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Physico-mechanical characterization of stabilized earth blocks with snail shell and termite mound powders as pozzolanic binders

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Abstract

The aim of this study is to reduce the reliance on cement in the construction of Stabilized Earth Blocks (SEBs) by assessing the addition of snail shell and termite mound powders as a partial substitute for cement. The focus of this study is on the valorization of local materials and animal waste in sustainable construction. Laterite, used as the base material, was stabilized by substituting 0 to 80% of the cement with snail shell and termite mound powders to create blocks that were tested for their mechanical strength and water absorption. The results show that the compressive strength of the blocks remains above the required threshold of 4 MPa up to a 50% substitution, with a downward trend at higher rates. The capillary water absorption of the stabilized earth blocks remains within the limits of blocks classified as low-absorption, with coefficients ranging from 0.58 $kg/m^2/min$ at a 50% substitution to 1.14 $kg/m^2/min$ at an 80% substitution. These findings suggest that a substitution up to 50% could represent an adequate balance between mechanical performance and environmental benefits, thus ensuring the required durability and mechanical strength. Although the research is limited to the study of these materials in their raw state, future work could explore the enhancement of the pozzolanic activity of snail shell and termite mound ash through treatments such as calcination to further strengthen the eco-efficiency of the process.

Keywords: Stabilized Earth Block; Snail shell; Termite mound; Bio-based materials; Sustainable construction

1. Introduction

The utilization of earth as a building material is ancient, esteemed for its availability and low energy impact, notably for its thermal insulation performance. However, this age-old material has seen renewed interest, especially in developing countries facing an ongoing housing crisis. In contrast to conventional building materials such as cement, concrete, and steel, earth allows for construction use that significantly reduces energy expenditures, in addition to offering substantial environmental, social, and economic benefits.

Despite its advantages, earth in its natural state has limitations, including marked sensitivity to weather conditions, thus affecting the durability of constructions. Mechanical stabilization, while improving the mechanical strength of earth bricks, fails to mitigate their water sensitivity, posing a durability problem in regions with high rainfall. Mechanically stabilized earth tends to become plastic and lose strength upon wetting, leading to stability issues and progressive erosion in earth constructions.

To enhance the mechanical hold and water resistance of bricks, the addition of binders such as cement and lime is common [1–6]. Stabilized earth blocks with 3 to 12% cement content are most widely used, yet this practice raises

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significant environmental concerns [7]. Cement production contributes 9-10% of global CO_2 emissions, accounting for up to 81% of concrete emissions [8]. [9] have assessed the environmental impact of adding Ordinary Portland Cement (OPC) for stabilizing earth materials, concluding that the mechanical improvement is modest considering the environmental cost. Moreover, a significant quantity of mineral binders can restrict the recyclability of earth materials, thus limiting the ecological benefits of their use [10]. Additionally, [11] highlights the environmental inconsistency of stabilizing earth with more than 4% mineral binder, as it would result in a cement content higher than that of a standard water-resistant concrete block, with a compressive strength of 4 to 8 MPa. His work reveals that low proportions of mineral binder (2 and 4%) do not significantly affect dry compressive strength or thermal conductivity but do significantly impact water resistance and humidity buffering value

In response to environmental concerns associated with the use of mineral binders, research has explored the use of natural organic binders such as starches, cow dung, or tannins [12–18]. However, while these organic additions are environmentally beneficial, their ability to enhance the compressive strength of earth construction materials is generally limited [14,17,19]. In an effort to balance mechanical performance and ecological impact, other studies are moving towards the use of low-carbon footprint pozzolans, often associated with industrial or agricultural by-products like wood ash, coal ash, sugarcane bagasse ash, or rice husk ash [20–25]. These studies show that reducing the quantity of cement or lime, coupled with these pozzolans, can preserve adequate mechanical properties while significantly lowering CO_2 emissions related to construction.

In this vein, the goal of this study is to propose a method for stabilizing raw earth that significantly reduces environmental impact by minimizing cement use. This research assesses the effectiveness of using snail shell and termite mound powders, agricultural waste, as a partial substitute for cement to create a pozzolanic binder and examines whether this approach meets the mechanical performance and durability criteria required for building materials.

This approach is fully aligned with sustainable construction practices, valuing local materials and by-products previously considered as waste. By exploring the potential of raw earth and assessing the impact of partially substituting cement with bio-based materials, this study contributes to the global effort to reduce the carbon footprint in the construction sector and underscores the importance of judicious use of natural resources in an environmentally respectful manner.

2. Material and methods

2.1. Laterite

The laterite used in this study (Figure 1) was sourced locally, displaying a granulometric curve within the standardized envelope [26] (Figure 2). The physical characteristics of the laterite are summarized in Table 1.

Figure 1 Laterite

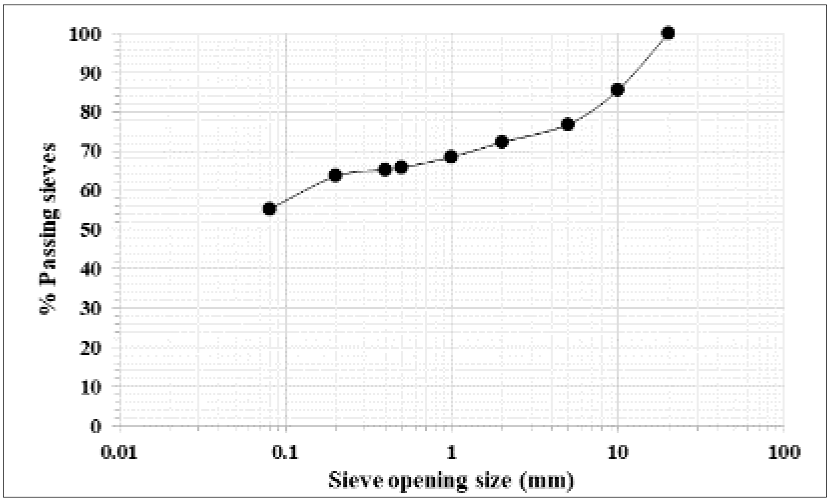

Figure 2 Size distribution of laterite

Table 1 Physical characteristics of laterite

Physical parameters	Values
Dry Density (t/m^3)	1.876
Optimal Moisture Content (%)	12.90
Natural Moisture Content (%)	2.25
Plasticity Index (%)	20.1
Consistency Index (%)	1.74
Percentage of Fines (%)	55.25
Methylene Blue Value "MBV"	1.37

2.2. Snail shells and termite mound

Snail shells, after being washed and dried, were crushed and ground into powder. This powder was then sieved through a 0.315 mm mesh (Figure 3). Similarly, the termite mound, collected in its natural state, was cleaned of impurities, crushed, and ground into a fine powder before being sieved through the same mesh size (Figure 4).

Figure 3 Whole and ground snail shells

Figure 4 Termite mound in natural state and after crushing and grinding

2.3. Cement

The cement used for this study is a composite Portland cement CEM II/B 32.5R. Its specific surface area Blaine and density are 3480 cm^2/g and 2.99, respectively. The chemical and mineralogical composition of the cement are provided in Table 2 and Table 3.

Table 2 Chemical composition of cement

Oxides	**CaO**	**SiO2**	**Al2O3**	**F2O3**	**MgO**	**Na2O**	**K2O**	**SO3**	**Cl**	**Loss on Ignition**
%	54.4	21.0	6.7	3.4	2.2	0.31	0.75	2.7	0.06	7.1

Table 3 Mineralogical composition

Phase	**Clinker**			
Minerals	C_3S	C_2S	C_3A	C_4AF
Content (%)	62.72	10.86	8.47	9.83

2.4. Production of Stabilized Earth Blocks (SEBs)

For the production of SEBs, a fixed mass of dry soil mixture was established, to which 10% cement was added as the main stabilizer. A portion of this cement was then substituted with a mixture of "snail shells + termite mound," varying from 0 to 80% by increments of 10% (Table 4). It is noted that this substitution mixture was composed of equal parts snail shells and termite mound, 50% each.

Table 4 Mix designs for the blocks

SOIL + CEMENT + (SNAIL SHELLS + TERMITE MOUND)				
Total dry mix = 9900 g				
Substitution Rate (%)	**Soil (g)**	**Cement (g)**	**Snail Shell + Termite Mound (g)**	**Water (ml)**
0	9000	900	0	1277.1
10	9000	810	90	1277.1
20	9000	720	180	1277.1
30	9000	630	270	1277.1
40	9000	540	360	1277.1
50	9000	450	450	1277.1
60	9000	360	540	1277.1
70	9000	270	630	1277.1
80	9000	180	720	1277.1

Dry mixing was first performed to ensure homogeneity of the mixture, indicated by a uniform color throughout the volume. Gaging water was then added to achieve optimal moisture content as determined by the Proctor test. The mixture was then wet mixed until homogeneous before being poured into a mold. After compaction, the samples were immediately demolded.

Curing the blocks is critical to developing optimal mechanical strength, particularly for cement-stabilized blocks, which require internal moisture. To maintain an adequate atmosphere, the samples were covered with a plastic sheet for 7 days to preserve moisture and shielded from sun and wind to prevent shrinkage cracks (Figure 5). Subsequently, the samples were stored in the open air with adequate ventilation to facilitate air circulation.

Figure 5 Appearance of the blocks inside the plastic bag

After the curing period, the blocks were subjected to tests to evaluate their capillary water absorption in accordance with standard NF EN 772-11 [27]. Mechanical properties, such as tensile splitting strength and compressive strength, were measured following standards NF EN 12390-6 [28] et NF EN 772-1+A1 [29], respectively.

3. Results and discussion

3.1. Water absorption by capillarity

As indicated in Figure 6, the capillary water absorption coefficient of the stabilized earth blocks varies with the percentage of cement substituted with snail shell and termite mound powders. It is observed that water absorption exhibits a nonlinear trend as the substitution percentage increases.

The initial increase in water absorption with low substitution rates could be attributed to changes in the microstructure of the blocks. The added powders may initially act as fillers, filling spaces between laterite particles, but without providing a sufficient pozzolanic bond to reduce porosity. However, as the substitution rate increases, a decrease in absorption is noted, reaching its lowest point at 50% substitution. This could be the result of a partial pozzolanic reaction, where the shells (primarily composed of calcium carbonate) and termite mounds (rich in silica and alumina) begin to react with the alkaline solution of the cement to form secondary cementitious products, thus improving the material's density and reducing its accessible porosity.

Yet, beyond 50% substitution, the marked increase in the absorption coefficient suggests a threshold beyond which the addition of these powders may reverse the gains in density, possibly due to a saturation of the mix that hinders the formation of effective cementing products or leads to a less favorable particle dispersion in the matrix.

It is important to note that despite these fluctuations, all blocks tested remain within an acceptable range of water absorption [27], indicating a generally satisfactory performance in terms of moisture resistance.

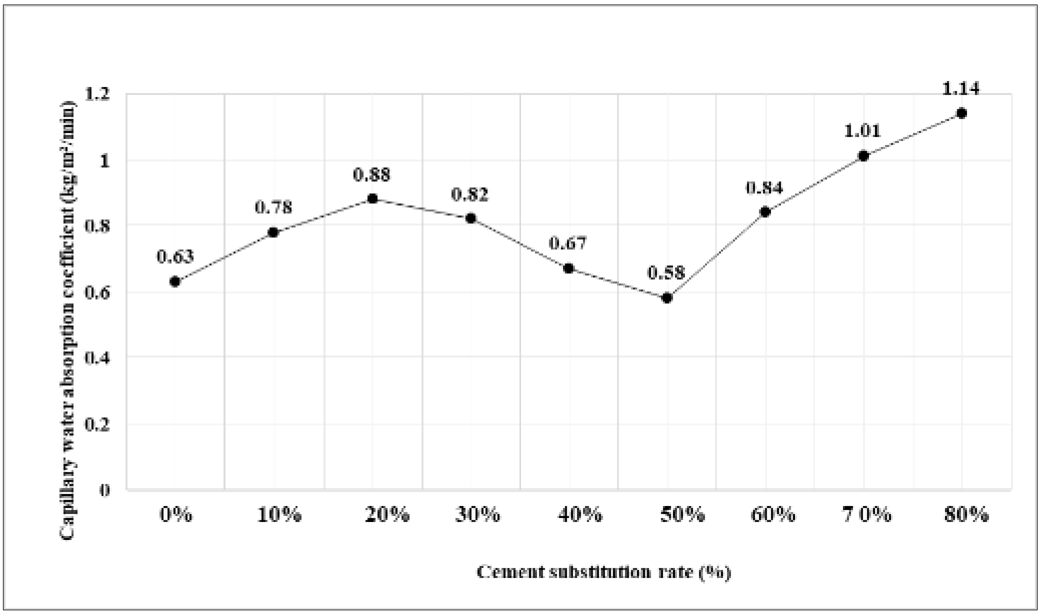

Figure 6 Variation of the capillary water absorption coefficient with the rate of cement substitution

3.2. Mechanical properties of the composites

Figure 7, compares the compressive and tensile strengths of stabilized earth blocks and reveals a general trend of decreasing strength with increasing rates of cement substitution by snail shell and termite mound powders. However, a key observation is that the compressive strength only falls below the 4 MPa threshold when a substitution rate of 60% is reached. At 50% substitution, the compressive strength remains above this threshold, suggesting that substitution up to this point could be viable for structural applications requiring a minimum strength of 4 MPa [26]. This observation, combined with the acceptable range of water absorption by capillarity, indicates that a substitution of up to 50% of cement with snail shell and termite mound powders could be viable from the perspectives of durability and structural performance.

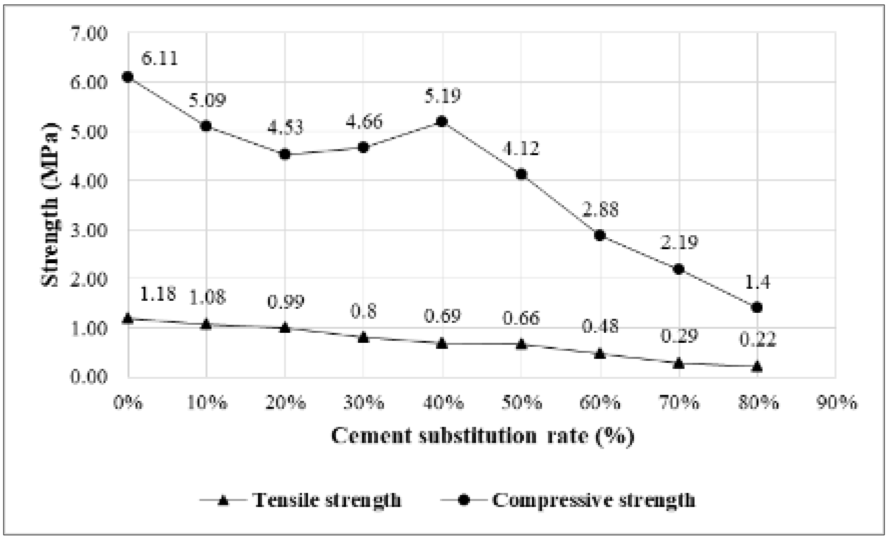

Figure 7 28-day strength variations with cement substitution rate

The decline in compressive strength can be attributed to several factors. At low rates, the powders may act as fillers that improve material density but do not significantly contribute to the formation of cementing products that enhance strength. With increasing substitution rates, a pozzolanic reaction may occur, contributing to the formation of cementitious products and improving strength up to a certain threshold, beyond which the benefits of pozzolanicity may decrease or be offset by other effects, such as overloading the cement matrix with non-reactive materials or an excess of fines that negatively affect the composite structure.

Considering the study's goal to reduce cement in earth blocks for a lesser environmental impact, it appears that substituting up to 50% of the initial cement with snail shell and termite mound powders is a viable approach. This substitution allows for the maintenance of acceptable mechanical properties while potentially enhancing the material's durability.

4. Conclusion

This research endeavored to assess the viability of utilizing local materials and agricultural by-products to reduce the environmental footprint of stabilized earth bricks. In addressing the challenges posed by cement production, such as significant CO_2 emissions and overall environmental impact, the study evaluated the effectiveness of partially substituting cement with snail shell and termite mound powders.

The findings revealed that up to a certain substitution threshold, it is possible to maintain compressive strength above 4 MPa, a value that meets structural requirements for certain construction applications. Moreover, the classification of the blocks as low-absorption is confirmed by the measured capillary water absorption coefficients, thus underlining the uncompromised durability of the blocks despite the applied substitution rates.

Considering these results, the addition of snail shell and termite mound powders acts as a partial substitute for cement in stabilized earth blocks, up to a rate of 50%. This practice not only reduces the use of cement but also contributes to the valorization of local materials and the sustainable management of agricultural waste.

For future studies, it would be pertinent to further investigate the pozzolanic activity of snail shell and termite mound, including the impact of calcination on this activity. A deeper exploration of these processes could provide additional insights to optimize the use of these materials in producing stabilized earth blocks with enhanced mechanical and durability properties.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that there are no conflicts of interest that could inappropriately influence, or be perceived to influence, the work reported in this manuscript.

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Author Contributions

- Conceptualization and study design: Gontrand C. Bagan, Edmond C. Adjovi
- Data collection: Megalvio Y. Tossa
- Data analysis and interpretation: Megalvio Y. Tossa, Edem Chabi
- Manuscript drafting: Megalvio Y. Tossa, Edem Chabi
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- Final manuscript approval: V Megalvio Y. Tossa, Edem Chabi, Gontrand C. Bagan, Edmond C. Adjovi.

Data and Code Availability

No additional datasets or code repositories are associated with this research.

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