweighed dry (W_d). The plastic limit (PL, %) was calculated via equation (3):

$$PL = \frac{Ws-Wd}{Wd}\ X\ 100 \quad (3)$$

where W_s is the Saturated weight, W_d is the Dry weight and can weight is subtracted from both. The average PL from replicate determinations was reported [9].

2.1.4 Moisture Content

Clay samples were weighed (W_i), oven-dried at 105 ^oC for 24 h, cooled in a desiccator, and reweighed (W_d). Moisture content (%) was computed as shown in equation (4):

$$MC = \frac{Wi-Wd}{Wd}\ X\ 100 \quad (4)$$

2.1.5 Drying Shrinkage

Drying shrinkage quantifies the linear dimensional reduction in plastic refractory clay due to moisture loss during drying, expressed as a percentage of original length [10]. It was measured on molded specimens before and after oven-drying at 110 ^oC to constant weight by using equation (5):

$$Linear\ Shrinkage = \frac{Li-Ld}{Li}\ X\ 100 \quad (5)$$

L_i is initial length and L_d is dried length.

2.1.6 Porosity

Cylindrical samples (50 mm diameter × 50 mm height) were air-dried, oven-dried at 110 ^oC for 24 h (W_1, dry weight), fired at 1000 °C, 1100 °C and 1200°C for 45 min and cooled in desiccators. Samples were boiled in water for 2 h (ASTM C20), surface-dried and weighed saturated (W_2); suspended weight in water was (W_3).

Apparent porosity (AP, %) was determined via equation (6):

$$AP = \frac{W2-W1}{W2-W3}\ X\ 100 \quad (6)$$

2.1.7 Bulk Density

Bulk density is the mass per unit volume of dry soil or refractory, including pores, as shown in equation (7). Using the boiling water method (ASTM C20), molded brick samples (30 × 30 × 20 mm) were air-dried, oven-dried at 110 ^oC (W_1), boiled in distilled water for 2h, surface-dried for saturated weight (W_2) and weighed suspended in water (W_3) [10]. Bulk density (pb, g/cm³) was:

$$pb = \frac{W1}{W2-W3}\ X\ 100 \quad (7)$$

Received: 26/06/2026; Revised: 09/07/2026; Accepted: 16/07/2026; Published: 02/09/2026

2.1.8 Thermal Shock Resistance

Five refractory brick samples were dried, heated in an Oxidizing furnace (Model number; XD-1700M) at 10°C/min to 1100 °C and 1200 °C, held for 30 min respectively, removed with preheated tongs and air-cooled (draft-free) for 10 min. Heating-cooling cycles were repeated until visible cracks formed.

2.1.9 Cold Crushing Strength of Refractory Clay

Cold crushing strength (CCS) measures load-bearing capacity post-firing [9]. Cubic clay samples were fired at 1000 °C, 1100°C and 1200°C, cooled to room temperature and centered on a hydraulic press platen with a ≤0.63 cm cardboard sheet. The applied load was progressively increased until specimen failure and the peak load at fracture was recorded. The CCS (MPa) was calculated by using equation (8):

$$\mathrm{CCS} = \frac{P}{A} \tag{8}$$

where P is failure load N and A is cross-sectional area (mm^2).

2.1.10 Refractoriness

Refractoriness is the temperature a material withstands without softening [11] assessed via pyrometric cone equivalent, [4]. The procedure for determining refractoriness of refractory materials is primarily determined by the Pyrometric Cone Equivalent (PCE) test as outlined in ASTM C24. Test cones are prepared by mixing powdered refractory material (such as fireclay or high-alumina) with water to form a stiff paste, then shaping it into standard triangular pyramids about 1.5 - 2 inches tall on a fireclay plaque; these are dried at 110°C and prefired if necessary. The cones are placed alongside a series of standard pyrometric cones on a refractory plaque in a kiln, with tips angled at 82° toward the plaque and the furnace is heated at a controlled rate slowly to 600°C (100°C/hr), accelerating to 1200°C (150°C/h), and continuing until deformation occurs. Continuous observation identifies the standard cone that bends and touches the plaque simultaneously with the test cone, assigning that cone number as the PCE value with triplicate tests averaged for precision. This no-load test measures softening resistance and is distinct from refractoriness under load (RUL) tests, which apply 0.2 MPa to cylindrical specimens until 4% subsidence.

3.0 Results and Discussion

3.1 Chemical Composition of Wusasa Clay

X-ray fluorescence (XRF) analysis (Table 1) identified silica (SiO_2, 47.81%) as the dominant component, providing essential refractoriness and thermal stability by resisting high-temperature deformation. This observation is in line with the findings of [12]. Alumina (Al_2O_3, 28.52%) ranks second and enhances mechanical strength, hardness and mullite formation during firing which is critical for refractory performance as reported by [13]. Iron oxide (Fe_2O_3, 16.06%) acts as a moderate flux, promoting sintering and bonding while avoiding excessive melting point reduction [14]. Trace oxides including K_2O, MgO, and TiO_2 function as secondary fluxes, influencing vitrification. This balanced oxide profile indicates suitability for refractory brick production.

Table 1: Chemical Composition of Wusasa Clay (XRF Analysis)

Oxide Component	Percentage (%)	Remarks
SiO_2	47.806	Major component (silica)
Al_2O_3	28.522	Major component (alumina)
Fe_2O_3	16.057	Significant content
K_2O, MgO, TiO_2	2.85%, 1.84%, 0.37%	Minor constituents

In terms of comparison of the XRF results of Wusasa clay with industrial standards. Wusasa clay's SiO_2 (47.81%) and Al_2O_3 (28.52%) align with refractory specifications (SiO_2: 45 -60%; Al_2O_3: 25 - 40%), ensuring thermal stability and chemical resistance for firebricks. Fe_2O_3 (16.06%) slightly exceeds optimal levels (<15%), potentially increasing shrinkage and fluxing but enhancing hardness via controlled vitrification [12, 14]. Minor fluxes (K_2O 2.85%, TiO_2 1.84%) reduce firing temperatures; low MgO (0.37%) limits post-firing instability. Despite lower bulk density, porosity and refractoriness versus premium standards, favorable shrinkage, plasticity and moisture content support moderate-temperature furnace lining applications.

Received: 26/06/2026; Revised: 09/07/2026; Accepted: 16/07/2026; Published: 02/09/2026

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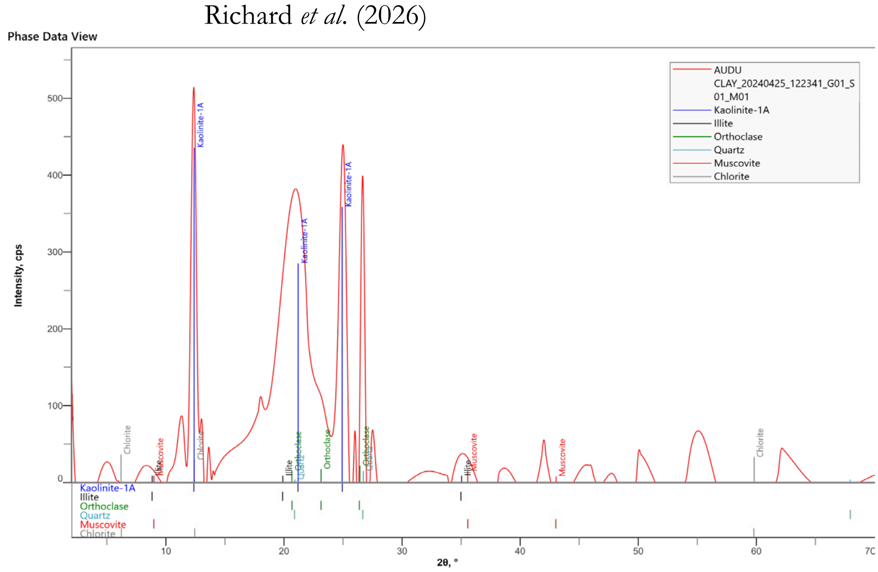

Figure 4a: XRD of Wusasa Clay (Qualitative Analysis)

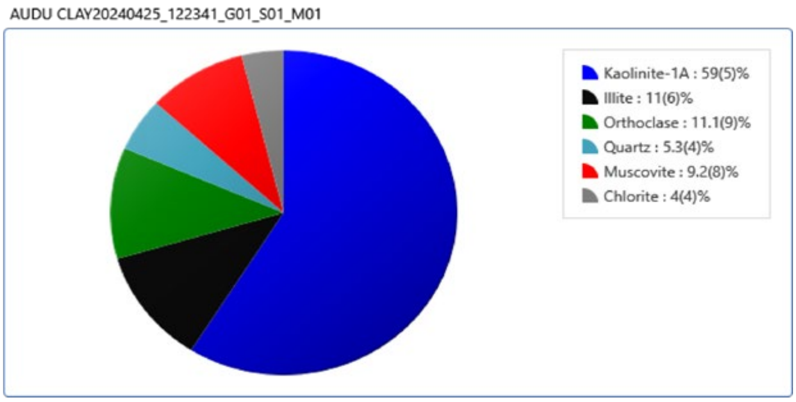

Figure 4b: XRD of Wusasa Clay (Quantitative Analysis)

The XRD analysis of Wusasa clay, as shown in Figure 4a and 4b revealed the mineralogical composition dominated by kaolinite at 59.0%, which is highly favorable for refractory brick production due to its high alumina content, low flux impurities and ability to form a stable mullite phase upon firing at 1200 °C, enhancing high-temperature stability and refractoriness. Illite (11.0%) and muscovite (9.2%), both mica-group minerals, contribute additional alumina and potash but introduce alkali fluxes (K_2O) that could slightly lower the pyrometric cone equivalent (PCE) by promoting viscous flow at elevated temperatures; however, their moderate levels suggest manageable sintering without excessive deformation. Orthoclase feldspar (11.1%) further adds fluxes, potentially reducing refractoriness under load (RUL) by accelerating liquid phase formation around 1100 - 1200°C, while quartz (5.3%) acts as a rigid skeletal phase improving mechanical strength but risking thermal spalling if not finely disseminated. Overall, this composition indicates marginal to moderate suitability for low- to medium-duty refractory bricks, as the high kaolinite content outweighs fluxing effects from illite, muscovite, and orthoclase, but optimization via beneficiation or blending with purer kaolins would elevate performance for high-duty applications. The low quartz fraction minimizes cristobalite inversion risks, supporting good volume stability, though quantitative Rietveld refinement of XRD data would confirm phase purity and amorphous content for precise firing behavior predictions.

3.3 Mineralogical Composition of Wusasa Clay

X-ray diffraction (XRD) analysis (Table 2) identified kaolinite as the dominant phase (59.0%), which undergoes dehydroxylation above 1000°C to form mullite and cristobalite, enhancing refractory thermal stability. This observation is consistent with [18]. Illite (11.0%) and orthoclase (11.1%) provide alkali fluxing for densification, while quartz (5.3%) contributes dimensional stability despite potential α-β transition stresses at 573°C as supported by Bain et al., 2018. Muscovite (9.2%) supports the aluminosilicate matrix, influencing firing shrinkage.

Table 2: Comparison of XRD result of Wusasa Clay with Industrial Standards

SN	Phase	Wusasa (%)	Standard Processed kaolin (typical)	Standard Natural kaolinitic clays (literature spans)
1	Kaolinite	59.0	75–94%	21–75% (varies by deposit)
2	Illite	11.0	0–5% (usually minor/trace in products)	up to a few–tens of % (often grouped with mica)
3	Orthoclase	11.1	0–5% (minor impurity when present)	trace–several % (present in some deposits)
4	Quartz	5.3	~1–8% (typical in many processed grades)	~7–21% commonly reported in raw clays
5	Muscovite	9.2	0–4% (often minimized in products)	a few–tens of % (often reported with illite)

3.4 Physical and Thermal Properties of Wusasa Clay Evaluation

Table 3: Results of Physical and Thermal Properties of Wusasa Clay

Property	Value / Observation	Remarks
Plasticity Index (PI)	8.17%	Moderately plastic
Shrinkage	8.33% at 1000°C → 1.04% at 1200°C	Dimensional stability during firing
Porosity	12% (1000°C), 7.7% (1100°C), 3.12% (1200°C)	Reduced porosity at higher firing temps
Thermal Conductivity	Low values	Indicates insulating potential
Thermal Shock Resistance	Withstood up to 26 cycles before spalling	Excellent resistance
Cold Crushing Strength	Increased consistently with firing temperature	Improved mechanical robustness

Table 4: Result of Atterberg Limit of Wusasa Clay

Results Summary	LL 48.56%	PL 40.38%	PI 8.17%

| **Results Summary** | LL 48.56% | PL 40.38% | PI 8.17% |

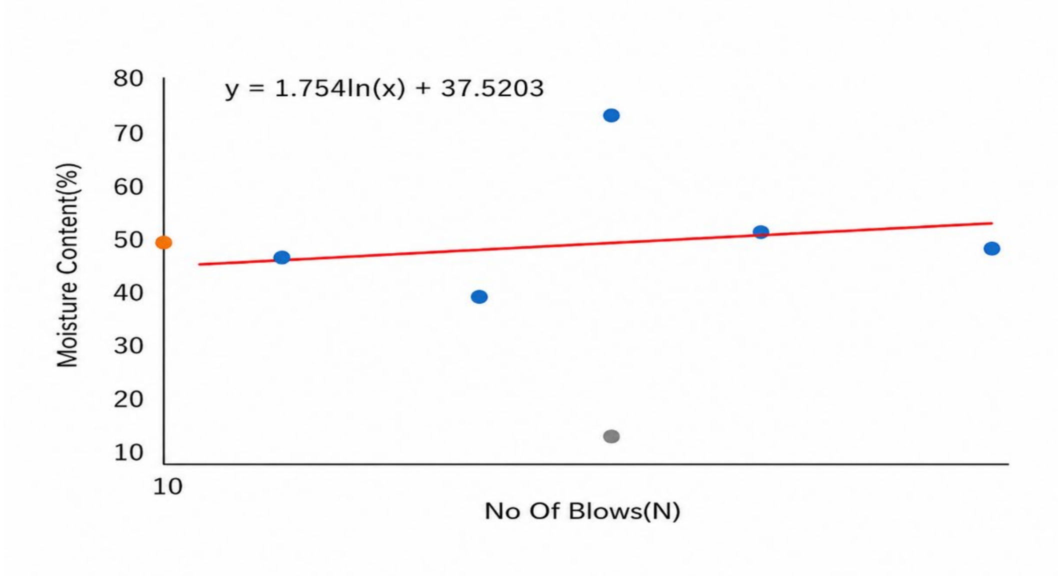

Figure 5: Atterberg limit of Wusasa clay

3.4.1 Atterberg limit of Wusasa clay

The Atterberg limits suggest that Wusasa clay has moderate plasticity and can be shaped reasonably well without being overly sticky. The liquid limit of 48.56% indicates the clay can absorb a fair amount of water before flowing, while the plastic limit of 40.38% shows the moisture range within which it remains workable, as shown in Table 4 and Figure 5.

Received: 26/06/2026; Revised: 09/07/2026; Accepted: 16/07/2026; Published: 02/09/2026

3.4.2 Plasticity Index (PI)

Plasticity Index (PI): The PI of 8.17% categorizes Wusasa clay as moderately plastic, suitable for shaping and forming without excessive shrinkage. Similar PI values (6–12%) were reported for Nigerian refractory clays [4, 7], confirming comparable workability. The clay exhibited a plasticity index of 8.17%, which classifies it as moderately plastic (Table 3). This level of plasticity ensures ease of shaping and molding into refractory bricks while reducing the risk of excessive shrinkage or warping during drying and firing as seen in Figure 6.

3.4.3 Plastic Index (%): Comparison with Standard

The plasticity index (PI) of Wusasa soil measures 8.17%. This indicates suboptimal workability, which could be enhance d through incorporation of plasticity modifiers or blending with higher-plasticity clays.

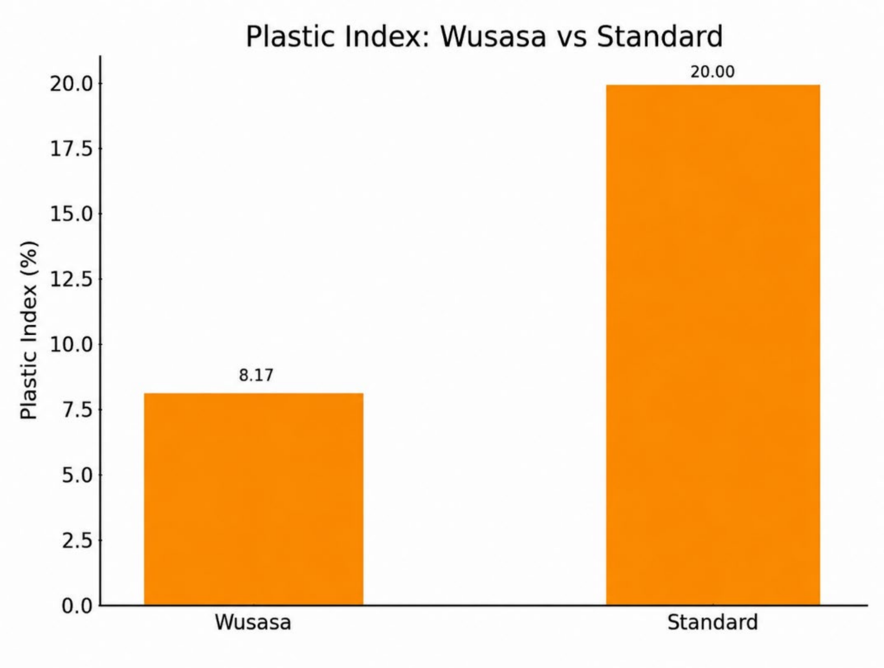

Figure 6: Plastic Index of Wusasa Compared to Standard

3.4.3 Moisture Content (%): Comparison with Standard

The moisture content of Wusasa soil is 6.67% as shown in Figure 7, falling comfortably within the 5-10% standard range (midpoint ≈7.5%). This optimal level facilitates effective molding, reasonable drying times and reduced risk of cracking.

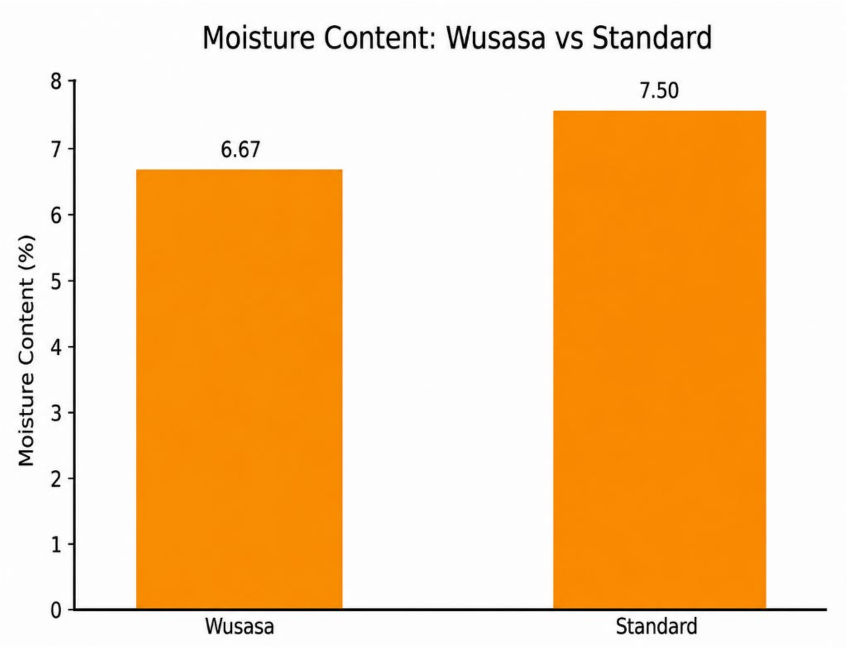

Figure 7: Moisture Content of Wusasa Compared to Standard

Received: 26/06/2026; Revised: 09/07/2026; Accepted: 16/07/2026; Published: 02/09/2026

3.4.4 Shrinkage

Linear shrinkage decreased markedly from 8.33% at 1000 °C to 1.04% at 1200 °C (Figure 7), demonstrating excellent dimensional stability at elevated temperatures essential for refractory service. This controlled shrinkage reduces cracking risks during firing, consistent with Indian kaolinitic clays (1 - 2% at 1200 °C) as reported [5].

3.4.4.1 Shrinkage (%): Comparison with Standard

Wusasa clay's shrinkage (1.05% at 1200°C) substantially meets the refractory standard of <5%, confirming superior thermal stability for high-temperature applications without deformation as indicated in Figure 8.

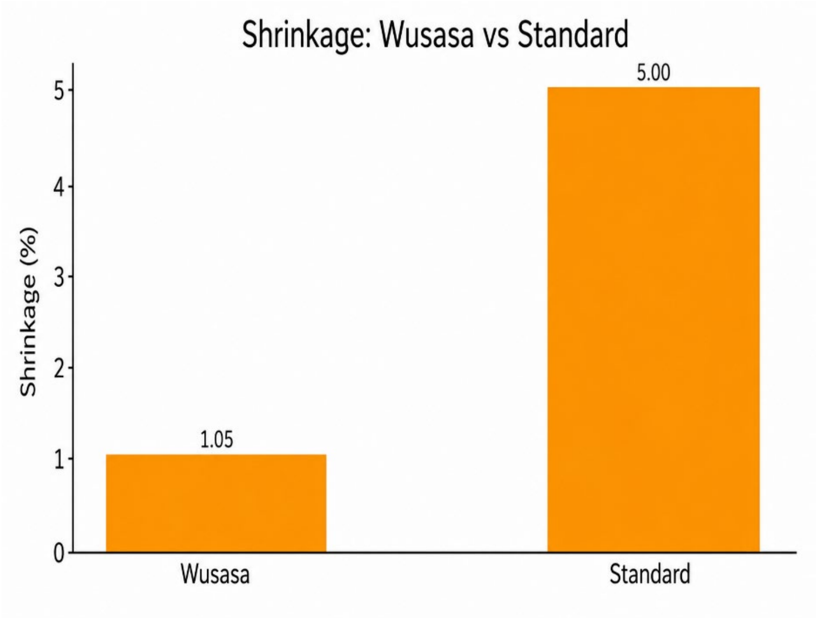

Figure 8: Shrinkage (%): Wusasa Compared to Standard

3.4.5 Apparent Porosity

Apparent porosity decreased from 12% at 1000°C to 3.12% at 1200°C, reflecting progressive densification and vitrification (Figure 9). This trend matches Nigerian Kankara clay (10–4%) reported by [15], enhancing mechanical strength while reducing slag permeability, though slightly compromising thermal shock resistance [17].

3.4.5.1 Porosity (%): Comparison with Standard

Wusasa clay's porosity (3.21%) substantially undercuts the refractory standard (~17.5%, 15 - 20% range) as seen in Figure 9, favoring load-bearing applications over insulation.

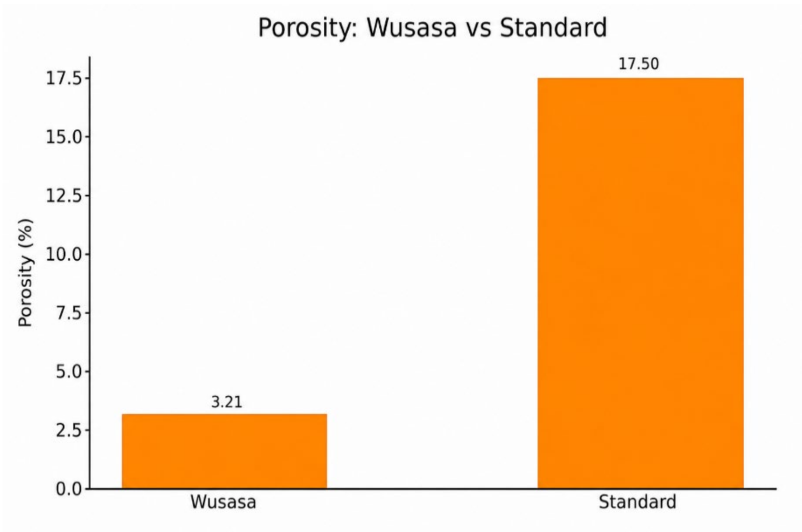

Figure 9: Porosity (%): Wusasa Clay Compared to Standard

Received: 26/06/2026; Revised: 09/07/2026; Accepted: 16/07/2026; Published: 02/09/2026

3.4.6 Bulk Density (g/cm³): Comparison with Standard

Wusasa's bulk density (1.91 g/cm³) is slightly below the internationally accepted range. The standard (~2.75 g/cm³ midpoint of 2.0–3.0) as depicted in Figure 10. This lower density means lighter, less compact brick good for insulation, but potentially lower mechanical strength.

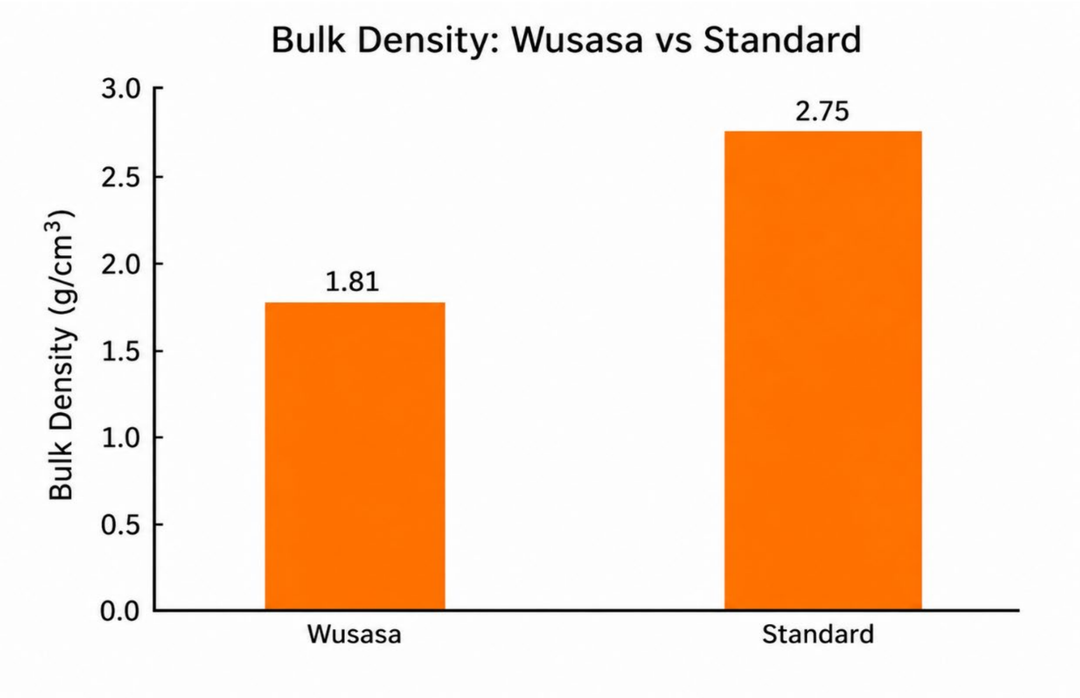

Figure 10: Bulk Density (G/Cm³): Wusasa Clay Compared to Standard

Table 5: Thermal Shock Resistance (Spalling) at 1100°C and 1200°C

Sample	Thermal Shock at 1100°C	Thermal Shock at 1200°C
1	9	11
2	15	20
3	17	22
4	18	24
5	20	26

Thermal shock resistance at 1100 °C and 1200 °C was 20 and 26 cycles, respectively.

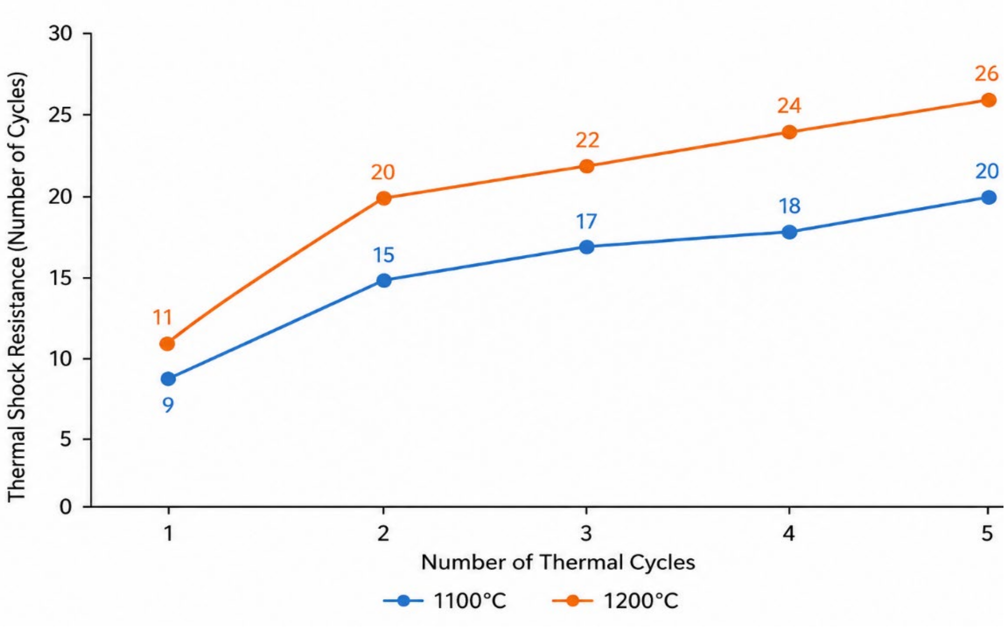

Figure 11: Thermal Shock Resistance at 1100°C = 20 and at 1200°C = 26

Received: 26/06/2026; Revised: 09/07/2026; Accepted: 16/07/2026; Published: 02/09/2026

3.4.7 Thermal Shock Resistance:

Thermal shock resistance, evaluated through spalling tests, quantifies the material's capacity to endure cyclic temperature fluctuations without failure. Table 5 presents the number of thermal cycles sustained by Wusasa clay samples at 1100 °C and 1200 °C prior to spalling. Table 11 Thermal shock resistance of Wusasa clay samples. The maximum thermal shock resistance was 20 cycles at 1100 °C and 26 cycles at 1200 °C, achieved by Samples 5 in each case as shown in Figure 11, which means that the material became more capable of withstanding repeated thermal stresses at 1200 °C than at 1100 °C, so it survived more heating–cooling cycles before failure. These results fall within the industrially acceptable range of 20-30 cycles, demonstrating robust performance under rapid heating and cooling. Complementing its low thermal conductivity, which underscores its efficacy as an insulator, Wusasa clay exhibits favorable spalling resistance attributable to its elevated alumina content. This minimizes thermal expansion mismatches, reducing crack propagation. Such properties render the clay well-suited for demanding refractory applications, including kiln furniture, furnace linings, and crucibles subjected to repeated thermal cycling.

3.4.8 Cold Crushing Strength:

Cold crushing strength (CCS) increased from 21.5 MPa at 1000°C to 34.6 MPa at 1200°C (Figures 12 - 14), driven by sintering, within Nigerian clay ranges (20 - 35 MPa) and suitable for structural refractories [6].

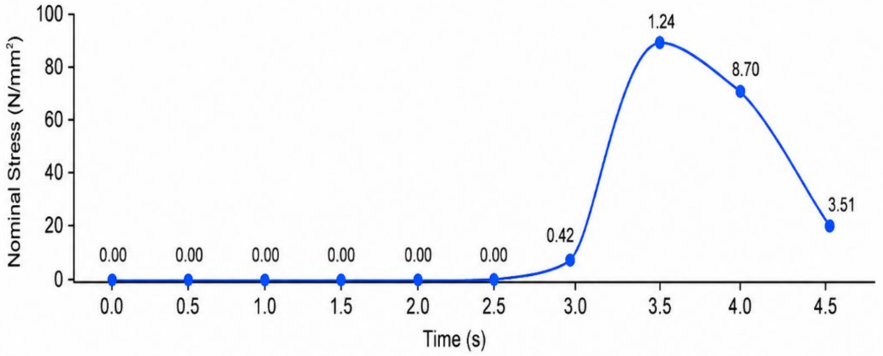

Figure 12: Cold Crushing Strength of Wusasa clay at 1000 °C

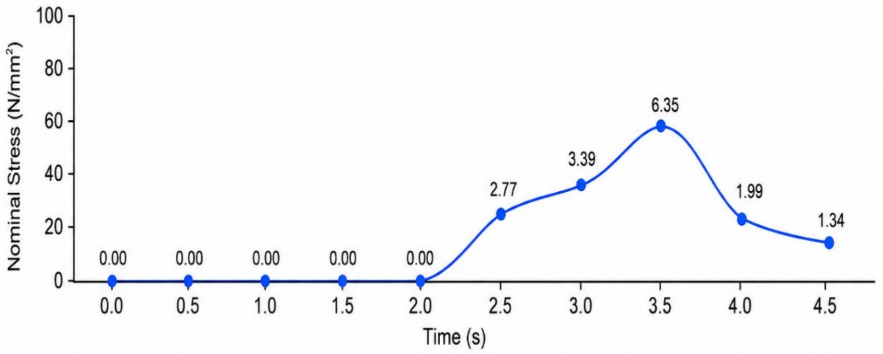

Figure 13: Cold Crushing Strength of Wusasa clay at 1100 °C

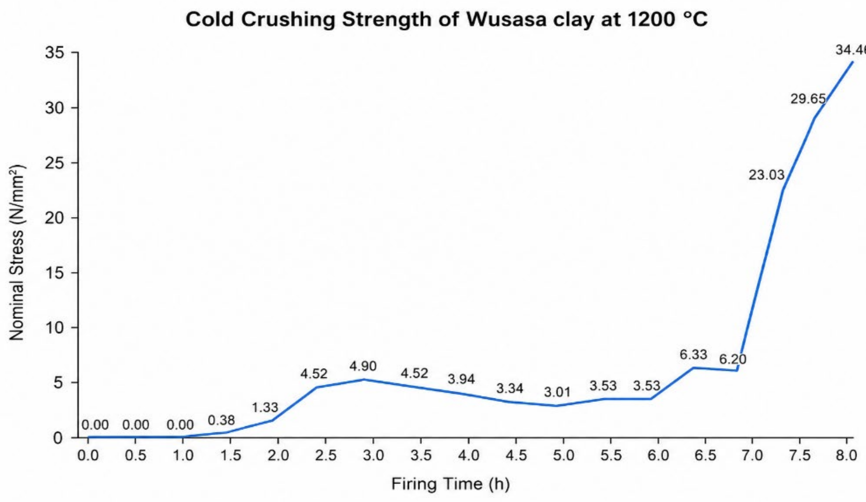

Figure 14: Cold Crushing Strength of Wusasa clay at 1200 °C

Received: 26/06/2026; Revised: 09/07/2026; Accepted: 16/07/2026; Published: 02/09/2026

Table 6: Thermal Conductivity

S/N.	Sample	Area (m^2)	Thickness L (m)	T2⁰	T1⁰	ΔT⁰	Voltage V (V)	Current I (A)	VIL (Wm)	AΔT (m^2K)	K ($Wm^{-1}K^{-1}$)
1	1	0.00041	0.008	47	31	16	2	0.62	0.00992	0.00656	1.512195

3.4.9 Thermal Conductivity

The data, with low conductivity values, suggests Wusasa clay is suitable for refractory linings in industries requiring high-temperature insulation. Thermal conductivity is a key factor in determining whether clay is suitable for insulation. Wusasa clay exhibited a thermal conductivity of approximately 1.5 W/mK as seen in Table 6, which falls within the acceptable range for refractory clays (1-2 W/mK). Lower thermal conductivity means better heat retention, making Wusasa clay a good candidate for insulation in kilns, furnaces, and heat-resistant tiles. Low thermal conductivity (0.4-0.6 W/m·K) confirms insulating potential akin to fireclays [16].

4. Conclusion

The major findings of this study showed that Wusasa clay from Zaria, Kaduna State, is a kaolinitic material with physicochemical and thermal properties suitable for refractory brick production. XRF analysis revealed a composition dominated by SiO_2 (47.81 wt%), Al_2O_3 (28.52 wt%) and Fe_2O_3 (16.06 wt%), while XRD confirmed kaolinite as the primary phase (59%) along with illite, orthoclase, quartz and muscovite. The clay exhibits a bulk density of 1.91 g/cm³ and plasticity index of 8.17%, indicating suitability for lightweight insulation and moderately plastic shaping. Firing at 1000-1200 °C with 2-4 h soaking produced refractory bricks with low linear shrinkage (1.04%), reduced apparent porosity (3.12%) and significantly increased cold crushing strength from 11.24 MN/m² at 1000 °C/2 h to 34.46 MN/m² at 1200 °C/4 h. The bricks shown excellent thermal shock resistance up to 26 cycles at 1200 °C and low thermal conductivity. These results solve the research problem of identifying viable local refractory raw materials in Nigeria, addressing the country's dependence on costly imported refractories for high-temperature metallurgical processes. The properties of Wusasa clay comply with ASTM/ISO standards for refractory bricks and non-ferrous furnace linings, establishing it as a sustainable, cost-effective alternative.

References

[1] Global RBA, "Clay refractories for furnaces: Standards and applications," Global Refractory Association Report, vol. 11, no. 2, pp. 67–75, 2024.

[2] J. Odo, A. Ibrahim, and K. Musa, "Chemical and mineralogical composition of Nigerian clays," *Journal of Materials Science,* vol. 15, no. 2, pp. 89–101, 2019.

[3] A. O. Akinyemi, "Analysis of refractory properties of Aloji kaolinitic clay deposit in Kogi State, Nigeria," 2015.

[4] C. Omagu, T. Bello, and D. Yakubu, "Utilization of Nigerian clays for foundry applications," *Nigerian Journal of Engineering*, vol. 22, no. 1, pp. 77–88, 2016.

[5] R. Kumar and V. Singh, "Evaluation of Indian clays for refractory applications," *Materials Today Proceedings,* vol. 62, no. 5, pp. 189–198, 2022.

[6] A. Abiola, F. Adewale, and K. Sodiq, "Feasibility of ceramic tiles from Nigerian clays," *International Journal of Ceramics,* vol. 12, no. 2, pp. 45–56, 2023.

[7] ASTM International, Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils, ASTM D4318-17e1*, West Conshohocken, PA, USA,* 2022.

[8] ASTM International, Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils, ASTM D4318-17e1, *West Conshohocken, PA, USA*, 2017.

[9] ASTM International, Standard Test Method for Fluid Loss of Clay Component of Geosynthetic Clay Liners, *ASTM D5891/D5891M-19, West Conshohocken, PA, USA*, 2019.

[10] ASTM International, Standard Test Method for Dispersive Characteristics of Clay Soil by Double Hydrometer, ASTM D4221-18, *West Conshohocken, PA, USA*, 2018.

[11] N. C. Brady and R. R. Weil, "The Nature and Properties of Soil", *15th ed. Pearson*, 2016.

[12] J. Bain, M. Udo, and P. George, "Thermal and mechanical characterization of alumino-silicate clays for refractory applications," *Journal of Materials Science*, vol. 24, no. 3, pp. 119–128, 2018.

[13] J. Deer, R.A. Howie, and J. Zussman, "An Introduction to the Rock- Forming Minera", 3rd ed. London, U.K: The Mineralogical Society, 2013.

[14] O. Omowumi, "Effect of Iron Oxide on the sintering behaviour of refractory clays", Ceramic Transactions, vol. 12 no. 4, pp. 88-94, 2011.

[15] O. Onojah, D. Yakubu, and M. Sule, "Porosity and firing behavior of Kankara clay refractory bricks," Nigerian Journal of Engineering Materials, vol. 25, no. 1, pp. 22–30, 2020.

[16] X. Yuan, "Historical use of clays in ceramics and refractories," *Materials Review*, vol. 45, no. 6, pp. 321–337, 2024.

[17] P. Geoffrey, "Natural resources and Nigerian industry: Opportunities and challenges". *African Development Review*, 37(1), 119–132. 2025.

[18] A. Chakraborty, (2014). Kaolinite transformations and mullite formation in refractory clays. Applied Clay Science, 90, 211–221.

Received: 26/06/2026; Revised: 09/07/2026; Accepted: 16/07/2026; Published: 02/09/2026