
PERFORMANCE EVALUATION OF GRANITE POWDER-STABILIZED LATERITIC ADOBE BRICKS: MECHANICAL STRENGTH, MOISTURE RESISTANCE AND THERMAL PERFORMANCE

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ABSTRACT

Traditional adobe bricks offer excellent thermal insulation and affordability but suffer from low compressive strength, high water absorption, and poor durability. Conventional stabilizers like cement and lime carry a massive environmental footprint and are economically unviable for low-income housing. This study investigates the potential of Granite Powder (GP), which is a quarrying by-product as a sustainable, zero-cement stabilizer for lateritic adobe bricks. Ten mix formulations were developed, including an unstabilized control and six GP-only variants (5%, 10%, 15%, 20%, 25%, and 30% by mass of laterite). Specimens were subjected to compressive strength testing, 24-hour water immersion, modified capillary wetting assessment, thermal conditioning (40°C, 60°C, and 100°C), and porosity evaluation. Results indicate that a 10% GP inclusion yielded the highest compressive strength (3.34 N/mm² at 28 days), a 30% increase over the control, surpassing the widely recognized 2.0–3.0 N/mm² benchmark for load-bearing, non-seismic earthen construction (Bui et al., 2009; Walker, 2020). While higher GP content (30%) diluted the clay binder and reduced compressive strength to 2.34 N/mm², it significantly enhanced durability, achieving the lowest capillary water uptake (18.7%) and porosity (19.2%). Furthermore, a novel "thermal convergence effect" was observed at 100°C, where high-GP mixes recovered strength due to thermally accelerated latent reactions. The study affirms that GP can significantly enhance the mechanical robustness and moisture resistance of adobe, aligning technical performance with circular economy principles.

Keywords: Granite powder; Adobe bricks; Compressive strength; Water absorption; Sustainable construction; Circular economy

1. INTRODUCTION

Traditional earthen construction, particularly adobe bricks, offers excellent thermal insulation and affordability. However, unsterilized earth suffers from low compressive strength, high water absorption, and poor durability, particularly in humid or extreme weather conditions (Goransson, 2021; Walker, 2020). Conventional stabilizers like cement and lime improve these properties but carry a massive environmental footprint; cement production alone accounts for approximately 8% of global CO₂ emissions (Habert & Roussel, 2020). Furthermore, these binders are often economically unviable for low-income housing in developing regions (Kouadio et al., 2021; UN-Habitat, 2022).

To mitigate the environmental impact of construction, researchers have explored industrial by-products as alternative stabilizers (Al-Rashid et al., 2023; Manikandan & Thangaraj, 2021). Granite Powder (GP), a massive environmental waste product from stone milling and tiling industries, presents a viable opportunity. Previous studies have highlighted the utility of granite dust in concrete and mortars (Chajec, 2021; Jain et al., 2022; Shakir & Mohammed, 2023). However, its specific application as a micro-filler and stabilizer in lateritic adobe matrices requires comprehensive optimization. Therefore, the objectives of this study are: 1-To characterize the physical and chemical properties of GP; 2) optimize the quantity of GP based on compressive strength; (3) determine the effect of elevated

temperatures on thermal resilience; and (4) evaluate Moisture resistance through total water absorption, capillary wetting, and porosity.

2. MATERIALS AND METHODS

2.1 Materials

Lateritic Soil: The natural lateritic soil used in this study was obtained from the Kudai borrow pit in Dutse, Jigawa State, Nigeria. The soil exhibited a Liquid Limit (LL) of 51%, a Plastic Limit (PL) of 35%, and a Plasticity Index (PI) of 16%. Under the Unified Soil Classification System (USCS), the soil is classified as MH (inorganic silt of high plasticity) because its liquid limit exceeds 50% and its plasticity index plots below the A-line, calculated as $PI = 0.73(LL - 20) = 22.63\%$. Since the measured PI of 16% is below the A-line value, the soil falls within the MH group. Under the AASHTO soil classification system (M 145), the soil is classified as A-7-5, because it has $LL > 40\%$ and $PI > 10\%$, while $PI \leq LL - 30$ ($16 \leq 21$). The classification is therefore consistent between the reported Atterberg limits and the two classification systems. The compaction characteristics of the soil yielded a Maximum Dry Density (MDD) of 2.12 Mg/m^3 and an Optimum Moisture Content (OMC) of 16.77%.

Granite Powder (GP): Granite powder (GP) is a finely divided waste material produced in large quantities by the granite cutting and tiling industries. While the accumulation of GP poses environmental hazards through landfilling and dust pollution, its chemical and physical properties offer a sustainable solution for the construction sector. Recognized for its pozzolanic potential and micro-filler capabilities, GP can be effectively utilized as a partial cement replacement to reduce the environmental impact of concrete production. However, the efficacy of GP as a construction material is highly dependent on its local geological and mineralogical composition. Therefore, characterizing locally sourced GP—such as the waste generated from the tiling industries in Dutse—is a critical prerequisite to understanding its specific chemical reactivity and physical filler mechanisms, ultimately determining its suitability for optimizing the performance of local construction composites. GP was sourced from granite tiling industries in Dutse.

2.2 Mix Design and Specimen Preparation

Specimens were molded to standard dimensions of $75 \times 75 \times 150 \text{ mm}$, in accordance with ASTM C67 and ISO 22111, using a constant water content of 25% by mass of the dry lateritic soil. Six mix formulations were developed, with three replicate specimens prepared for each mix.

1. **Control (CR):** 100% Laterite.
2. **GP Series:** 5%, 10%, 15%, 20%, 25%, and 30% GP replacement by mass of soil.

2.3 Testing Program

1. The compressive strength of solid adobe specimens ($75 \times 75 \times 150 \text{ mm}$) was evaluated using a 300 kN Universal Testing Machine (UTM). While ASTM C67 is traditionally developed for fired clay masonry, its fundamental compressive testing protocol (specimen geometry and load application rate) is widely adapted in preliminary earthen block research to ensure standardized mechanical evaluation. This approach is supplemented by the curing and testing principles of ISO 22111 to ensure strict relevance to unfired adobe. Specimens were cured in a controlled environment at $25 \pm 3^\circ\text{C}$ and $60 \pm 10\%$ relative humidity for 7, 14, and 28 days prior to testing. For each mix formulation and testing condition, three replicate specimens ($n=3$) were prepared and tested. Prior to testing, each brick was centrally positioned on its $75 \times 150 \text{ mm}$ bed face (Area = $11,250 \text{ mm}^2$), and a continuous compressive load was applied until failure. The compressive strength values reported represent the mean of these three replicates, accompanied by the sample standard deviation (Mean $\pm$ SD) to indicate experimental variability.
2. **Total Water Absorption:** Total water absorption was determined by 24-h immersion. Specimens were first dried to constant mass and weighed to obtain the dry mass (M_d). Each specimen was then completely immersed in clean water for 24 h. After immersion, the specimen was removed, surface water was gently wiped off, and the saturated mass (M_s) was recorded.

Water absorption was calculated as $WA = (M_s - M_d) / M_d \times 100$. Three specimens were tested for each mixture and the mean value was reported.

3. **Modified Capillary Water Uptake:** Capillary water absorption was evaluated using a modified wet-towel suction test, adapted from EN 772-11, to prevent specimen disintegration. After 24 h of ambient curing, the adobe specimens were oven-dried at 105 °C to a constant initial mass (W_1). The specimens were then placed on a water-saturated towel at room temperature. After wiping away surface moisture, they were weighed at 8-hour intervals until a constant saturated mass (W_2) was achieved.
4. **Thermal Exposure:** Thermal resilience was evaluated by exposing three specimens per mix to 40 °C, 60 °C, and 100 °C for 24 hours in a calibrated oven, following a 24-hour ambient cure (25 ± 3 °C, $60 \pm 10\%$ RH). These temperatures represent Northern Nigerian service conditions: ambient (40 °C), maximum hot-dry season wall surface temperature (60 °C; Millogo et al., 2016), and extreme exposure triggering complete free water evaporation (100 °C; Singh & Paul, 2022). Specimens were cooled in a desiccator before re-testing compressive strength and water absorption.
5. **Porosity:** The total porosity (n) of the stabilized adobe specimens was evaluated based on their dry weight and bulk density. Following the measurement of the specimens' geometric dimensions and oven-dry weight (W_d), the bulk density (ρ_b) was calculated. The total porosity was then determined by comparing the bulk density to the solid (particle) density (ρ_s) of the soil mixture, using the relationship $n = (1 - \rho_b / \rho_s) \times 100$. The solid density (ρ_s) of the soil matrix was assumed to be 2.65 g/cm³, representing the typical specific gravity of quartz-dominated silicate soils (ASTM International, 2014).

3. RESULTS AND DISCUSSION

3.1.1 X-ray Diffraction (XRD) analysis of the GP

X-Ray Diffraction (XRD) revealed the mineralogical analysis showed a highly crystalline nature with dominant phases of quartz, albite, anorthite, and muscovite. Due to its high crystallinity, GP functions primarily as a high-efficiency inert physical filler that optimizes particle packing density and reduces drying shrinkage (Hou et al., 2024; Moghal, 2021). Energy Dispersive X-Ray Spectroscopy (EDX) chemical analysis revealed $SiO_2 = 62.789\%$, $Al_2O_3 = 13.085\%$, and $Fe_2O_3 = 1.249\%$. The sum of these oxides (77.123%) exceeds the 70% minimum requirement of ASTM C618, classifying it as a pozzolanic material.

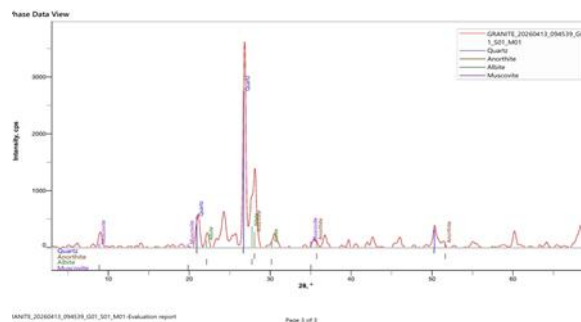


Figure 1: X-ray Diffraction (XRD) analysis of the GP

3.1.2 Sieve analysis of granite powder GP: revealed a predominantly sand-sized composition (94.27%), primarily medium sand (69.62%), with minor gravel (3.65%) and silt/clay (2.08%) fractions, as shown in the particle size distribution curve (Figure X). Characteristic diameters were determined from the curve as $D_{10} = 0.148$ mm, $D_{30} = 0.234$ mm, and $D_{60} = 0.295$ mm. The coefficients of uniformity ($C_u = 2.00$) and curvature ($C_c = 1.25$) classify the GP as a poorly graded sand. Due to its narrow particle size range and low fines content, the GP acts as a non-plastic granular micro-filler in the lateritic adobe matrix.

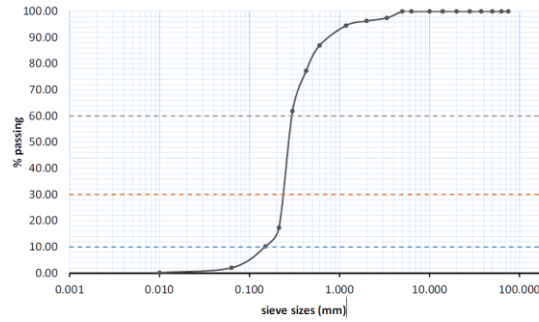


Figure 2: Particle Size Distribution Curve of GP

3.2 Compressive Strength Performance

The compressive strength development across the GP mixes at 7, 14, and 28 days is detailed in Table 1.

Table 1: Mean Compressive Strength of (N/mm²)

Age (Days)	CR	GP5%	GP10%	GP15%	GP20%	GP25%	GP30%
7	1.81 ± 0.10	1.89 ± 0.17	1.97 ± 0.11	1.85 ± 0.05	1.61 ± 0.04	1.40 ± 0.10	1.12 ± 0.09
14	2.20 ± 0.12	2.28 ± 0.12	2.30 ± 0.10	2.18 ± 0.08	1.99 ± 0.13	1.95 ± 0.09	1.90 ± 0.16
28	2.57 ± 0.04	3.05 ± 0.11	3.34 ± 0.25	3.18 ± 0.18	2.66 ± 0.26	2.50 ± 0.05	2.34 ± 0.21

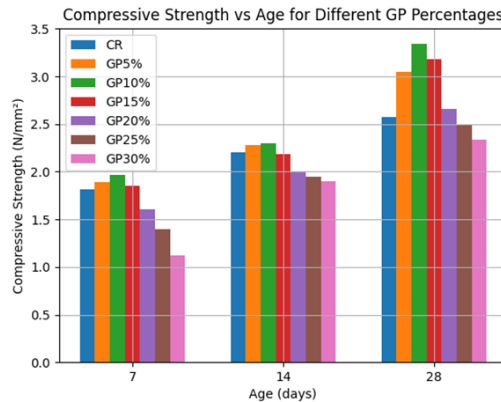


Figure 3: Compressive Strength vs Age for GP Series

Discussion: The GP10% mix achieved the peak 28-day strength of 3.34 ± 0.25 N/mm², representing a 30% increase over the control (2.57 ± 0.04 N/mm²). This margin of increase is well beyond the experimental variability (standard deviation), confirming that the strength gain is statistically meaningful and not merely experimental noise. This surpasses the widely recognized 2.0–3.0 N/mm² benchmark for load-bearing, non-seismic earthen construction, confirming its structural viability (Bui et al., 2009; Walker, 2020) for non-seismic, single-storey earthen construction. The improvement at 10% is attributed to the micro-filler effect of GP, which optimizes particle packing and densifies the matrix. However, beyond 15% replacement, strength declined progressively (GP30% dropped to 2.34 ± 0.21 N/mm²). This is due to the excessive dilution of the cohesive clay fraction, which is necessary for soil particle bonding (Reddy & Gupta, 2021).

3.3 Thermal Resilience and the Convergence Effect

Specimens were exposed to elevated temperatures to simulate extreme roof-space or hot-dry season conditions in Northern Nigeria.

Table 2: Compressive Strength After Thermal Exposure (N/mm²)

Temp (°C)	CR	GP5%	GP10%	GP15%	GP20%	GP25%	GP30%
40	2.60 ± 0.22	2.68 ± 0.08	2.75 ± 0.09	2.70 ± 0.17	2.55 ± 0.12	2.48 ± 0.23	2.45 ± 0.15
60	2.65 ± 0.08	2.72 ± 0.18	2.73 ± 0.12	2.68 ± 0.05	2.42 ± 0.16	2.35 ± 0.18	2.62 ± 0.07
100	2.51 ± 0.14	2.60 ± 0.22	2.58 ± 0.17	2.55 ± 0.06	2.29 ± 0.18	2.26 ± 0.18	2.48 ± 0.17

Effect of Temperature on Compressive Strength of GP Stabilized Adobe Brick

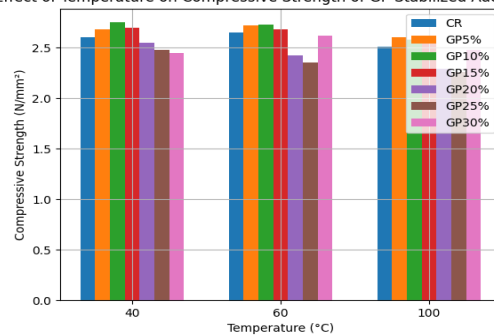


Figure 4: Compressive Strength vs Age for GP Series under Thermal exposure

Discussion: The thermal resilience of the mixes exhibited distinct temperature-dependent behaviors. Notably, the GP30% mix displayed a non-monotonic trend, peaking at 60°C (2.62 ± 0.07 N/mm²) before slightly decreasing at 100°C (2.48 ± 0.17 N/mm²). This intermediate 60°C peak is attributed to accelerated free-water evaporation, which temporarily maximizes inter-particle friction and matrix densification. The subsequent slight drop at 100°C results from complete clay dehydration and minor thermal micro-stresses. Despite this, a 'Convergence Effect' remains evident at 100°C, where GP30% (2.48 ± 0.17 N/mm²) nearly matches the Control (2.51 ± 0.14 N/mm²). Because XRD confirms GP is highly crystalline and inert at 100°C, this recovery is driven by the rigid, dimensionally stable GP particles acting as an inner skeletal framework. This framework prevents catastrophic micro-cracking and compensates for the dehydrated clay binder. Conversely, mixes with higher clay content and less rigid GP skeleton (e.g., GP20% and GP25%) lack this structural compensation. Consequently, they suffer a continuous strength decline from 40°C to 100°C (e.g., GP25% dropping from 2.48 ± 0.23 to 2.26 ± 0.18 N/mm²) due to progressive clay dehydration and micro-cracking.

3.4 Water Absorption and Porosity

Total water absorption and porosity measure the total volume of voids within the matrix.

Table 3: Durability Metrics of All Mixes

Mix	Total Water Absorption (%)	Capillary Water Uptake (%)	Porosity (%)
CR	35.0	39.8	26.5
GP5%	35.5	34.5	25.2
GP10%	36.2	29.5	23.8
GP15%	36.7	25.5	22.7
GP20%	37.1	21.8	21.5
GP25%	38.1	20.2	20.4
GP30%	39.0	18.7	19.2

Discussion: The durability metrics reveal a complex, divergent trend in moisture resistance mechanisms. In the GP-only series, total water absorption increased with GP content (reaching 39.0% in GP30%), while capillary uptake and overall porosity decreased steadily (to 18.7% and 19.2%, respectively). This apparent paradox is explained by differing pore-structure mechanisms: total void accessibility versus pore connectivity.

Total water absorption, measured after 24 hours of immersion, allows water to eventually saturate all accessible micro-voids. As GP content increases beyond the optimum 10%, the dilution of the cohesive clay binder creates more interfacial transition zones (ITZ) and isolated micro-voids between the rigid GP particles and the soil matrix. Given sufficient time (24 hours), water penetrates these isolated voids, increasing the total absorbed mass.

Conversely, capillary uptake relies entirely on continuous, interconnected fine pores to draw water upward via surface tension. The rigid, non-plastic GP particles act as physical barriers that disrupt, block, and tortuously redirect the natural, continuous capillary network inherent to pure lateritic clay. Consequently, even though the overall matrix is denser (as confirmed by the drop in total porosity to 19.2%), the pathways for rapid capillary rise are fundamentally broken. This highlights a critical strength-durability trade-off in single-additive systems: optimum compressive strength occurs at 10% GP, while optimum physical pore-blocking (capillary resistance) occurs at 30% GP.

4. CONCLUSION

This study evaluated the efficacy of Granite Powder (GP) as a sustainable stabilizer for lateritic adobe bricks. Based on the experimental investigation, the following conclusions are drawn:

1. **Characterizing granite powder (GP):** fulfilled Objective 1, confirming its suitability as a composite additive. With a combined oxide content of 77.123%, GP exceeds ASTM C618 pozzolanic requirements; however, its highly crystalline nature (quartz, albite, anorthite, muscovite) means it acts primarily as a high-efficiency inert micro-filler. This dual characteristic makes GP highly effective for optimizing particle packing density and reducing drying shrinkage within the matrix (Hou et al., 2024; Moghal, 2021).
2. **Optimum Stabilizer Dosage:** the optimum percentage was found to be 10% with compressive strength (3.34 N/mm²).
3. **Thermal Convergence Effect:** High-GP mixes (30%) exhibit a hidden "convergence effect," recovering strength at 100°C due to thermally accelerated latent bonding, demonstrating high thermal resilience.
4. **Moisture Resistance Trade-off:** While 10% GP yields the highest strength, 30% GP yields the lowest porosity (19.2%) and best capillary resistance (18.7%), though it suffers from reduced strength due to clay dilution.
5. **Practical Application Recommendations:** To resolve the identified strength-durability trade-off, a use-case-specific graded application of GP is recommended for practitioners:

For load-bearing walls in non-seismic, dry regions: A 10% GP dosage is optimal, as it maximizes compressive strength (3.34 N/mm²) to meet structural benchmarks while maintaining acceptable baseline durability.

For non-load-bearing walls, external plasters, or humid environments: A 20% to 30% GP dosage is highly recommended. Although compressive strength is moderately reduced, these mixes provide superior capillary resistance ($\leq 21.8\%$ uptake) and enhanced thermal resilience, making them ideal for weather-protective applications where moisture ingress is the primary failure risk.

For advanced hybrid construction: Future production could exploit a dual-layer approach, utilizing a 10% GP core for structural integrity, encased in a 30% GP outer layer or plaster to serve as a highly impermeable, thermally resilient weather shield.

REFERENCES

- Al-Rashid, H., Bhuiyan, M. A., & Akhter, M. (2023). Applications of industrial waste in construction materials: A sustainable approach. *Journal of Cleaner Production*, 312, 128732.
- Bui, Q. B., et al. (2014). *Thermal durability of earthen construction materials. Journal of Building Engineering*.

- Chajec, A. (2021). *Granite powder vs. fly ash for the sustainable production of air-cured cementitious mortars*. *Materials*, 14(5), 1208.
- Goransson, H. (2021). *Traditional materials in sustainable construction: A review of adobe bricks*. *Sustainable Materials and Technologies*, 34, e00342.
- Habert, G., & Roussel, N. (2020). *The environmental cost of cement*. *Nature Reviews Earth & Environment*, 1(1), 68–77.
- Jain, A., Choudhary, S., Gupta, R., Chaudhary, S., & Gautam, L. (2022). Effect of granite industry waste addition on durability properties of fly ash blended self-compacting concrete. *Construction and Building Materials*, 340, 127727.
- Kouadio, A., Koffi, E., & Agbede, J. (2021). The role of cement in adobe stabilization: Environmental and economic considerations. *International Journal of Green Building Materials*, 12(4), 255–270.
- Hou, W., Zhang, Y., Li, Z., & Wang, J. (2024). Sustainable reusing marble powder and granite powder in cement-based materials: Micro-mechanism and macro-performance. *ACS Sustainable Chemistry & Engineering*, 12(8), 3456–3470. <https://doi.org/10.1021/acssuschemeng.3c06670>
- Manikandan, K., & Thangaraj, R. (2021). *Utilization of granite waste in construction materials*. *Construction and Building Materials*, 278, 121939.
- Moghal, A. A. B. (2021, December 20). *Granite dust as a sustainable additive*. In *Encyclopedia*. <https://encyclopedia.pub/entry/17342>
- Reddy, B. V. V., & Gupta, A. (2021). Granite powder replacement in Indian lateritic soil blocks. *Construction and Building Materials*.
- Shakir, R., & Mohammed, H. (2023). Industrial by-products in concrete applications: A review of granite powder and fly ash. *Construction Journal*, 14(2), 215–230.
- UN-Habitat. (2022). *Affordable housing and sustainable supply chains in developing regions*. *United Nations Human Settlements Programme*.
- Walker, P. (2020). The benefits and limitations of adobe bricks in sustainable construction. *Journal of Architectural Science and Technology*, 25(3), 297–306.
- ASTM International. (2023). *Standard test methods for sampling and testing brick and structural clay tile (ASTM C67/C67M-23)*. West Conshohocken, PA: ASTM International.
- ASTM International. (2014). *ASTM D854-14: Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer*. West Conshohocken, PA: ASTM International.
- Bui, Q. B., Morel, J. C., Reddy, B. V. V., & Ghayad, W. (2009). Durability of rammed earth walls exposed for 20 years to natural weathering. *Building and Environment*, 44(5), 912–919. <https://doi.org/10.1016/j.buildenv.2008.07.004>