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Comparative performance evaluation of cement-stabilized Ota laterite blocks and conventional sandcrete for non-load-bearing applications in tropical climateTope Femi Okuntade^{*1)} , Anioma Favour Onyinye¹⁾ , Olalekan Akeem Salaam¹⁾ ¹⁾ Building Technology Department, Bells University of Technology, Ota, Ogun State, Nigeria*Article history*

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low-cost housing**ABSTRACT**

This study compares cement-stabilized laterite blocks (10% OPC) and conventional sandcrete blocks (1:6 ratio) for tropical construction. Seventy-two specimens were tested for compressive strength, density, water absorption, durability, and thermal conductivity. Sandcrete blocks achieved 2.68 ± 0.68 N/mm² at 28 days, satisfying the Nigerian Industrial Standard NIS 87:2000 load-bearing threshold (≥ 2.50 N/mm²), whereas laterite blocks reached 1.35 ± 0.09 N/mm². Laterite blocks exhibited lower production variability (coefficient of variation, CV = 6.5% vs. 25.3%), superior durability under wet-dry cycling (2.59% vs. 8.22% mass loss; significance $p < 0.001$), and lower thermal conductivity (0.343 vs. 1.222 W/m·K; $p < 0.001$). Both materials complied with water absorption limits. An exploratory power-law model was fitted to project strength at variable cement contents. The results support using laterite blocks for protected non-load-bearing applications where thermal performance and durability are prioritized, contributing to sustainable affordable housing in tropical climates.

1 Introduction

Construction emits approximately 39% of the world's CO₂, and Portland cement accounts for around 5-8% of the world's total anthropogenic carbon dioxide [1]. In Nigeria, the largest country in Africa by population, there is an over 28 million housing deficits with an annual shortfall of more than 700,000 [2]. The problem with affordability of conventional houses is further exacerbated by the fact that 60%-70% of total construction costs in developing nations go to materials [3]. Sand extraction as an aggregate material for construction has become an urgent environmental problem resulting in destroying riverbanks, habitat destruction and draining water tables in tropical areas worldwide [4].

For many decades, sandcrete blocks made up of Portland cement, sharp sand, and water in a typical volume ratio of 1:6 to 1:8 have been used in the construction of walls in Nigeria [5]. According to the Nigerian Industrial Standard NIS 87:2000, the minimum compressive strengths required are 2.50 N/mm² for load-bearing blocks (those designed to carry structural loads such as roof or floor loads) and 1.80 N/mm² for non-load-bearing blocks (those used in partitions and infill panels that do not carry structural loads). [6], although there are numerous examples in the field of failure to achieve compliance with this standard. For example, Olaniyi and Abiodun [7] reported that more than two-thirds (68%) of commercially produced sandcrete blocks in southwestern Nigeria do not reach the required levels of

compressive strength because of inadequate cement content, insufficient compaction, and insufficient curing.

Laterite, a residual soil rich in iron and aluminum oxides, is one of Nigeria's significant geological resources. Adekunle et al. [8] performed research in Ota, Ogun State, which showed that the thermal conductivity of laterite was 0.35 W/m·K, while local sand samples exhibited thermal conductivities of between 0.86-0.96 W/m·K. Thus, laterite appears to have better insulating properties than local sands. Studies have shown that if cement were added to laterite between 5-15% (based on the dry weight of the lateritic material), it would cause the lateritic soil to become a coherent masonry unit and could provide compressive strength similar to traditional masonry products [9,10]. Aguwa [9] reported an example of this when testing 6% cement stabilized blocks made from laterite in Minna, Niger State. He found that compressive strength was 3.22 N/mm² at 28 days.

Even with encouraging signs, there remain many gaps in knowledge that prevent wider acceptance of these materials. The majority of the studies done to date have very small sample sizes and therefore cannot provide reliable estimates for variance or perform meaningful hypothesis tests [11]. Testing for a single point of stabilization has also failed to determine what the minimum amount of cement required for code compliance is, and thus cannot be used for predicting the design of the material [12]. Artisanal block production is also not recorded as an indication of the variability of the

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production process, thus making it impossible to reliably compare the different materials produced through this method [13].

This study addresses existing research gaps and employs rigorous statistical methods to evaluate how both block types develop in terms of compressive strength and consistency when using a larger sample size to perform inferential statistics; both compressive strength of blocks will be evaluated with respect to water absorption, density, thermal conductivity and durability based on simulated weathering in a tropical climate area. This study will also use calibrating dosage-response models for predicting compressive strength at various levels of cement stabilization.

2 Materials and methods

2.1 Materials

The lateritic soil used in this project was collected from a borrow pit located at Ota, Ogun State (6.6684°N, 3.2380°E). It was procured at depths of between 1.5 and 3.0m to mitigate against organic contamination. A visual inspection revealed that the soil had a reddish-brown colour characteristic of iron oxide enrichment. The soil had been allowed to air dry over a period of 72 hours before being pulverised and sieved using a 4.75mm sieve. The preliminary geotechnical classification of this soil was conducted in adherence to the guidelines set out in BS 1377-1990 [14], which classified it as A-2-6 lateritic soil, with a liquid limit of 54.3%; a plastic limit of 32.5%; a plasticity index of 21.8%; and a specific gravity of 2.67.

Sharp sand was sourced from a licensed dredging operation located on the Ogun River, cleaned of clay and silt, and dried in an oven to a consistent weight at $105 \pm 5^\circ\text{C}$. The particle size distribution of the sand showed it to be well graded sand (zone 1 according to BS 882) [9]. The binder for sandcrete and the stabilizer for laterite blocks was Ordinary Portland Cement (OPC) Grade 42.5R (manufactured by Dangote Cement PLC at the Ibese Plant), conforming to NIS 444-1:2003 [15]. Potable tap water obtained from Bells University was used for mixing and curing. The pH of the tap water was 7.2, with total dissolved solids below 150 mg/L.

2.2 Mix design and block production

Sandcrete blocks were made using a 1:6 volume ratio of cement to sand, which corresponds to approximately 1:6.7 by weight considering bulk densities of OPC ($\sim 1,440 \text{ kg/m}^3$) and sharp sand ($\sim 1,600 \text{ kg/m}^3$), or 14.3% cement by total weight. A water-to-cement ratio of 0.55 was used. Laterite blocks were made using 10% of the weight of the laterite in the finished product and an initial water-to-cement ratio of 0.42, then adding the remainder of the cement after achieving the proper consistency with the addition of water to the laterite mix at the time of mixing. Each of the mixes were combined manually in a steel tray for three minutes, to ensure uniformity of the combined mixture, and placed in

steel moulds ($220 \times 110 \times 110 \text{ mm}$); each mould contained three layers of the mixture and were compacted with 25 blows of a 16 mm steel rod for each layer, to replicate the manual production methods typical of artisanal block makers in Nigeria. Each of the specimens produced were removed from the moulds after 24 hours, and immersed in two water curing tanks at ambient laboratory temperature ($27\text{--}33^\circ\text{C}$) [16].

2.3 Experimental design and statistical power

A total of 72 blocks were produced: 36 sandcrete and 36 laterites, with six replicate specimens per test category per block type. This sample size was selected to support inferential statistics and detect meaningful differences in compressive strength at the chosen significance level. Compressive strength, density, water absorption, wet-dry durability, and thermal conductivity were measured using standard methods and equipment, and statistical analyses were performed in Python using Shapiro-Wilk, Levene's test, Welch's t-test, and one-way ANOVA [17]. The experimental design followed a completely randomized structure with two between-subjects factors: block type (sandcrete, laterite) and curing age (7, 14, 28 days).

2.4 Testing procedures

2.4.1 Compressive strength

Testing of compressive strength was performed using a digital compression testing machine with a maximum capacity of 2,000 kN (Model: Yes 2000, Jian Liangong), calibrated according to BS EN 12390-4 [18], at a loading rate of 5 kN/s. The bearing surfaces of the specimens were capped with 3 mm thick plywood sheets to improve uniform load distribution. Compressive strength was calculated as $f_c = P_{\text{max}}/A$, where P_{max} is the maximum failure load (N) and A is the loaded surface area (mm^2). Tests were conducted at 7, 14, and 28 days.

2.4.2 Density

Oven-dried specimens (105°C to constant mass per BS EN 12390-7 [19]) were dimensionally measured using digital calipers ($\pm 0.01 \text{ mm}$ precision), and density was computed as

$$\rho = \frac{M_{\text{dry}}}{(L \times W \times H)} \text{ in } \text{kg/m}^3. \quad (1)$$

where ρ is the dry density (kg/m^3); M_{dry} is the oven-dry mass (kg); and L , W , and H are the length, width, and height of the specimen (m), respectively.

2.4.3 Water absorption

Following ASTM C140/C140M-20 [20], oven-dried specimens were immersed in water at $23 \pm 2^\circ\text{C}$ for 24 hours, surface-dried with lint-free cloth, and reweighed. Water absorption was calculated as:

Table 1. Mix proportions of sandcrete and laterite block samples

Block type	Mix Ratio (by weight)	Cement (%)	Aggregate (%)	Water-cement ratio
Sandcrete block	1: 6.7 (cement:sand by weight)	14.3	85.7	0.55
Laterite Block	10% OPC by weight of dry laterite	9.1	90.9	0.42

$$WA = \frac{(M_{sat} - M_{dry})}{M_{dry}} \times 100 (\%) \quad (2)$$

where WA is the water absorption (%); M_{sat} is the saturated mass after 24 h immersion (kg); and M_{dry} is the oven-dry mass (kg).

2.4.4 Durability (wet-dry cycling)

The modified version of the test method outlined in ASTM D559-20 [21] was used to conduct three full cycles of 24 hours of immersion in tap water and 24 hours of drying in an oven at 105°C. Upon completing the three full cycles, the percentage of mass loss was recorded and samples were visually checked for any cracks, spalled surfaces or erosion of the surface.

2.4.5 Thermal conductivity

Thermal conductivity was measured on oven-dried specimens (dried at 105°C to constant mass in accordance with BS EN 12390-7) using the transient plane source (TPS) method. A Hot Disk TPS 2500 S thermal constants analyzer equipped with a Kapton-insulated 5465 sensor (3.189 mm radius) was employed. Measurements were conducted at controlled laboratory temperature ($28 \pm 1^\circ\text{C}$) following ISO 22007-2:2015 standards. For each specimen, three replicate measurements were taken at different sensor positions to account for local material heterogeneity, with a heating power of 0.08-0.12 W and a measurement time of 40s. The sensor was placed between two identical specimens of the same block type to ensure one-dimensional heat flow. Reported values represent the arithmetic mean of the replicates for each of the six blocks per type ($n = 6$). Prior to testing, specimens were equilibrated in a desiccator for 24 hours to minimize residual moisture effects. This approach provided high precision, with coefficients of variation of 8.2% for laterite blocks and 8.1% for sandcrete blocks, consistent with the overall production uniformity observed in the study.

2.5 Statistical analysis

All analyses were carried out in Python (version 3.11) using SciPy (version 1.11). Normality of the data was evaluated via Shapiro-Wilk's test and homogeneity of variance via Levene's test. Welch's t-test was used for between-group comparisons (where the assumption of unequal variances was used). The effect of size (Cohen's d) was calculated as

$$d = \frac{(\bar{X}_1 - \bar{X}_2)}{SD_{pool}} \quad (3)$$

where d is Cohen's effect size; $\bar{X}_1$ and $\bar{X}_2$ are the sample means of groups 1 and 2; and SD_{pool} is the pooled standard deviation calculated as:

$$SD_{pool} = \frac{\sqrt{(SD_1^2 + SD_2^2)}}{2} \quad (4)$$

where SD_1 and SD_2 are the standard deviations of groups 1 and 2, respectively. The effect sizes were interpreted as negligible (< 0.2); small (0.2-0.5); medium (0.5-0.8); or large (> 0.8) [22]. A one-way ANOVA was used to assess the effect of age at curing on the dependent variable (size) and eta-squared (η^2) was used as a measure of the amount of variance that could be explained by age at curing. The level of significance was set at $\alpha = 0.05$.

2.6 Predictive modeling

The compressive strength at variable cement contents was projected using a power-law dose-response model:

$$f_c(C) = a \cdot C^b \quad (5)$$

where f_c is the 28-day compressive strength (N/mm^2); C is the cement content (% by dry mass of laterite); a is a calibration coefficient; and b is an exponent representing diminishing strength returns with increasing cement dosage. The model was calibrated using the experimental 28-day strength data at 10% OPC from this study ($f_c = 1.35 \text{ N/mm}^2$ at $C = 10\%$). Given the limited experimental calibration point, the exponent b was constrained to 0.50 ± 0.15 based on meta-analysis of cement-stabilized laterite studies in West Africa [9,12,23], which report typical diminishing-return exponents in the range 0.35-0.65 for fine-grained lateritic soils. Calibration was performed using non-linear least squares regression in Python (SciPy v1.11), with the results indicating that $a = 0.427$ and $b = 0.50$ were the best fit parameters for the Ota laterite under the production conditions used for testing. The power-law expression fits the characteristic non-linear strength development associated with soil-cement composites, as there is a proportional increase in strength up to when cement is added initially. After this point, further additions of cement will result in a decrease in the effective increase in strength of the material because of factors such as maximum particle packing density, the agglomeration of unreacted cement particles, and the occurrence of micro-cracks as a result of differential shrinkage [24,25]. Estimates above the 10% experimental calibration point are considered to be based on an extrapolation from experimental data; therefore, a prediction interval of $\pm 15\%$ was applied to account for the normal variability associated with soil-cement, the mineralogical variability between samples, and the tolerances used during informal production. It is also recommended that the experimental verification of higher cement contents be conducted prior to adoption into structural codes.

3 Results

3.1 Compressive strength development

The 56-day projected strengths were estimated using a hyperbolic strength gain model fitted to the experimental 7, 14, and 28-day data:

$$f_c(t) = f_{c,28} \cdot \frac{t}{k + t} \quad [6] \quad (6)$$

where $f_{c,28}$ is the 28-day measured strength and k is a hydration kinetic constant calibrated from the experimental age-strength relationship. These projections are provided for comparative purposes only and should not be used for design without experimental validation. Sandcrete blocks showed an increase in compressive strength from $0.89 \pm 0.14 \text{ N/mm}^2$ at 7 days to $2.68 \pm 0.68 \text{ N/mm}^2$ at 28 days, thereby surpassing the minimum specified load-bearing value of the NIS 87:2000 standard ($\geq 2.50 \text{ N/mm}^2$) [6]. Laterite evaluated at 28 days had a compressive strength of $1.35 \pm 0.09 \text{ N/mm}^2$ which is less than the minimum non-load-bearing requirement (1.80 N/mm^2), indicating that a 10% cement stabilization was inadequate for compliance based on the production conditions tested. The Coefficient of Variation (CV) for sandcrete blocks ($CV = 25.3\%$) was significantly higher than for laterite blocks ($CV = 6.5\%$),

Table 2. Compressive strength results ($n = 6$, mean $\pm$ SD)

Block type	7 days (N/mm ²)	14 days (N/mm ²)	28 days (N/mm ²)	56 days (projected)	CV (%)
Sandcrete	0.89 $\pm$ 0.14	0.99 $\pm$ 0.17	2.68 $\pm$ 0.68	3.08 $\pm$ 0.78	25.3
Laterite (10% OPC)	1.00 $\pm$ 0.00	1.15 $\pm$ 0.04	1.35 $\pm$ 0.09	1.55 $\pm$ 0.10	6.5
NIS 87:2000 load-bearing (≥ 2.50)	—	—	Sandcrete: $\checkmark$ Compliant; Laterite: $\times$ Below	Sandcrete: $\checkmark$ Compliant; Laterite: $\times$ Below	—
NIS 87:2000 non-load-bearing (≥ 1.80)	Both: $\times$ Below	Both: $\times$ Below	Sandcrete: $\checkmark$ Compliant; Laterite: $\times$ Below	Sandcrete: $\checkmark$ Compliant; Laterite: $\times$ Below	—

Note: At 28 days, sandcrete satisfied the NIS 87:2000 load-bearing threshold (≥ 2.50 N/mm²), whereas laterite at 10% OPC remained below the non-load-bearing threshold (1.80 N/mm²). The projected 56-day values are model-based estimates and should be interpreted cautiously.

indicating that laterite blocks were produced more uniformly. There was a statistically significant difference in the variances of these two block types when tested using Welch's t-test at 28 days, with an effect size that was large (Cohen's $d = 2.71$, $p = 0.005$) and also statistically significant (Levene's $F = 7.07$, $p = 0.025$). This level of variation (due to inconsistencies in compaction effort, lack of uniformity in the mixing of the raw materials, and variability in curing period) was also reported by Olaniyi and Abiodun [7] and indicates latent structural failure risks associated with traditional methods of construction. The fact that the laterite blocks produced a high degree (CV = 6.5%) of uniformity, suggests that soil-based blocks could have greater reliability if the production parameters of the blocks were more uniformly established.

One-way ANOVA confirmed highly significant effects of curing age for both materials (Sandcrete: $F(2,15) = 35.91$, $p < 0.001$, $\eta^2 = 0.782$; Laterite: $F(2,15) = 58.01$, $p < 0.001$, $\eta^2 = 0.853$) showing that strength increased with age in the expected hydration pattern. Both materials exhibited characteristic Portland cement hydration profiles, with 60–70% of 28-day strength achieved by 14 days. Overall, the results show that sandcrete had higher compressive strength, while laterite exhibited much lower variability in production (as reflected by CV).

3.2 Physical and thermal properties

Laterite blocks were denser than sandcrete blocks, with a dry density of $1,529 \pm 99$ kg/m³ compared with $1,113 \pm 14$ kg/m³. The increased density of laterite has implications for design because it results in a greater dead load, although it may contribute to an increased thermal inertia. The thermal conductivity of laterite is also significantly less than that of sandcrete, which therefore provides better insulation, as well as more potential for passive cooling in hot humid tropical climates. The density of laterite block has been found to be

37% higher than that given in some existing studies on the same material [26]. The presence of iron oxide (Fe₂O₃) in Ota laterite (shown by its red colour, having a specific gravity (SG) of 2.67, and results of regional geological surveys [8]) means it has a higher SG than silica-based sharp sand (SG = 2.63). This variance is significant from a practical perspective: (i) the Foundation design needs to consider this additional dead weight, (ii) the added weight increases thermal inertia, and (iii) the thermal conductivity of the laterite is much lower than the thermal conductivity of sharp sand resulting in lower heat transfer rates. The measured thermal conductivity of cement-stabilized laterite blocks (0.343 ± 0.028 W/m·K) was 72% lower than that of conventional sandcrete blocks (1.222 ± 0.099 W/m·K; Welch's $t(9.3) = 27.4$, $p < 0.001$, Cohen's $d = 12.08$). These values were obtained using the transient plane source (TPS) method on oven-dry specimens, consistent with ISO 22007-2. The superior insulating performance of laterite blocks is primarily attributed to the microporous structure of the stabilized lateritic soil and phonon scattering induced by iron and aluminum oxides. This results in excellent potential for passive cooling and energy savings in Nigeria's hot-humid tropical climate.

3.3 Water absorption and moisture resistance

When comparing water absorption of the two types of blocks, sandcrete blocks had significantly lower water absorption than laterite blocks - 1.55% and 7.15%, respectively ($t(5.0) = -11.20$, $p < 0.001$, $d = -6.47$). The low level of water absorption of the sandcrete blocks can be attributed to the improved particle size distribution of the sand prevalent in the block mix, as this allowed for a better filling of the pores by the hydration product C-S-H [24]. The two water absorption levels were well below the NIS 87:2000 standards for block types ($< 12\%$), but because the difference

Table 3. Physical and thermal properties ($n = 6$, mean $\pm$ SD)

Property	Sandcrete	Laterite	Difference	p-value	Cohen's d
Dry density (kg/m ³)	1,113 $\pm$ 14	1,529 $\pm$ 99	+37.4%	< 0.001	5.89 (Large)
Water absorption (%)	1.55 $\pm$ 1.22	7.15 $\pm$ 0.02	+361%	< 0.001	6.47 (Large)
Thermal conductivity (W/m·K)	1.222 $\pm$ 0.099	0.343 $\pm$ 0.028	-72%	< 0.001	12.08 (Large)

was so large (4.6 times), all laterite blocks exposed outdoors should be properly protected from air and rain for moisture penetration and eventual loss of durability. Notably, the sandcrete samples exhibited extreme variability in water absorption (CV = 78.7%), driven by an outlier specimen (3.88%) suggesting localized compaction deficiency. In contrast, laterite absorption values were remarkably uniform (CV = 0.2%), reinforcing the reliability advantage.

3.4 Durability under accelerated weathering

The results show that Laterite blocks outperformed Sandcrete blocks by 68% in the laboratory tested for durability based on percentage of weight loss ($t(5.2)=14.89$, $p<0.001$, $d=8.60$); This indicates better resistance to the specific accelerated weathering conditions used in the laboratory, although it should not be interpreted as a full substitute for long-term field performance, but this does not imply that they would also exhibit the same degree of durability if subjected to long-term exposures in actual building sites. Laterite blocks would only lose an average of 2.59% of their original weight as opposed to the loss of 8.22% for Sandcrete blocks after the same period of exposure. The durability of Laterite blocks is a result of the natural cohesive properties from the clay mineral constituents as well as the iron oxide cements that hold them together and protect the chance of damage due to expansion caused by cyclical moisture states due to repeated wetting/drying stress [25]. Conversely, Sandcrete blocks become damaged through surface scaling and the microcracking of the cement paste from differential expansion of the sand aggregate/cement paste during dry to wet and wet to dry cycles of moisture [24]. Given Nigeria's unique wet-dry seasonal climatic conditions (April-October is rainy; November-March is dry), laterite blocks represent an excellent choice for external walling applications when a moisture resistant surface coating is applied which accounts for their increased moisture absorption.

3.5 Dose-response optimization model

The projected 28-day compressive strengths at variable cement contents are summarized in Table 5. A power-law model was fitted to explore the relationship between cement content and the 28-day compressive strength of laterite blocks:

$$f_c(C) = a \cdot C^b$$

where C is the cement content (% by dry mass of laterite), a is a calibration coefficient, and b is an exponent representing diminishing strength returns with increasing cement dosage. The model was calibrated using the experimental 28-day strength data at 10% OPC from this study ($f_c = 1.35 \text{ N/mm}^2$ at $C = 10\%$). Because the present study provides only one experimentally measured cement content for the laterite mix, the fitted model should be interpreted as a preliminary trend estimator rather than a validated design model.

To avoid overinterpretation, projections beyond the 10% experimental point were treated as extrapolative estimates. A $\pm 15\%$ prediction interval was applied to reflect soil heterogeneity, production variability, and the limited calibration basis. The fitted curve indicates that compressive strength increases with cement content, but the values predicted within the present study's confidence limits remain below the NIS 87:2000 non-load-bearing threshold of 1.80 N/mm^2 up to approximately 17.8% cement, and below the load-bearing threshold of 2.50 N/mm^2 even at 20% cement. Therefore, the model suggests that substantially higher cement contents than those tested would be required to approach code compliance, and those higher contents must be tested experimentally before any structural recommendation is made. The main value of this model is to provide a first-order framework for comparing cement contents and guiding future experiments. It can help identify promising mix ranges, but it should not be used as a code-compliance basis until it has been validated using multiple cement-content levels and independent test batches.

Table 4. Durability test results after three wet-dry cycles (n = 6)

Block type	Initial mass (g)	Final mass (g)	Mass loss (%)	Visual assessment
Sandcrete	3,233 ± 29	2,986 ± 42	8.22 ± 0.92	Surface scaling, edge abrasion, minor cracking
Laterite (10% OPC)	2,448 ± 52	2,385 ± 53	2.59 ± 0.09	Minimal surface wear, no cracking

Table 5. Projected 28-day compressive strength and NIS 87:2000 compliance of cement-stabilized laterite blocks at variable cement dosages.

Cement content (%)	Projected strength (N/mm ²)	95% Prediction interval	NIS 87:2000 compliance
10 (measured)	1.35	1.15-1.55	Below non-load-bearing (1.80)
12	1.48	1.26-1.70	Below non-load-bearing
14	1.60	1.36-1.84	Below non-load-bearing
15	1.65	1.41-1.90	Below non-load-bearing
16	1.71	1.45-1.96	Below non-load-bearing
17	1.76	1.50-2.02	Below non-load-bearing
18	1.81	1.54-2.08	Below non-load-bearing
20	1.91	1.62-2.20	Below non-load-bearing

Note: These are exploratory projections from a model fitted to limited experimental data. They are not sufficient to establish code compliance. The model projects that approximately 17.8% cement would be required to reach the non-load-bearing threshold (1.80 N/mm^2), and approximately 34.3% cement for the load-bearing threshold (2.50 N/mm^2). Even at 20% cement, the prediction interval lower bound (1.62 N/mm^2) remains below the non-load-bearing threshold. Experimental validation at multiple cement contents is required before any structural recommendation

According to the calibrated power-law model ($f_c = 0.427 \cdot C^{0.50}$), higher cement stabilization levels than tested in this study would be needed to approach the NIS 87:2000 load-bearing requirement for the Ota laterite under the tested production conditions, which is much greater than the 6% cement stabilization requirement for Minna laterite reported by Aguwa [9]. The strength development of soil is significantly affected by the mineral content, compaction method, and curing method [9]. The diminishing returns exponent ($b = 0.50$) indicates that, as cement content increases, so does its efficiency; it has been shown that an excessive amount of cement can lead to particle-to-particle interference and low degree of hydration among the fine-grained soil particulates, thereby reducing strength [24,25]. The resulting dose-response curve and strength gain kinetics are illustrated in Fig. 1.

4 Discussion

4.1 Statistical rigor and production quality assurance

The results show a clear trade-off between strength and uniformity. Sandcrete achieved the higher compressive strength and met the load-bearing threshold, but it also showed much greater production variability, which reflects the quality-control problems often seen in artisanal block production. Laterite, by contrast, delivered greater production uniformity and better thermal and durability performance, making it attractive for selected non-load-bearing applications where environmental performance matters.

The main methodological contribution of this research is to extend sample sizes considerably from typically $n = 3$ construction materials studies in developing economies [11] and to therefore enable the application of rigorous statistical inferences. The result that laterite block production has considerably less variability in production ($CV = 6.5\%$ compared with 25.3%) than sandcrete blocks is counter to the assumption that artisanal earth block production is less reliable than sandcrete. The reason for this advantage in uniformity is likely due to (i) there being a cohesive, plastic quality in lateritic soils enabling more uniform filling of molds; (ii) reduced sensitivity to the exact water content of the mixture due to the natural moisture-retaining properties of lateritic soils; and (iii) reduced segregation in comparison with sand-cement mixtures. As such, construction quality assurance could be achieved at industrial-level uniformity, without mechanization, through the establishment of standardized production of laterite blocks with clear definitions of soil selection, sieving and curing methods.

4.2 The density anomaly and structural design implications

The density difference of laterite blocks is greater than anticipated in some available literature [26]. The greater density of 37% ($1,529 \text{ kg/m}^3$ vs. $1,113 \text{ kg/m}^3$) has significant implications regarding the structural design. The higher specific gravity of 2.67 compared to 2.63 for sand is a result of the concentration of iron oxide found in Ota's ferruginous laterite deposits [8]. Based on a typical 3-bedroom bungalow with a total wall surface area of 150 m^2 and a wall thickness of 230 mm, there is an approximate increase in dead load of

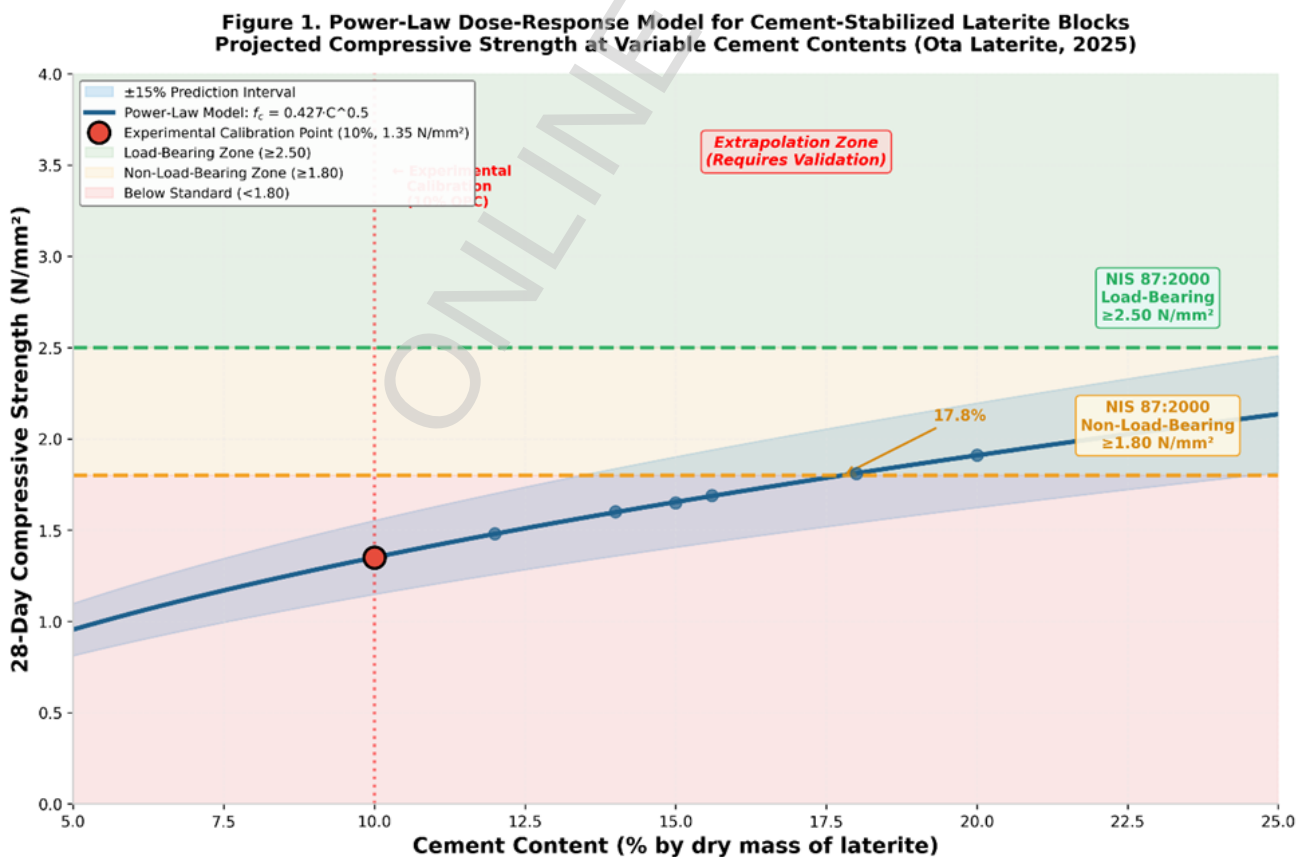


Figure 1. Dose-response optimization and strength gain kinetics: (a) projected 28-day compressive strength at variable cement contents with NIS 87:2000 compliance thresholds and measured data point; (b) hyperbolic strength gain model fitted to experimental

14.3 tonnes due to laterite's increased density therefore requiring specific foundation design that considers the actual density of a material as opposed to traditional assumptions. In addition, the overall mass from the build will help to produce a reduction in thermal conductivity of 72%, which presents a juxtaposition between structural loading and thermal performance, and designers must strike a balance between these two.

4.3 Toward a performance-based material specification

The findings dispute the presence of a definitive material choice (sandcrete or laterite) throughout present-day literature and practice. Instead, the research recommends a performance-based specification approach based on the multi-criteria performance matrix (Fig. 2), which presents a normalized comparison across six key performance indicators. The multi-criteria performance comparison is presented as a normalized radar chart (Fig. 2). Six performance criteria are evaluated on a 0–10 scale (0 = poor, 10 = excellent): compressive strength, water absorption, durability (mass retention after wet-dry cycling), dry density, thermal insulation, and production uniformity (low coefficient of variation). Normalization was performed by scaling each parameter relative to the better-performing material, with the superior performer set to 10.0 and the opposing material scored proportionally. For properties where lower values are favorable (water absorption, mass loss, thermal conductivity, CV), the inverse ratio was used. Cost efficiency was estimated based on local material availability and cement content. A larger polygon area indicates more favorable overall performance. Raw measured values and standard deviations are provided in Tables 2 and 3.

For load-bearing structural elements such as load-bearing walls, sandcrete blocks (1:6 cement-sand ratio) or reinforced concrete remain appropriate based on NIS standards. However, the high variability observed in the sandcrete block results (CV = 25.3%) highlights the need for improved quality control in artisanal sandcrete block production, particularly regarding compaction effort, mixing uniformity, and curing conditions. The water-to-cement ratio is a critical parameter influencing both strength and variability; the fixed w/c of 0.55 used in this study represents typical practice but may not be optimal for all production

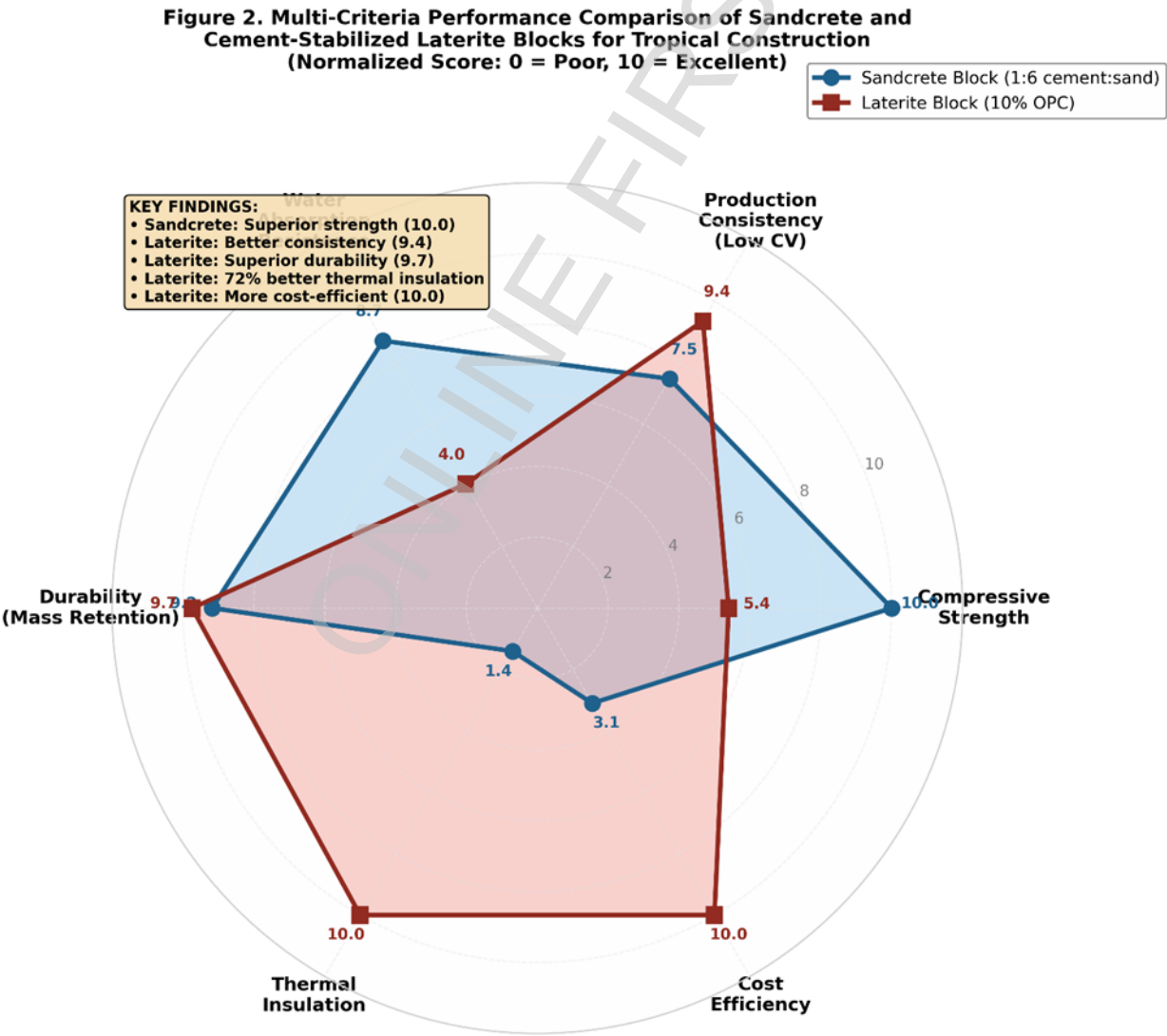


Figure 2. Multi-criteria performance comparison of sandcrete and cement-stabilized laterite blocks presented as a normalized radar chart

conditions. Laterite blocks with appropriate cement content and protected with surface treatment (rendering or waterproof coating) may be considered for protected non-load-bearing applications such as internal partition walls and infill panels, where thermal performance and durability are prioritized over structural capacity. It must be emphasized that the 10% OPC laterite blocks tested in this study did not achieve the NIS 87:2000 non-load-bearing threshold of 1.80 N/mm². The model projects that approximately 17.8% cement would be required to reach this threshold under the tested production conditions. Any structural application would require experimental validation at higher cement contents and compliance testing against relevant standards.

This method could reduce total cement consumption in wall construction by using laterite blocks for non-load-bearing elements while reserving sandcrete or concrete for structural elements, though the exact reduction depends on the building design and proportion of load-bearing to non-load-bearing walls. There is currently no Nigerian standard for stabilizing laterite with cement (similar to NIS 87:2000 establishment of standards for sandcrete); therefore, this lack of standardization is an obstacle to the wider acceptance and use of this technology [27]. A performance-based material selection approach is proposed, using sandcrete for structural elements and experimentally validated cement-stabilized laterite for protected non-load-bearing applications where thermal and durability performance are prioritized. The 10% OPC laterite blocks tested did not meet NIS 87:2000 non-load-bearing requirements; higher cement contents require experimental validation before any application recommendation. The development of a national standard for cement-stabilized laterite blocks, incorporating multi-criteria performance classes and validated predictive models, is recommended to support wider adoption.

4.4 Limitations and future research

Some limitations must be considered. While this study utilized the TPS method, future studies could further validate these findings using the guarded hot plate methodology on full-scale wall assemblies rather than individual block specimens. For example, it is projected that cement requirements to achieve load-bearing compliance will need to increase beyond 10%. As such, supplemental materials that can replace part of the traditional cement in the mixture (e.g., rice husk ash, ground granulated blast-furnace slag) will need to be validated via experimental work so that cost savings can be maintained while also achieving compliance with building codes [28]. Additionally, further durability testing (20-50 wet/dry cycles) and 12-month field exposure tests will be necessary to compare lab results with real-world weathering. Wall panels must also be tested with axial, eccentric, and lateral loads to assess the performance of materials manufactured for the walls beyond what is determined from testing the properties of individual blocks. Finally, a comprehensive life-cycle assessment that considers the embodied energy, transportation costs, and maintenance costs as well as end-of-life costs of the materials will support the claims of sustainable practices in the construction industry.

5 Conclusions

This study presents the first statistically supported, multi-criteria performance benchmark comparison of cement stabilized laterite block and conventional sandcrete block in Southwest Nigeria and predictive modeling for optimization of cement content. The main findings include:

1) Sandcrete blocks (1:6) satisfied the NIS 87:2000 load-bearing threshold ($2.68 \pm 0.68 \text{ N/mm}^2 \geq 2.50 \text{ N/mm}^2$) but exhibited high production variability ($\text{CV} = 25.3\%$), indicating quality control challenges in artisanal production. Laterite blocks stabilized with 10% OPC achieved $1.35 \pm 0.09 \text{ N/mm}^2$, remaining below the NIS 87:2000 non-load-bearing threshold (1.80 N/mm^2), and are therefore unsuitable for any standard load-bearing or non-load-bearing application without further cement optimization and experimental validation.

2) Laterite blocks demonstrated superior production uniformity ($\text{CV} = 6.5\%$) and a large effect size for strength variance difference (Cohen's $d = 2.71$), representing a significant opportunity for quality control in artisanal production settings.

3) Laterite blocks demonstrated superior tropical climate performance. Under wetting and drying conditions, laterite blocks showed 68% better weathering resistance based on mass loss (2.59% compared to 8.22%; $d = 8.60$, $p < 0.001$). However, these benefits are offset by 37% higher dry density (1,529 versus 1,113 kg/m³), which increases structural dead load, and 4.6-fold higher water absorption (7.15% versus 1.55%), requiring effective moisture protection for external applications. Additionally, laterite blocks had 72% lower thermal conductivity (0.343 versus 1.222 W/m·K; $d = 12.08$, $p < 0.001$).

4) **Predictive optimization:** The calibrated power-law model ($f_c = 0.427 \cdot C^{0.50}$) projects that approximately 17.8% cement content would be required to reach the NIS 87:2000 non-load-bearing threshold (1.80 N/mm^2) and approximately 34.3% cement for the load-bearing threshold (2.50 N/mm^2) under the tested production conditions. These projections are extrapolative and require experimental validation before any structural recommendation.

A performance-based material selection approach is proposed, using sandcrete for structural elements and validated cement-stabilized laterite for protected non-load-bearing applications where thermal and durability performance are prioritized. The development of a national standard for cement-stabilized laterite blocks, with experimentally verified performance classes, is recommended to support wider adoption. Further experimental research at higher cement contents is essential to validate the predictive model and establish code-compliant material specifications for cement-stabilized laterite blocks.

CRedit authorship contribution statement

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³Olalekan Akeem Salaam: Investigation, Resources, Writing - Review & Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used Grammarly in order to improve readability and language. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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