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ARTICLE

Performance of Clay-Based Earth Bricks with Varying Sand Content: A Case Study of Lendi Soil, Douala

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ABSTRACT

This study evaluates the influence of sand content on the mechanical behavior and water resistance of compressed earth bricks (CEBs) manufactured from Lendi clay (Douala, Cameroon). Twenty-seven specimens (prismatic and cubic) were produced with three formulations: 0%, 30% and 60% sand substitution by dry mass, compacted at 2.5 MPa and cured for 7, 14 and 28 days. Raw material characterization included particle size distribution, sand equivalent, Atterberg limits, bulk density and Proctor compaction. The clay displayed a liquid limit of 44.07%, plastic limit of 35.23% and plasticity index of 8.84%; optimum moisture content was 15.9% and maximum dry density 1.24 g·cm^{-3}. Mechanical testing showed that pure-clay bricks achieved the highest compressive and flexural strengths at all ages (up to ≈ 1.98 MPa and 0.56 MPa respectively). Although the 30% sand mix exhibited marginally higher early compressive strength (7 days),

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strength decreased substantially by 28 days. Capillary absorption tests revealed an important distinction: while 0% sand bricks exhibited continuous water uptake, they retained cohesion during immersion; conversely, 30% and 60% sand bricks disintegrated into a slurry within seconds of immersion, evidencing severe loss of internal bonding. These findings indicate that, for this highly plastic tropical clay, sand acts primarily as a microstructural diluent that undermines long-term cohesion and durability despite short-term packing benefits. The study underscores the need for locally tailored formulations or stabilizers when designing durable CEBs for humid tropical climates.

Keywords: Earth Brick; Clay Soil; Physical Properties; Mechanical Properties; Aggregates

1. Introduction

Earth has been used as a building material since antiquity and continues to offer a sustainable alternative for modern construction. With rapid urban growth and rising environmental concerns, the demand for affordable, eco-friendly materials has increased significantly. Compressed earth bricks (CEBs), manufactured from locally available clay and aggregates, provide a low-cost, low-embodied-energy solution with favorable thermal properties, particularly adapted to tropical climates [1–8]. This positions them as a promising substitute for traditional fired bricks and concrete, which often carry higher environmental costs.

The performance of CEBs largely depends on the soil's composition and the additives incorporated. Clay functions as a natural binder, while the addition of sand and fibers can modify critical properties such as strength, porosity, and durability. However, the ideal ratio of these components remains a subject of ongoing research, especially regarding the sand proportion's influence on brick plasticity and cohesion [9–14]. In tropical regions like Douala, Cameroon, resistance to water penetration is paramount due to the humid climate, making durability a major concern [15–18].

This research investigates the effect of sand content variation at different proportions (0%, 30%, 60%) on the physical and mechanical properties of earth bricks produced from local clay soils. Unlike approaches focusing on chemical stabilization, this work emphasizes natural material variation, aiming to identify an optimal mix that maintains sufficient strength while improving durability. The experimental program spans curing times of 7, 14, and 28 days to capture the evolution of mechanical performance and moisture behavior [19–25]. This detailed assessment, grounded in locally sourced materials, contributes novel insights for sustainable building practices tailored to tropical contexts.

Despite some benefits of sand addition in improving granular packing, excessive amounts may impair the mixture's plasticity, weakening the bonds between particles and reducing mechanical resistance. Additionally, increased sand content can elevate porosity, thereby increasing water absorption and risking premature degradation under humid conditions [26–31]. Hence, balancing sand proportion is crucial to optimize both strength and durability.

Furthermore, recent research emphasizes that the mechanical and durability performance of compressed earth bricks (CEBs) depends not only on their composition but also on their internal packing structure and moisture-transport behavior. The Proctor-derived optimum moisture content and dry density define the initial packing and void ratio, which govern both particle bonding and capillary continuity within the matrix. These microstructural parameters directly influence sorptivity, permeability, and strength retention under wet conditions.

Contemporary studies integrating moisture-transport theory and pore-network models [32,33] have shown that reducing interconnected porosity decreases capillary sorptivity and enhances long-term resistance to degradation. Thus, aligning compaction energy, pore structure, and moisture migration mechanisms provides a coherent framework for interpreting both strength and durability in tropical soils.

The general objective is to evaluate how varying sand content influences the physical, mechanical, and durability attributes of compressed earth bricks from Douala. Specific goals include characterizing raw materials through granulometry and Atterberg limits, producing bricks with controlled sand contents, and assessing their flexural and compressive strengths as well as capillary water absorption over time.

To structure the investigation, three research questions are proposed: What impact do different sand proportions have on the physical and mechanical performance of clay-based bricks? Which sand percentage offers the best compromise between strength and moisture resistance? How does curing duration affect these properties in reinforced bricks?

Accordingly, three hypotheses guide the study: Firstly, increasing sand content reduces clay plasticity and cohesion, thereby diminishing mechanical strength. Secondly, moderate sand levels may initially enhance granular compactness and compressive strength, but higher amounts lead to brittleness and weakening. Third, greater sand proportions elevate water absorption, undermining durability.

These assumptions are tested through standardized laboratory methods, including granulometric analysis and Atterberg limits to assess soil plasticity, mechanical testing at multiple curing ages to evaluate strength development, and water absorption tests to measure moisture resistance. The findings aim to inform formulation strategies for durable, sustainable earth bricks adapted to humid tropical regions, addressing pressing environmental and construction challenges.

The paper is structured as follows: Section 2 details the materials and methods used, including soil characterization, brick manufacturing, and testing protocols. Section 3 presents and discusses the experimental results, focusing on physical properties, mechanical performance, and durability indicators. Finally, Section 4 concludes with key findings, limitations, and recommendations for future research to optimize earth brick formulations in similar contexts.

2. Materials and Methods

2.1. Study Area and Material Collection

The raw clay soil used in this investigation was collected from the locality of Lendi in Douala V, Cameroon, at coordinates 4°07'43” N and 9°46 '22” E. This area was selected because of the high availability of fine-grained lateritic soils and the growing interest in sustainable construction materials in peri-urban zones of Douala. Soil sampling was conducted manually at a depth of 1.00 m to ensure the extraction of undisturbed subsurface layers, as surface soil is often altered by organic matter or anthropogenic activities. The collected samples were sealed in plastic woven bags and transported to the laboratory for preparation.

Figure 1 illustrates the location of the sampling site in Douala, and **Figure 2** shows both the site and the clay sample collected.

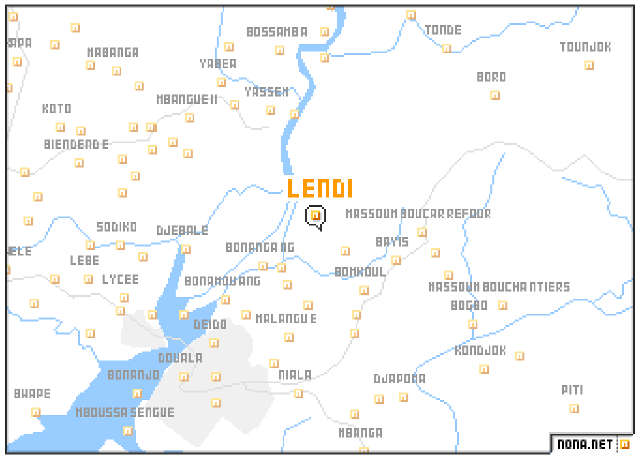

Figure 1. Location map of the study area in Douala, Cameroon [15].

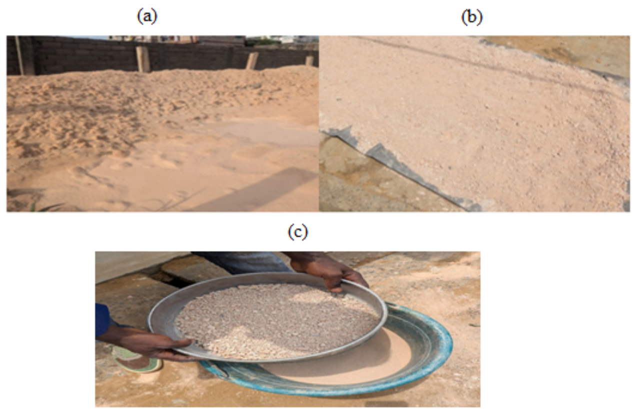

Figure 2. (**a**) Sampling site at Lendi; (**b**) Raw clay sample collected at 1 m depth; (**c**) Soil sieving for clay paste preparation.

The sand used as aggregate was clean river sand extracted from the Sanaga River in Edéa, within the Sanaga Maritime division of the Littoral region. With a fineness modulus of 2.652 and a sand equivalent of 95.74%, it was confirmed to be of excellent quality and nearly free from clayey fines, meeting the standards defined by Malbila, E. et al. [18] and Che, P.B. [19]. Before use, the sand was washed and oven-dried to eliminate organic residues and ensure consistency during formulation.

2.2. Characterization of Raw Materials

2.2.1. Natural Water Content

The natural water content (W) reflects the moisture retained by the soil at the time of sampling, an important parameter influencing compaction and plasticity. It was determined following NF P 94–050[16] using Equation (1):

$$W\%=\frac{(W_h-T)-(W_d-T)}{(W_d-T)} \times 100 \quad (1)$$

Where W_h is the mass of the wet soil sample (g), W_d the mass of the dried sample after 24 h at 105 °C (g), and T the mass of the tare (g).

2.2.2. Bulk Density and Specific Gravity

Bulk density (D) represents the mass per unit volume of a material, including the solid particles and the pores between them. It is calculated from the mass of a known volume of material according to:

$$D=\frac{M}{V} \quad (2)$$

where M is the mass of the sample (g) and V the total volume (cm³). Specific gravity (Gs), on the other hand, expresses the ratio between the density of solid particles and that of water, representing only the solid phase. It is typically measured using a pycnometer or density bottle.

2.2.3. Sand Equivalent

To quantify the proportion of fine particles in the sand, the sand equivalent (SE) test was performed using two methods: the visual sand equivalent (VSE) and the piston method (PSE)[18,19]. The results are calculated using:
Visual sand equivalent (VSE)

$$VSE=\frac{H_2}{H_1} \times 100 \quad (3)$$

Piston sand equivalent (PSE)

$$PSE=\frac{H_2'}{H_1} \times 100 \quad (4)$$

Where: H_1 is the total height of the suspension (mm), H_2 the sediment height (VSE), and H_2' the sediment height using the piston (PSE).

A high SE value (>80%) indicates minimal clay content and improved aggregate cleanliness, critical for enhancing bonding properties in earthen bricks[8].

2.2.4. Particle Size Distribution

The particle size distribution of the sand was determined through dry sieving, consistent with NF P 18-598[19]. A stack of sieves with decreasing mesh sizes was used to separate particles based on diameter. From the retained mass on each sieve, the cumulative rejection percentage and fineness modulus Mf were calculated as follows:

$$M_f=\frac{\sum \text{Cumulative rejections in \% on a series of sieves}}{100} \quad (5)$$

A fineness modulus in the range $2.0<M_f<3$ is indicative of fine sand, suitable for blending with cohesive soils[23].

2.2.5. Atterberg Limits

Atterberg limits liquid limit (W_L), plastic limit (W_P), and plasticity index (PI) characterize the consistency range of clayey soils. According to EN ISO 17892–12[20], the plasticity index is defined by:

$$P_I=W_L-W_P \quad (6)$$

High plasticity indices indicate clays that may undergo significant volumetric changes during drying or wetting cycles[6].

2.2.6. Proctor Compaction Test

The Proctor test was carried out as per NF P94-093[21] to determine the optimal moisture content for maximum dry density (γ_d). Compaction was performed in a standardized mold in three layers with controlled blows using a Proctor hammer. The dry density at each moisture level was computed and plotted to generate the compaction curve. The peak of this curve defines the optimal water content (W_{opt}) and maximum dry density ($\gamma_{d,max}$):

$$\gamma_d=M_d/V_m \quad (7)$$

Where: M_d is the mass of the dry compacted sample (g), and V_m is the volume of the mold (cm³).

2.3. Fabrication of Test Specimens

2.3.1. Clay Paste and Brick Formulation

The prepared clay was sieved through a 1.25 mm mesh (**Figure 2c**) to ensure fine granularity. The clay paste was prepared by mixing 600 g of oven-dried clay (equivalent to a volume of 483.8 mL) with 95.4 mL of water, corresponding to the Proctor-derived optimum moisture content of 15.9% and a maximum dry density of 1.24 g/cm³.

2.3.2. Specimen Molding

The paste was molded using a hydraulic press into prismatic specimens (4 × 4 × 14 cm³) for flexural strength tests and cubic specimens (4 × 4 × 4 cm³) for compressive strength tests (refer **Figure 3**). A compaction pressure of 2.5 MPa was applied, based on previous experimental work on similar lateritic soils, which reported that pressures between 2 and 3 MPa maximize density without inducing cracking or rebound. This range also corresponds to the mechanical limits of the manual and semi-mechanical presses typically available in local CEB production units. The reinforced bricks were prepared with 30% and 60% sand substitution, as presented in **Table 1**. 18 specimens were produced for each formulation, cured under ambient laboratory conditions, and tested after 7, 14, and 28 days of curing.

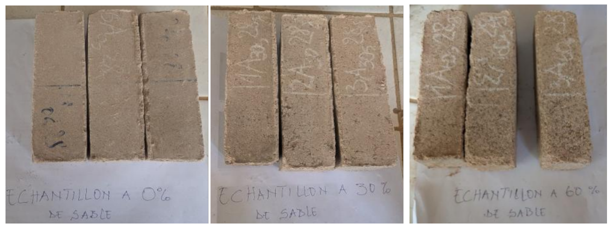

Figure 3. Bricks manufactured with varying aggregate content (0%, 30%, and 60% sand).

Table 1. Proportions of clay and sand in brick formulations.

	Clay (%)	Sand (%)	Water (%)	Number of CEB
CEB 0	100	0	15	9
CEB 1	70	30	10.5	9
CEB 2	40	60	6.5	9

2.4. Mechanical Tests

2.4.1. Flexural Strength

Flexural strength was assessed using a three-point bending test on prismatic samples [4,13]. The stress σ was calculated as:

$$\sigma=\frac{3FL}{2bh^2} \tag{8}$$

where F is the maximum load before failure (N); L the span length (cm), b the width of specimen (cm), and h the height of specimen (cm). For our tests, b=h=4cm, L= 14 cm, which approximately is more than 2.5 times the specimen height, consistent with ASTM C67 [32] recommendations for clay masonry.

2.4.2. Compressive Strength

Cubic samples were subjected to uniaxial compression tests using a Form Test hydraulic press. Compressive strength R_c was obtained as:

$$Rc = \frac{F}{S} \tag{9}$$

where F is the failure load (N), and S: cross-sectional area (mm²).

2.5. Durability Assessment

2.5.1. Water Absorption and Sorptivity

Capillary absorption tests were performed according to ASTM C20 [22] but interpreted following the modern principles of capillary sorptivity (the rate at which water penetrates a porous material through capillary suction) described in ASTM C1585 (2020) [33] and RILEM TC 116-PCD [34]. The rate of water absorbed is calculated as follows:

$$A_w\,(\%) = \frac{(m_h - m_s)}{m_s} \times 100 \tag{10}$$

Where: m_h is the wet mass (g), m_s the dry mass (g), A_w= absorption rate (%).

3. Results and Discussion

3.1. Physical Properties of Materials

3.1.1. Natural Water Content

The natural water content, determined according to Section 2.2.1, was found to be 26.95% (**Table 2**). This relatively high water content is characteristic of stiff clay, influencing plasticity and compaction behavior critical for brick molding and drying shrinkage control [1,23]. High moisture favors workability but can increase the risk of cracking during drying, a significant limitation in both compressed earth bricks (CEBs) and soil applications in geotechnical roadworks [10,35].

Table 2. Natural water content results.

Tests No.	1	2
Total Wet Weight (W_h)	100	100
Total Dry Weight (W_d)	92.6	92.2
Tare Weight (T)	64.2	64.2
Water Weight (W_h−T) −(W_d−T)	7.4	7.8
(W_d−T) (Dry Material Weight)	28.4	28
Water Content (W (%))	26.05	27.85
Average Water Content (%)	26.95	

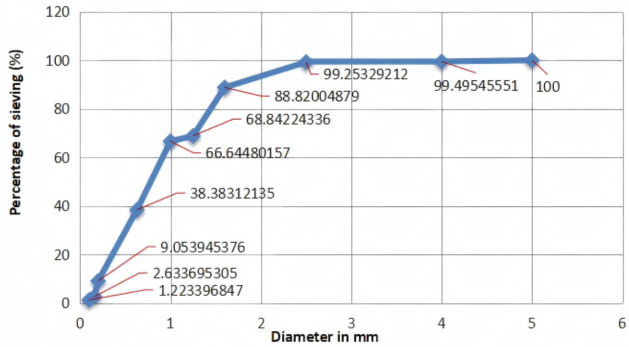

Figure 4. Particle size curve of 0/5 sand.

3.1.2. Bulk Density

Using the procedure from Section 2.2.2, bulk densities of 0.88 g/cm³ for the clay and 1.52 g/cm³ for the sand were obtained (**Table 3**). These values corroborate existing studies [23] and imply a porous clay matrix, which affects mechanical resistance and durability of bricks, as well as subgrade stiffness in road construction [8,29].

Table 3. Bulk density results of the materials used.

Material	Bulk Density (g/cm^3)
Clay Soil	0.88
0/5 Sand	1.52

3.1.3. Sand Equivalent

The sand cleanliness tests, following Section 2.2.3, yielded high sand equivalent values (VSE ≥ 85, PSE ≥ 80), confirming minimal clay fines and excellent aggregate quality (**Table 4**). Such clean sand enhances bonding potential and mechanical strength but must be balanced against loss of plasticity from excessive sand [18,26].

Table 4. Sand equivalent results.

Sand Type	VSE	PSE	SE
Sanaga sand	95.91	95.57	95.74

3.1.4. Particle Size Distribution

Particle size distribution was assessed by dry sieving following Section 2.2.4. The sand's fineness modulus (M_f = 2.652) classifies it as fine-grained sand, beneficial for packing density but potentially detrimental in excess (refer **Figure 4** and **Table A1**). This matches recommendations for sand content in earth bricks and road base materials to optimize strength and reduce shrinkage [9,14].

3.1.5. Atterberg Limits

Atterberg limits testing followed Section 2.2.5, yielding a liquid limit of 44.07%, plastic limit of 35.23%, and plasticity index of 8.84% (**Table 5** and **Figure 5**). This places the soil in the sandy clay category, with moderate plasticity conducive to earth construction and road foundation applications [10,24,36]. The various data obtained for these results are shown in **Table A2** of the **Appendix A**.

Table 5. Atterberg limit results.

Formulation	W_L	Wp	PI
3%	35.91	32.54	3.37
6%	47.85	34.15	13.7
8%	48.46	39	9.46
Average	**44.07**	**35.23**	**8.84**

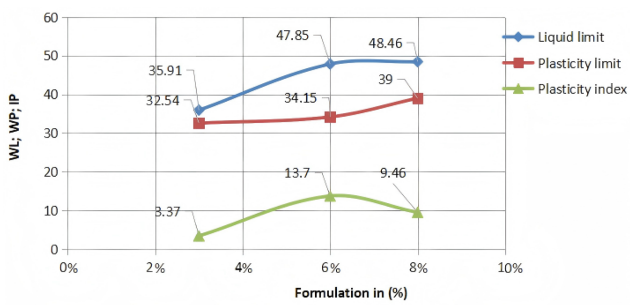

Figure 5. Atterberg limits (liquid limit, plastic limit, plasticity index).

3.1.6. Proctor Compaction Test

The Proctor test conducted following subsection 2.2.6 as presented in **Figure 6** yielded an optimal water content (Wopt) of 15.9% and maximum dry density (γd,max) of 1.24 g/cm³. These values are critical for defining compaction parameters to maximize strength and stability in both brick production and soil compaction for roads [6,12,30].

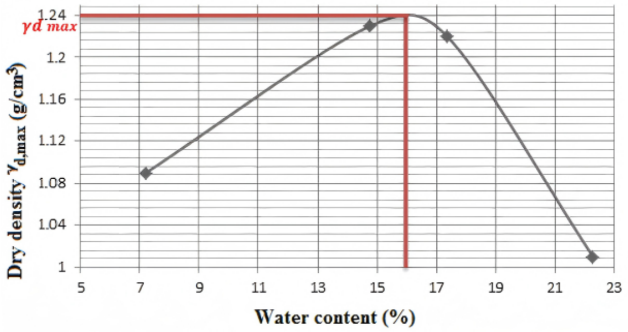

Figure 6. Proctor compaction curve showing dry density vs. water content.

3.1.7. Evolution of Bulk Density of CEB Samples over 28 Days

Bulk density measurements on bricks over 28 days (subsection 2.3.2 and 2.4) showed that drying reduces density due to moisture loss (**Figure 7**), as presented in the **Appendix A** in **Table A3**. Pure clay bricks have the highest initial density but also the highest shrinkage; sand additions reduce density but limit shrinkage, with 30% sand providing a good balance. This is consistent with literature advocating sand contents of 20–40% to control shrinkage while preserving density and strength[14,23,36].

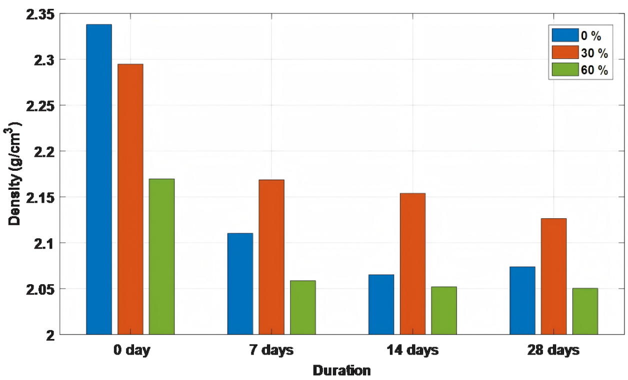

Figure 7. Bulk density evolution of CEB samples over 28 days.

3.2. Mechanical Properties

For each formulation, three specimens were tested and the mean values with their standard deviations were calculated. Error bars representing ± standard deviation are used to visualize variability.

3.2.1. Flexural Strength

Three-point bending tests as shown in **Table A4** in the **Appendix A**, and calculated according to Section 2.4.1 showed a clear decline in flexural strength with increased sand content and curing time (**Figure 8**). Pure clay bricks (0% sand) had the highest flexural strength (up to 0.558 MPa at 14 days), while 60% sand bricks reached as low as 0.032 MPa at 28 days, indicating loss of cohesion and brittleness. Excess sand disrupts clay plasticity and bonding, a limitation corroborated by Kenmogne et al.[5], Anglade et al.[23], and Wang and Abuel-Naga[26]. Optimal sand content should remain near 30% to maintain acceptable flexural strength for masonry and road base materials[37]. The standard deviation Δσ on **Figure 8** decreases over time for the 0% and 30% sand mixtures, indicating that the structure becomes more homogeneous with curing, The experimental variability stabilizes as the bricks dry. Δσ remains very low for the 60% sand mix, reflecting weak cohesion but a relatively uniform internal structure.

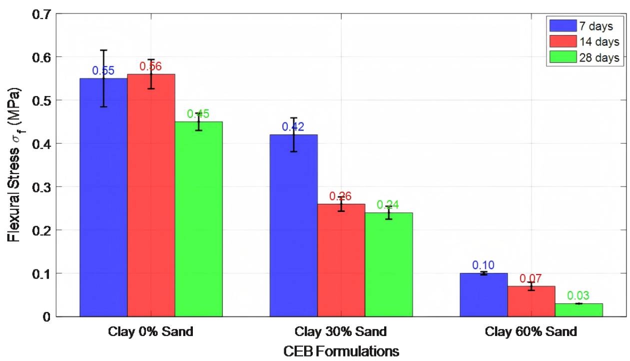

Figure 8. Evolution of flexural strength as a function of sand proportion and curing time.

3.2.2. Compressive Strength

Compression tests using the process outlined in subsection 2.4.2 and shown in **Table A5** of the **Appendix A** and **Figure 9** revealed that pure clay bricks maintain strengths above 1.5 MPa at 28 days, with 30% sand initially improving strength (2.013 MPa at 7 days) due to granular packing but deteriorating over time (1.220 MPa at 28 days). The 60% sand mix exhibits a major decrease in compressive strength (< 0.15 MPa), unsuitable for structural use[9,23,27,38]. This supports the critical threshold for sand content in CEBs and geotechnical applications to be below 40%[23,27]. The standard deviation Δσ increases for the 30% sand mix, indicating microstructural instability. For the 0% sand mix, Δσ decreases from 0.1266 to 0.1146, reflecting a consistent and reliable behavior. Pure clay exhibits a reproducible mechanical response, whereas the addition of sand increases mechanical uncertainty.

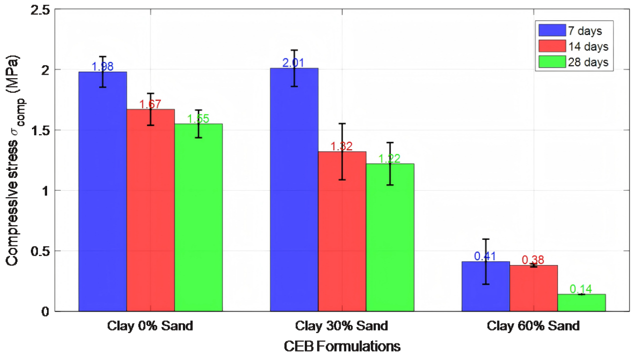

Figure 9. Evolution of compressive strength as a function of sand proportion and curing time.

3.3. Durability: Capillary Water Absorption

Capillary absorption tests calculated using the process of subsection 2.5. showed the highest capillary water uptake (~4.4%) for pure clay bricks, with absorption decreasing as sand increased but accompanied by faster physical degradation during immersion (refer **Figure 10** and **Table A6** in the **Appendix A**). Increased sand increases porosity and decreases cohesion, reducing durability especially in humid climates such as Douala [4,8,13,26,29]. This observed differences in water uptake and disintegration are consistent with capillary-transport theory, according to moisture-diffusion and sorptivity models [8,31], the continuity and size of capillary pores determine both the absorption rate and the material's structural stability.

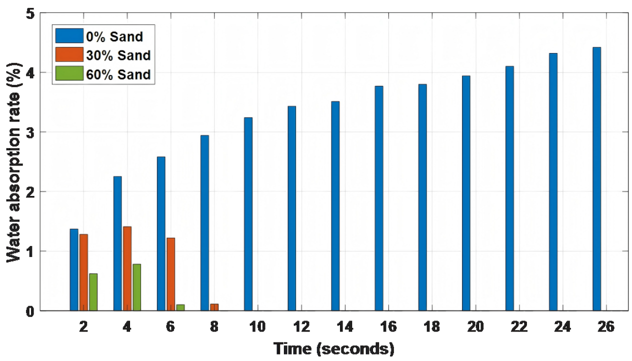

Figure 10. Capillary water absorption test results for CEBs with varying sand content.

3.4. Discussion

The mechanical behavior observed can be explained by the microstructural interactions between clay and sand. At early curing ages (7 days), the 30% sand formulation showed a slightly higher compressive strength due to improved particle packing and reduced drying shrinkage. However, as curing progressed, the discontinuity of the clay matrix caused by excessive sand led to weak interparticle bonding and stress concentration, resulting in a gradual strength decline.

From a microstructural standpoint, sand acts as an inert diluent: its grains interrupt the cohesive clay bridges responsible for adhesion and strength transfer within the matrix. When the sand content exceeds 30%, these discontinuities become dominant, promoting internal voids and brittle behavior. Moreover, during the water absorption test, bricks containing 30% and 60% sand exhibited rapid disintegration after only 5 seconds of immersion.

This indicates that despite lower apparent absorption rates, the internal cohesion of sand-rich bricks is extremely poor. Conversely, the 0% sand bricks, although showing continuous water uptake, maintained their structural integrity throughout the test, revealing a much more stable microstructure under wet conditions. This highlights that water resistance in CEBs is not only governed by capillary absorption but also by the material's cohesive strength and integrity when saturated.

4. Conclusion

This study examined the effect of varying sand contents (0%, 30%, and 60%) on the physical and mechanical performance of compressed earth bricks (CEBs) made from Lendi clay soil. The bricks were evaluated after 7, 14, and 28 days of curing, focusing on key properties such as compressive and flexural strengths, as well as water absorption. The results indicated that increasing the sand proportion reduces both compressive and flexural strengths due to decreased clay cohesion.

Pure clay bricks (0% sand) exhibited the highest compressive strengths of 1.975, 1.665, and 1.548 MPa and flexural strengths of 0.545, 0.558, and 0.448 MPa at 7, 14, and 28 days, respectively. Notably, during water absorption tests, these bricks retained their cohesion and shape throughout immersion. In contrast, bricks with 30% and 60% sand rapidly disintegrated into sludge within the first five seconds. Although the initial absorption rate of the pure clay bricks was higher, their ability to maintain structural integrity under prolonged water exposure demonstrates superior durability. Therefore, the 0% sand formulation can be considered the "highest performing" in terms of both mechanical strength and resistance to water-induced degradation. The addition of sand in this clay matrix weakens particle bonding and accelerates structural breakdown in humid environments like Douala.

However, the study has limitations. Only a single type of clay and one sand source from the Douala region were tested. The influence of other factors, such as mineralogical composition, curing conditions, and environmental exposure, was not assessed. Additionally, the absence of chemical stabilizers (lime, cement, pozzolans) restricts the generalization of these findings to other construction contexts.

In conclusion, this study emphasizes the importance of locally adapted formulations and a thorough understanding of material interactions when promoting CEBs as sustainable building alternatives in tropical and subtropical climates. Future research should address:

- The behavior of similar formulations under varied climatic curing conditions;
- The use of alternative granular additives (e.g., volcanic ash, crushed laterite, agricultural residues);
- Incorporation of natural stabilizers or fibrous additives to enhance both strength and moisture resistance while maintaining environmental sustainability.

Author Contributions

Conceptualization, E.E.N. and F.K.; methodology, E.E.N., R.E. and R.T.T.; software, A.M.M. and W.C.G.K.; validation, G.T., B.N.B. and R.N.; formal analysis, G.T., B.B., E.E.N. and F.K.; investigation, B.B.; data curation, B.N.B., R.E. and R.T.T.; writing—original draft preparation E.E.N., A.M.M. and W.C.G.K.; writing—review and editing, E.E.N., F.K. and R.T.T.; visualization, G.T.; supervision, R.N. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

All data generated or analyzed during this study are included in this published article.

Conflicts of Interest

The authors declare that there are no conflict of interest.

Appendix A

Table A1. Granulometric analysis of sand.

Granulometric Analysis			
Sample		**Sand**	
Origin		**Sanaga River**	
Initial Dry Weight:	**2225.77 g**		
Sieves (mm)	**Retained (g)**	**Cumulative Retained**	**% Retained**
5	27.23	27.23	1.2233968
4	31.39	58.62	1.4102985
3.15		58.62	0
2.5	142.9	201.52	6.4202501
2		201.52	0
1.6	652.8	854.32	29.329176
1.25	629.04	1483.36	28.26168
1	48.91	1532.27	2.1974418

Table A1. *Cont.*

Granulometric Analysis			
	Sample	**Sand**	
	Origin	**Sanaga River**	
Initial Dry Weight:	**2225.77 g**		
Sieves (mm)	**Retained (g)**	**Cumulative Retained**	**% Retained**
0.8		1532.27	0
0.63	444.66	1976.93	19.977805
0.4		1976.93	0
0.315	0	1976.93	0
0.25		1976.93	0
0.2	232.22	2209.15	10.433243
0.16	5.39	2214.54	0.2421634
0.15		2214.54	0
0.1	11.23	2225.77	0.5045445
0.08	0	2225.77	0
0.063	0	2225.77	0
0.05	0	2225.77	0
0.04	0	2225.77	0
0.032	0	2225.77	0
0.025	0	2225.77	0
0.02	0	2225.77	0
Pan	0	2225.77	0
	2225.77		100

Table A2. Atterberg limit on clay soil.

Operation	**3% Water** W_L		**Wp**	
Tare Number	1	2	3	4
Number of Shots	30	22		
Total Wet Weight	68.28	71.98	67.47	66.52
Total Dry Weight	67.02	71.13	65.81	66.39
Tare Weight	64.22	67.89	63.11	62.78
Dry Soil Weight	1.26	0.85	1.66	0.13
Water Content	0.45	0.26235	0.61481	0.03601
Water Content at 25 Shots	0.46004	0.25832		
Result	0.359178352		0.325412948	
PI in percentage	3.376540408			
Operation	**6% Water** W_L		**Wp**	
Tare Number	1	2	3	4
Number of Shots	30	22		
Total Wet Weight	75.23	73.71	64.06	63.83
Total Dry Weight	73.68	72.29	62.28	61.87
Tare Weight	70.53	69.21	63.27	61.08
Dry Soil Weight	1.55	1.42	1.78	1.96
Water Content	0.49206	0.46104	−1.798	2.48101
Water Content at 25 Shots	0.50304	0.45396		
Result	0.47850102		0.34151643	
PI in percentage	13.69845895			
Operation	**9% Water** W_L		**Wp**	
Tare Number	1	2	3	4
Number of Shots	30	22		

Table A2. *Cont.*

Operation	9% Water W_L		Wp	
Total Wet Weight	75.98	76.23	67.78	77.96
Total Dry Weight	72.11	72.89	60.15	61.87
Tare Weight	64.22	65.86	30.9	30.88
Dry Soil Weight	3.87	3.34	7.63	16.09
Water Content	0.49049	0.47511	0.26085	0.5192
Water Content at 25 Shots	0.50144	0.46781		
Result	0.484624821		0.390027221	
PI in percentage	9.459760003			

Table A3. Densities calculated on 28-day samples.

Formulation	Density at 0 Day	7 Days	14 Days	28 Days
Clay 0%S	2.337924818	2.11017953	2.065146277	2.073787791
Clay 30%S	2.294746662	2.168622553	2.153757061	2.126377166
Clay 60%S	2.169562817	2.058618315	2.05193266	2.050290129

Table A4. Three-point bending strength as a function of sand proportions.

Formulation	Strength (N) EP1	EP2	EP3	Average	Standard Deviation	Stress (Mpa) σ_f	$\Delta\sigma_f$
7 Days CEB							
Clay 0% Sand	144.38	162.79	192.185	166.45	19.69	0.55	0.0654
Clay 30% Sand	113.05	131.46	142.12	128.88	12.01	0.42	0.039
Clay 60% Sand	28.75	31.33	29.716	29.93	1.06	0.10	0.0035
14 Days CEB							
Clay 0% Sand	155.686	177.97	177.004	170.22	10.28	0.56	0.0337
Clay 30% Sand	71.06	80.43	82.688	78.06	5.03	0.26	0.0165
Clay 60% Sand	23.579	25.19	18.411	22.39	2.89	0.07	0.0095
28 Days CEB							
Clay 0% Sand	132.43	132.43	145.35	136.74	6.09	0.45	**0.020**
Clay 30% Sand	67.83	77.52	77.52	74.29	4.57	0.24	0.015
Clay 60% Sand	9.69	9.69	9.69	9.69	0.00	0.03	0.00

Table A5. Compressive strength as a function of sand proportions.

Formulation	Strength(N) EP1	EP2	EP3	Average	Standard Deviation	Stress (MPa) σ_{comp}	$\Delta\sigma_{comp}$
Clay 7 Days							
Clay 0% Sand	2995.03	3445.41	3040.07	3160.17	202.53	1.98	0.1266
Clay 30% Sand	2882.43	3422.89	3355.33	3220.22	240.44	2.01	0.1503
Clay 60% Sand	337.79	585.49	1058.39	660.56	298.93	0.41	0.1868
14 Days							
Clay 0% Sand	2657.24	2927.47	2409.53	2664.75	211.51	1.67	0.1322
Clay 30% Sand	2634.72	1869.08	1824.04	2109.28	372.00	1.32	0.2325
Clay 60% Sand	585.494	585.49	630.532	600.51	21.23	0.38	0.0133
28 Days							
Clay 0% Sand	2702.28	2477.09	2251.9	2477.09	183.87	1.55	0.1146
Clay 30% Sand	2026.71	2251.9	1576.33	1951.65	280.86	1.22	0.1755
Clay 60% Sand	225.19	225.19	225.19	225.19	0.00	0.14	0.000

Table A6. Water absorption by capillarity.

Time (s)	CEB Formulation					
	0%S		30%S		60%S	
	Dry Mass (g)					
	155.53		142.65		147.25	
	Absorbed Water (g)					
	Mass	Rate (%)	Mass	Rate (%)	Mass	Rate (%)
2	2.13	1.37	1.83	1.28	0.91	0.62
4	3.50	2.25	2.01	1.41	1.15	0.78
6	4.01	2.58	1.74	1.22	0.15	0.10
8	4.57	2.94	0.16	0.11	0.00	
10	5.03	3.24	0.00		0.00	
12	5.33	3.43	0.00		0.00	
14	5.46	3.51	0.00		0.00	
16	5.86	3.77	0.00		0.00	
18	5.91	3.80	0.00		0.00	
20	6.13	3.94	0.00		0.00	
22	6.38	4.10	0.00		0.00	
24	6.72	4.32	0.00		0.00	
26	6.87	4.42	0.00		0.00	

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