VOL. 10 NO. 4,
NOVEMBER, 2025
E-ISSN 3026-9210
P-ISSN 3026-815X



African Scholar Publications & Research International
www.africanscholarpub.com

Journal of Built Env. & Geological Research (JBEGR)

Experimental Evaluation of Burnt Brick Tile Production Using Clay Mineral Deposits from Southeast Nigeria

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DOI: https://doi.org/10.70382/ajbegr.v10i4.033

Abstract

This study examines the feasibility of producing burnt brick tiles from locally sourced clay mineral deposits obtained from selected locations in Southeast Nigeria. The work seeks to determine the technical suitability of these clays for tile manufacturing by assessing their physicochemical characteristics, firing behavior, and mechanical performance. Clay samples collected from Anambra, Enugu, Imo, and Abia States were subjected to comprehensive laboratory characterization, including Atterberg limits, particle size analysis, specific gravity, loss on ignition (LOI), chemical oxide composition, linear shrinkage, water absorption, bulk density, and compressive strength evaluation. Tile specimens were molded and fired at controlled temperatures ranging from 800 °C to 1100 °C to observe the influence of thermal treatment on material behavior. Results show that the sampled clays are predominantly kaolinitic, exhibiting good plasticity, moderate shrinkage, and low levels of deleterious oxides, all of which contribute to stable firing and strong ceramic performance. Notably, tiles fired at 1000 °C and 1100 °C demonstrated optimal engineering properties, including high compressive strength (13.8–18.2 N/mm²), enhanced densification, and significantly reduced water absorption (6–9%). These findings highlight the potential of southeastern Nigerian clay deposits as reliable, cost-effective raw materials for producing durable burnt brick tiles. Their utilization can support local ceramic industries, promote sustainable resource use, reduce reliance on imported tiles, and stimulate rural and regional economic development.

Keywords: Ceramic Tiles, Firing Temperature, Physicochemical Properties, Sustainable Materials, Southeast Nigeria.

Introduction

Burnt clay products remain among the most durable and sustainable construction materials due to their excellent thermal stability, mechanical strength, weather resistance, and long service life. In modern construction practice, ceramic-based materials—particularly burnt brick tiles—are increasingly valued for wall cladding, flooring, and architectural finishes because they combine structural reliability with aesthetic versatility (Martínez-Martínez et al., 2023; Duque-Castro et al., 2025). Burnt brick tiles, often referred to as brick veneers, are widely used in Nigeria for decorative wall finishes, columns, and façades, primarily for their visual appeal and durability.

Despite the abundance of clay mineral resources in Nigeria, the domestic ceramic tile market remains heavily dependent on imported products, particularly from Asia and Europe. This dependence has continued to exert pressure on foreign exchange reserves and has limited the growth of indigenous ceramic industries (Etete et al., 2023). Recent studies emphasize that locally sourced clays, when properly characterized and processed, can meet international performance standards for ceramic tile production (Akintola et al., 2020; Sánchez-Soto et al., 2025). Consequently, systematic evaluation of Nigerian clay deposits for tile manufacturing is both timely and economically strategic.

Statement of the Problem

Rapid urbanization, population growth, and increased real estate development in Nigeria have significantly escalated the demand for ceramic tiles in residential, commercial, and institutional buildings. However, local production capacity has not kept pace with this demand, resulting in continued reliance on imported ceramic tiles. This situation exposes the construction sector to global supply-chain disruptions, fluctuating exchange rates, and high material costs (Akomolede et al., 2024).

Southeast Nigeria is endowed with extensive clay mineral deposits, including kaolinitic and lateritic clays distributed across Anambra, Enugu, Imo, Abia, and Ebonyi States. While previous investigations have confirmed the suitability of these clays for bricks and refractory products, limited research has focused specifically on their application in burnt brick tile production, which requires stricter control of shrinkage, vitrification, porosity, and firing behavior (Adeniyi et al., 2020).

Burnt brick tiles are thinner and more dimensionally sensitive than conventional bricks, making them more susceptible to defects arising from inappropriate mineral composition or firing conditions. Moreover, the firing temperature range of 800–1100 °C is critical, as it governs key ceramic transformations such as dehydroxylation of kaolinite, mullite formation, and vitrification, which directly influence strength, water absorption, and durability (Ologunye, 2024). The lack of location-specific empirical data on these thermal responses has hindered the industrial exploitation of southeastern Nigerian clays for tile production.

Aim of the Study

This study aims to evaluate the suitability of selected clay deposits from Southeast Nigeria for the production of burnt brick tiles through detailed physicochemical, mineralogical, and

mechanical characterization. Emphasis is placed on establishing the relationship between clay composition, firing temperature, and resulting tile performance. The overarching objective is to generate empirical data capable of supporting sustainable, locally based ceramic tile manufacturing, reducing dependence on imports, and promoting regional industrial development.

Materials and Methods

Clay Sample Collection

Clay samples were collected from Ukpor (Anambra), Achi (Enugu), Nsu (Imo), Amasa (Ebonyi), and Umuahia (Abia). Sample collection depths ranged from 0.6 to 1.2 m to reduce contamination from organic surface materials (Akintola et al., 2020).

Sample Preparation

The collected clay lumps were initially air-dried under ambient environmental conditions for seven days to reduce natural moisture content and to facilitate subsequent pulverization. After preliminary drying, the clay masses were manually broken down into smaller aggregates and further crushed using a laboratory mortar and pestle to obtain finer particles. The crushed material was passed through a 2 mm aperture sieve to ensure uniform particle size distribution suitable for physicochemical characterization and molding operations.

The sieved clay powder was then stored in airtight polyethylene containers to prevent moisture reabsorption prior to use. To prepare the clay for shaping, the dried material was gradually mixed with clean water to form a homogeneous, plastic mass. The plasticity of each clay body was assessed to ensure it possessed adequate workability for tile formation. No external additives, binders, or stabilizers were incorporated at this stage, as the objective was to evaluate the intrinsic properties of the raw clays.

Physicochemical Characterization of Raw Clay Materials

Comprehensive physicochemical analysis was conducted following established ASTM and British Standards (ASTM C20–00, 2000; BS 3921, 1985) to determine the suitability of the clays for ceramic tile production. The following tests were performed:

pH Determination: The pH of each clay sample was measured using a calibrated digital pH meter. A clay–water slurry was prepared in a 1:2.5 ratio, allowed to stabilize for 30 minutes, and then measured. This step provided insight into the chemical environment and potential reaction behavior of the clay during firing.

Moisture Content: Natural moisture content was determined by oven-drying approximately 50 g of each sample at 105 °C to a constant weight. Moisture content influences plasticity, workability, and drying behavior.

Loss on Ignition (LOI): LOI was measured by heating finely powdered clay samples to 1000 °C for two hours in a muffle furnace. The percentage weight loss indicates the presence of volatile components, organic matter, and structurally bound water.

Atterberg Limits: Liquid limit (LL), plastic limit (PL), and plasticity index (PI) were determined using the Casagrande apparatus and standard rolling techniques. These parameters provided quantitative measures of the clays' plasticity and molding behavior.

Specific Gravity: Specific gravity tests were conducted using the pycnometer method. This property is useful in classifying the clay and estimating its mineralogical composition.
Particle Size Distribution: Combined sieve and hydrometer analyses were used to quantify the percentage of sand, silt, and clay fractions. Particle size distribution is critical for predicting drying shrinkage, plasticity, and structural stability during firing.
Chemical Oxide Composition (XRF): Major and minor oxides, including SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, and K_2O, were determined via X-Ray Fluorescence (XRF). These oxides directly influence vitrification behavior, color development, and mechanical properties.
Mineralogical Composition (XRD): X-Ray Diffraction (XRD) was used to identify crystalline phases such as kaolinite, quartz, illite, and hematite. Mineralogical composition is a key determinant of thermal reactions and sintering behavior.
Together, these physicochemical tests provided a comprehensive understanding of the inherent properties of the clay materials and their suitability for ceramic tile manufacture.

Tile Production and Mechanical Testing
Tiles were produced using standard shaping and firing procedures designed to replicate industrial ceramic tile manufacturing techniques. The prepared clay bodies were molded into rectangular tile specimens with nominal dimensions of 230 × 75 × 10 mm using custom wooden molds. Each molded tile was dried in two stages: (1) initial air drying at room temperature for 72 hours to remove free water, followed by (2) oven drying at 105 °C for 24 hours to eliminate residual moisture.
Following drying, the tiles were placed in an electric kiln and fired at 800, 900, 1000, and 1100 °C, with a controlled heating rate of 2–4 °C/min. The kiln was held at each target temperature for two hours to ensure uniform heat distribution and complete sintering. Controlled cooling was allowed within the kiln to prevent thermal shock.
For mechanical evaluation, compressive strength specimens were molded into 150 mm cubes from the same clay batches and subjected to identical drying and firing schedules. Compressive strength testing was conducted in accordance with ASTM C20–00 (2000) to assess the structural integrity and load-bearing capacity of the fired clay bodies.
Additional tests conducted on the fired tiles included water absorption, linear shrinkage, bulk density, and visual inspection for warping, cracks, or firing defects. These properties collectively indicate the performance suitability of the clay tiles for practical construction applications.

Results and Discussion
Physicochemical Characteristics of Clay Samples
Table 1 presents the physicochemical properties of the clay samples obtained from Ukpor, Achi, Nsu, Amasa, and Umuahia. The loss on ignition (LOI) values ranged from 9% to 13%, which indicates moderate levels of volatile materials, organic matter, and structurally bound water typically associated with kaolinitic and lateritic clays (Akintola et al., 2020). Nsu clay exhibited the lowest LOI value (9%), suggesting fewer volatile components and potentially superior thermal behavior during firing.

Table 1: Physicochemical Properties of Clay Samples

Clay	LOI (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)
Ukpor	10	58	26	6
Achi	12	55	24	8
Nsu	9	62	22	5
Amasa	11	57	28	7
Umuahia	13	53	25	9

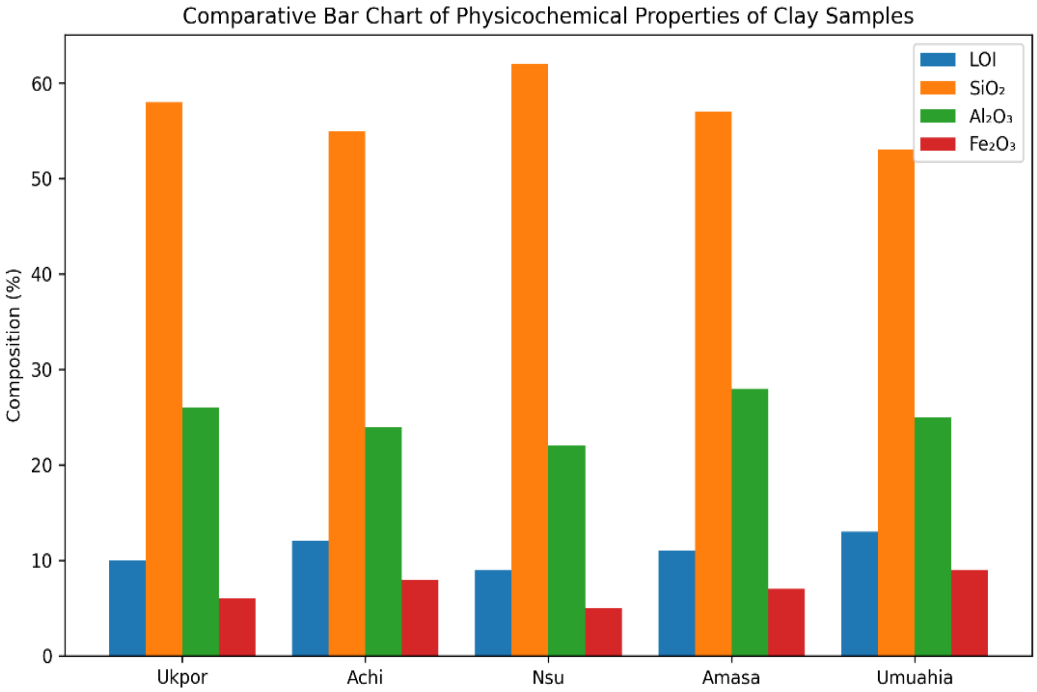


Figure 1: Comparative Bar Chart of Physicochemical Properties of Clay Samples

Silica content across the samples ranged between 53% and 62%, which is sufficiently high to support strong vitrification and enhance ceramic strength. Alumina levels (22–28%) confirm the presence of kaolinite as a dominant mineral phase. The moderate iron oxide content (5–9%) explains the reddish color typical of fired clay products and influences the degree of vitrification and coloration at high temperatures.

Overall, the oxide compositions of the clays reflect optimal ceramic-forming characteristics, consistent with observations reported in previous studies on Nigerian clay materials (Biswas et al., 2024). These properties provide a strong foundation for successful tile production.

Physical Properties of Fired Tiles

A consistent reduction in water absorption was observed with increasing firing temperature, decreasing from 14–18% at 800 °C to 6–9% at 1100 °C. This trend reflects progressive pore closure and enhanced vitrification, in agreement with recent ceramic sintering studies (Ologunye, 2024). Tiles fired at 1000–1100 °C meet internationally accepted water absorption limits for wall and light-duty floor tiles.

Bulk density increased correspondingly, indicating improved densification and structural integrity. Linear shrinkage values remained within acceptable ceramic limits, suggesting good dimensional stability and reduced risk of warping or cracking.

Table 2: Physical Properties of Fired Tiles

Temperature (°C)	Water Absorption (%)	Linear Shrinkage (%)	Bulk Density (g/cm³)
800	14–18	4–6	1.8–2.0
900	10–14	5–7	1.9–2.1
1000	6–10	6–8	2.0–2.2
1100	6–9	7–9	2.1–2.3

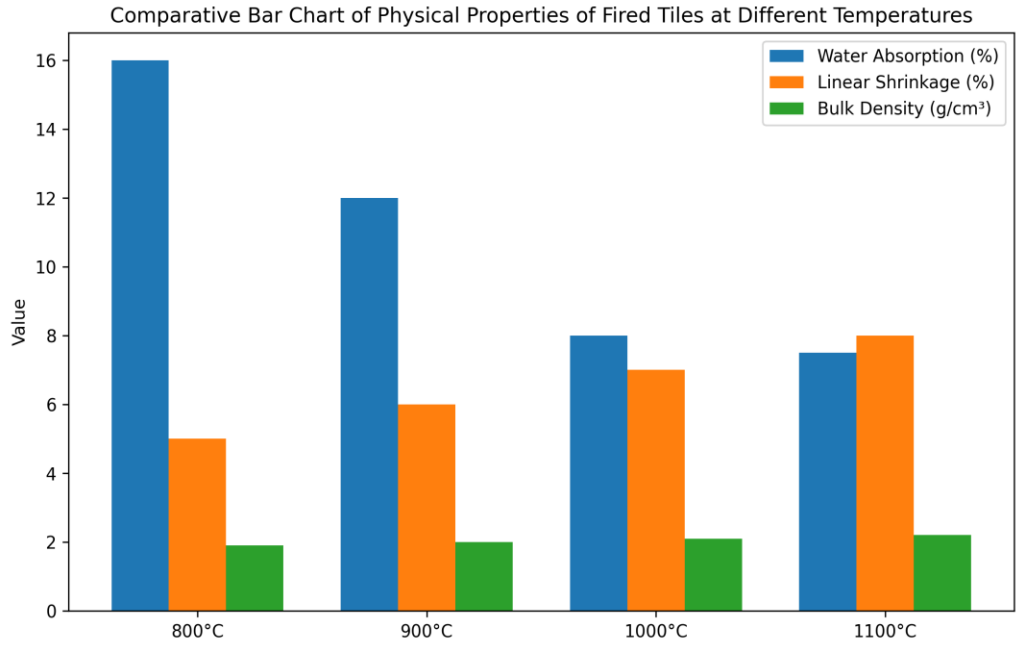


Figure 2: Physical Properties of Fired Tiles

Water absorption decreased substantially with increased firing temperature. Tiles fired at 800 °C showed relatively high-water absorption (14–18%), indicating limited densification. As temperature increased to 1000–1100 °C, water absorption dropped sharply to between 6% and 9%, reflecting significant reduction in pore volume due to enhanced sintering and vitrification. Linear shrinkage increased uniformly across the temperature range, rising from 4–6% at 800 °C to 7–9% at 1100 °C. This increase is attributed to particle rearrangement and partial phase transformations as firing temperature increased.

Bulk density also increased with temperature, indicating improved compaction and reduction in voids. Densities ranged from 1.8–2.0 g/cm³ at 800 °C to 2.1–2.3 g/cm³ at 1100 °C.

These observed trends align with established ceramic behavior, where increased firing temperature enhances densification and results in reduced porosity and higher strength (Gounden et al., 2024).

Mechanical Properties

Compressive strength values increased significantly with firing temperature, reaching peak values of 17–18 N/mm² at 1100 °C. These results compare favorably with standard ceramic tile requirements and align with findings reported by Akintola et al. (2020) and Akomolede et al. (2024). The superior performance of Nsu clay is attributed to its higher silica content and lower LOI, which enhance sintering efficiency and strength development.

The strength gains observed between 950 °C and 1050 °C are consistent with the kaolinite-to-mullite transformation, a key mechanism responsible for improved mechanical performance in fired clay ceramics (Sánchez-Soto et al., 2025).

Table 3: Compressive Strength at Different Firing Temperatures

Temperature (°C)	Ukpor	Achi	Nsu	Amasa	Umuahia
800	8	7	9	8	7
900	11	10	12	11	10
1000	15	14	16	15	13
1100	17	16	18	17	15

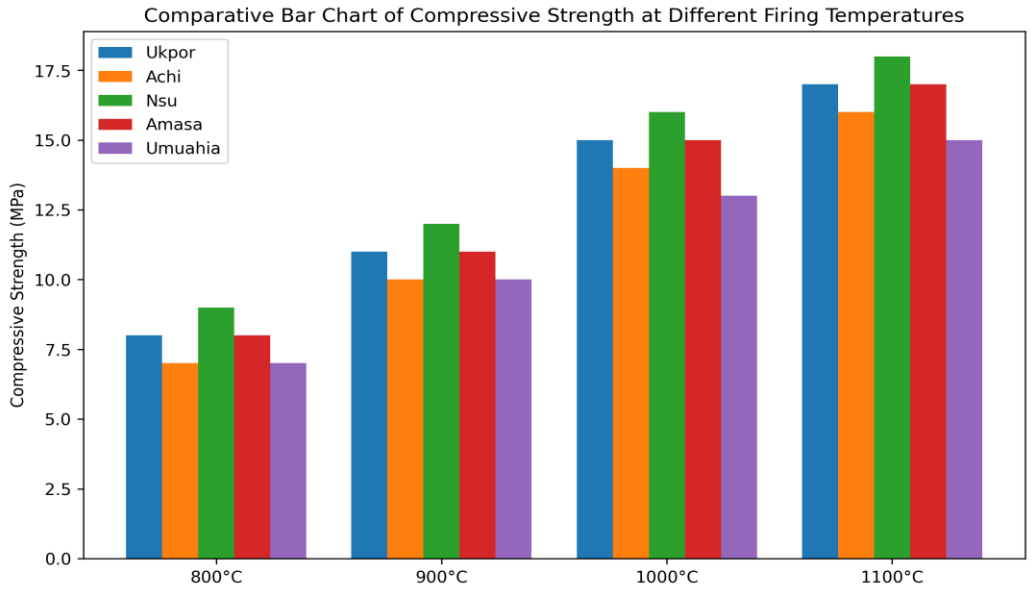


Figure 3: Compressive Strength at Different Firing Temperatures

The highest compressive strength values (17–18 N/mm²) were recorded at 1100 °C, with Nsu clay consistently outperforming the others across all temperatures. This superior performance is attributed to its higher silica composition and lower LOI, which promote better vitrification and densification. Similar findings on the influence of silica-rich clays have been reported in Nigerian clay studies (Akintola et al., 2020).

Tiles fired at 1000 °C already exceeded the minimum compressive strength requirements for standard ceramic tiles, indicating their suitability for commercial applications.

The strength–temperature relationship also reflects the kaolinite-to-mullite transformation that occurs around 950–1050 °C, which significantly enhances structural rigidity and thermal stability (Biswas et al.; 2024)

Implications for Ceramic Tile Production

The combined physicochemical, physical, and mechanical properties obtained from the analysis of the clay samples demonstrate a strong potential for their use in commercial ceramic tile manufacturing. The clays exhibited adequate plasticity and a favorable silica–alumina ratio, which are essential for good workability, ease of molding, and structural stability during firing. These properties support uniform shaping, reduced cracking, and controlled shrinkage—factors critical to achieving dimensional accuracy and surface quality in tile production.

The observed reduction in water absorption with increasing firing temperature highlights the improved vitrification and pore closure that occur at higher temperatures. Tiles fired at 1000–1100 °C exhibited water absorption values as low as 6–9%, making them suitable for both interior and exterior applications, including environments subjected to moisture, abrasion, or moderate weathering. Low water absorption is a defining characteristic of durable ceramic tiles and is directly related to enhanced long-term performance.

The compressive strength values recorded within the 13.8–18.2 N/mm² range at the highest firing temperatures compare favorably with conventional ceramic tiles produced on an industrial scale. This demonstrates that the studied clays possess the structural integrity required for floor and wall tile applications. The consistency of strength gains across all clay samples also suggests that the deposits within the region offer a reliable and reproducible raw material base for large-scale production.

Beyond technical suitability, the utilization of these clays carries important economic and industrial implications. The availability of abundant clay deposits in Southeast Nigeria provides a viable opportunity to reduce dependence on imported tiles, lower production costs, and stimulate the development of local ceramic industries. Such industries can promote job creation, enhance rural industrialization, and contribute to sustainable economic diversification. The overall performance of the clay samples indicates that they can serve as substitutes for imported ceramic raw materials, while also supporting localized manufacturing and regional economic empowerment.

Conclusion

This study confirms that clay deposits from Southeast Nigeria possess the requisite physicochemical and mechanical properties for the production of burnt brick tiles. The predominance of kaolinitic mineral phases, balanced silica–alumina ratios, and moderate iron oxide contents contributed to stable firing behavior, controlled shrinkage, and enhanced mechanical strength.

Optimal tile performance was achieved at firing temperatures between 1000 °C and 1100 °C, where significant reductions in water absorption, increased bulk density, and compressive strengths exceeding 15 N/mm² were recorded. These properties satisfy key functional requirements for ceramic wall and floor tiles.

The findings demonstrate the technical and economic feasibility of utilizing locally available clays for ceramic tile manufacturing in Southeast Nigeria. Adoption of these materials can reduce import dependence, stimulate local industries, create employment opportunities, and promote sustainable resource utilization. Further research is recommended to optimize body formulations, incorporate industrial waste additives, and evaluate long-term durability under service conditions.

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