Scientific Research Publishing

Open Journal of Applied Sciences, 2025, 15(8), 2344-2359
https://www.scirp.org/journal/ojapps
ISSN Online: 2165-3925
ISSN Print: 2165-3917

Combined Litho- and Cement Stabilization of Earth Bricks: Experimental Study of Compressive Strength

Mouctar Mahamat Zakaria[1], Bozabe Renonet Karka[1], Amir Moungache[2], Mahamat Barka[2], Yacoub Idriss Halawlaw[2]

[1]Department of Civil Engineering, National Higher Institute of Arts and Crafts of Biltine (INSAMB), Biltine, Chad
[2]Faculty of Exact and Applied Sciences, University of N'Djaména, N'Djamena, Chad
Email: walmah.zak@gmail.com

How to cite this paper: Zakaria, M.M., Karka, B.R., Moungache, A., Barka, M. and Halawlaw, Y.I. (2025) Combined Litho- and Cement Stabilization of Earth Bricks: Experimental Study of Compressive Strength. *Open Journal of Applied Sciences*, **15**, 2344-2359.
https://doi.org/10.4236/ojapps.2025.158157

Received: May 14, 2025
Accepted: August 16, 2025
Published: August 19, 2025

Abstract

This article presents an experimental study on the evaluation of the dry and wet compressive strengths, after immersion in water, of cement-stabilized and compressed earth bricks (CCEB) with dimensions of 13 × 15 × 30 Cm^3. The (CCEB) were subjected to wet curing under cover in a curing bag for compression test periods of 3, 7 and 28 days. Compressive strength was measured by crushing the bricks using a hydraulic concrete press. The results show that increasing the cement content significantly improves the compressive strength of bricks, with dry compressive strength ranging from 3.50 to 6.08 MPa for cement contents of 4% to 8% after 28 days. These results are in line with the values recommended by the Construction Materials Centre (CMC) in N'Djamena (2.4 MPa) and the Earth Materials Research Centre (EMRC) (5 MPa). Wet compressive strength ranges from 2.71 to 4.89 MPa for cement contents of 4% to 8% after 28 days curing. The compressive strength drops from 19.64% to 22.52%, but remains acceptable (above 4 MPa). The bricks have a suction capacity that varies between 1.53 and 4.21 $g/cm^2 \cdot s^{1/2}$. However, all these measurements remain below the threshold imposed by standard NFP554, which is set at 20 $g/cm^2 \cdot s^{1/2}$ for blocks with low capillarity. Based on the compressive strengths obtained, both dry and wet, and in accordance with standard NF XP P13-901, (CCEB) containing at least 8% cement are suitable for building load-bearing walls, while CCEB stabilized with 6% cement can be used for building non-load-bearing walls.

Keywords

Compressive Strength, CCEB, Cement, Immersion, Suction

1. Introduction

Chad, a landlocked country in Central Africa, has a hot, dry climate. In this part of the world, one of the main challenges is the considerable heating up of dwellings caused by high levels of insolation. The use of conventional materials such as concrete and steel, because of their thermal properties, makes these variations more noticeable in housing. Furthermore, these materials are expensive to import and have a negative impact on the environment [1]. Earth construction is a promising alternative to building with conventional materials, given the economic and environmental issues involved [2]. Earth building materials (fired clay bricks, roof tiles and compressed earth blocks) are renowned for their high thermal inertia. They are inexpensive, readily available locally and can be used directly by small communities [3].

Although the use of earth as a building material is widespread in developing countries such as Chad, it still faces some challenges, such as the lack of manufacturing standards and building codes. Thus, further research is still needed to gain an in-depth understanding of its mechanical performance and durability properties [4]. This study is a contribution towards overcoming this deficit. This new material (cement-stabilized, compressed earth bricks) is intended for use in house walls. To encourage its use, it is essential to understand its characteristics, such as its ability to resist compression. In addition, numerous studies have shown that the incorporation of stabilizers such as cement leads to a variation in its properties [5] [6]. The aim of this study is therefore to measure the compressive strength of these bricks and to study the influence of cement on this property.

2. Materials and Methods

2.1. Materials

The CCEB are based on mixtures with clay, laterite, sand and cement. We provide a brief overview of the intrinsic properties of the constituents used.

2.1.1. Definition and Families of Clays

According to the Robert dictionary, clay is defined as “a clay rock, water-hungry, waterproof and plastic, known as clay”. In geotechnics, clay refers to any mineral of low particle size; the limit is set at 2 or 4 microns as the case may be. It is very sensitive to bad weather: it decreases in volume when it dries out and flows in the presence of moisture. Clay is indeed more or less plastic because it can form after superficial humidification or mixed with water a binder paste, easy to knead, to shape with precision, like a real modeling paste for children. This paste, when drying, contracts and splits. The important layers of clay are found in valleys, plains and streams. There are several families of clay soils but the most used are [7] [8]:

Black clays: they have low iron content; they are usually illites, montmorillonites and smectites;

White clays: they are composed of two layers namely a tetrahedral and another octahedral. Its crude formula $Si_2O_5(OH)_4$, less rich than illite, shows that it is composed only of aluminum, silicon, oxygen and hydroxide ion. It is a kaolinite type made of hydrated aluminum silicates and was discovered in China under "Kao Ling" or "high hills" near King Te Ching. It forms in hot and humid climates, especially tropical and subtropical, in drained (dry) environments by acidic Ph.

2.1.2. Origin and Process of Clay

Clay is a word of Latin origin Argilla and also of Greek origin. Clayey rocks are present on almost the entire surface of the earth, but not all rocks of this type are identical. Indeed, depending on their formation conditions (mainly geological), their properties and composition vary and make each rock unique [9].

The conditions that vary the properties and composition of these rocks are mainly: climatic or cosmic conditions (such as rain, heat, tide, etc.); the terrain and composition of the soil on which sediments and rocks that formed these clayey rocks are deposited, such as feldspar or basalt.

2.1.3. Distribution and Field of Use of Clay in Chad

In general, clays are present a few centimeters deep in the earth. They can be found in almost all regions of Chad [10]. We used black montmorillonite clay, extracted from the quarry located at the teacher training college in Moundou, Chad (**Figure 1**). According to the Google Maps application used on 12 May 2024 at 09:42, the geographical position indicated is 8˚33'11.74"N, 16˚04'41.95"E.

2.1.4. Definition and Formation of Laterite

Laterites belong to the lateritic gravel family [11] [12]. They are hard, loose or indurated soils, rich in iron oxide or aluminium, resulting from the weathering of rocks in tropical climates. Laterisation is the process by which lateritic soils are formed. It is specific to hot, humid tropical regions and is influenced by a number of key factors: climate, topography, vegetation, parent rock and weather conditions.

2.1.5. Chemical and Mineralogical Characteristics of Laterite

Laterites are characterised by high levels of iron oxide (Fe_2O_3) and/or alumina (Al_2O_3) relative to the other components. In some laterites, the Fe_2O_3 content can exceed 80%, while the Al_2O_3 content is very low (a few per cent). In other cases, alumina content can be as high as 60%. Mineralogically, laterites consist of a mixture of goethite, hematite, kaolinite, quartz and residual minerals (ilmenites, rutiles, anatase, zircons, chromites, neoformed gibbsite) [13].

The laterite used in this study comes from the Koutou quarry, located at the northern entrance to the town of Moundou in Chad (**Figure 1**). According to Google Maps used on 12 May 2024 at 12 h 23 minutes, its position is: 8˚35'59.68"N, 16˚04'0.97"E. It is taken from 30 cm below the natural ground level.

2.1.6. Grain Size of Sand

In geotechnical terms, sand refers to granular materials made up of small particles with diameters ranging from 2 to 5 mm. The sand used in this study comes from the Lake Wey river, located to the west of the town of Moundou in Chad. It was taken from the riverbed about 3 m below the natural ground level. According to Google Maps, its position is 8˚33'14.9"N, 16˚03'10.59"E.

Figure 1. Location and sampling site for clay and laterite.

2.1.7. Cement

The hydraulic binder used is cement CPJ-CEM II/B 32.5, manufactured locally by the National Cement Company (SONACIM). It is composed of 80% to 85% clinker, 10% to 15% natural pozzolana and 5% gypsum [14].

2.2. Methods of Testing

Laboratory Testing of Clay Soils and Sand

The various identification tests carried out at the laboratory of the National High School of Publics Works (NHSPW) in N'Djamena and the expressions of the results are presented below [15] [16].

1) Density of Solid Particles: Standard NF P 94-054

The absolute density of solid particles is determined from Equation (1):

$$\gamma_s = \frac{\gamma_{w(m3-m1)}}{m2+m3-m1-m4} \tag{1}$$

With the γ_w density of water equal to 1 g/cm^3; $m1$: the mass of the empty pycnometer; $m2$: mass of the pycnometer + distilled water; $m3$: mass of the pycnometer + soil sample and $m4$: mass of the pycnometer + soil sample + distilled water. The apparent density is calculated from Equation (2):

$$\gamma = \frac{m}{v} \tag{2}$$

2) Particle Size Analysis by Sieving: Standard NF P 94-056

The shape of the particle size curve indicates the degree of spread or uniformity of the particle size. This uniformity is expressed by the HAZEN C_u coefficient defined by:

$$C_u = \frac{d_{10}}{d_{60}} \tag{3}$$

d_{10}: diameter corresponding to 10% cumulative sieving;

d_{60}: diameter corresponding to 60% cumulative sieving.

- If $C_u < 2$, the particle size is uniform (or tight).
- If $C_u > 2$, the particle size is spread out (or varied).

The curvature coefficient is defined by the following relationship:

$$C_c = \frac{(d_{30})^2}{(d_{10} \times d_{60})} \quad (4)$$

- if C_c is between 1 and 3, the soil is well graded.

3) Atterberg Limits: Standard NF P 94-051

Atterberg limits consist of determining the moisture content of two consistencies of a coherent soil. Its purpose is to measure water contents and the identification of limits (liquid or plastic) to allow the classification of soils.

- Liquidity Limit The liquidity limit W_L is the water content which corresponds to a closure of the groove of about 1 cm after 25 strokes. The Casagrande device is used to determine the liquidity limit. The mean line is drawn between the points whose abscissas are the number of strokes and the ordinates, the corresponding water contents.
- The plasticity limit W_p is the water content expressed as a percentage of the clay soil roll of about 10 centimeters in length that breaks in small sections of 1 to 2 centimeters in length when its diameter reaches 3 millimeters.
- Plasticity Index This is the difference between the liquidity limit and the plasticity limit $I_p = W_L - W_p$.

4) Sand equivalent: Standart NF EN 933-8

The test consists of pouring a sand sample and a small quantity of flocculant solution into a graduated cylinder and shaking so as to detach the clay coatings from the sand particles in the sample. After a prescribed settling period, the height of the flocculated clay is measured and the height of the sand in the cylinder is determined. The sand equivalent is the ratio of the sand height to the clay height multiplied by 100:

$$ES = \frac{H_1}{H_2} \times 100 \quad (5)$$

where:

H_1: Height of flocculate.

H_2: Height of sediment.

2.3. Study of the Mixture Composition

There is no universally recognised standard for the manufacture of earth blocks, but techniques do exist to ensure their quality. According to standard NF XP P13-901, earth blocks must contain an average of 10% - 30% clay and at least 30% sand. The same standard allows cement to be added up to 10% of the total mass. Studies suggest that mixes with 30% sand and 70% clay are optimal for producing quality earth blocks. Larger quantities of clay can be used depending on the properties of the material and production techniques [17] [18].

The optimum raw material proportions for this study are summarised below:

- 60% clay + 16% laterite + 20% fine sand + 4% cement;
- 60% clay + 14% laterite + 20% fine sand + 6% cement;
- 60% clay + 12% laterite + 20% fine sand + 8% cement.

Using this formulation, a total of 24 sample bricks (8 bricks with 4% cement, 8 bricks with 6% cement and 8 bricks with 8% cement) with dimensions of 13 × 15 × 30 cm^3 will be made for the experimental tests. The quantities of materials used are summarized in **Table 1**.

Table 1. Summary of material quantity calculations.

Materials	Dosage	Total weight (Kg)
Clay	60%	87.84
Laterite	12%, 14% et 16%	20.496
Fine sand	20%	29.28
Cement	4%, 6% et 8%	8.784

2.4. Modified Proctor Test

The principle of water dosing is to determine the quantity of water needed to make a good wet mix for good compactness. To determine the quantity of water required, we will mix the earth fractions with a quantity close to the optimum content (Proctor tests on clay). We make four (4) bricks. The weight of each brick is known just after it is removed from the mould and its water content is noted. These two values (weight and water content) allow us to calculate the dry density (ρd) and the water content (ω). These two (2) values are used to draw a curve with the water content (ω) on the x-axis and the dry density (ρd) on the y-axis. The determination of the optimum moisture content to be considered is the apex of this curve, which will be projected vertically downwards on the abscissa axis.

2.5. The CCEB Production Process

CCEB have a variety of shapes and physical-mechanical properties depending on the constituents used, but their manufacturing stages are similar. They include extraction, preparation, mixing, pressing and curing (**Figures 2-6**).

1) Extraction

The material must be extracted in such a way that the sample is representative of the quarry. Because of this principle, it is advisable to carry out tests to determine the characteristics of a soil, such as sight and touch tests to identify the granulometry of the soil, and smell tests to determine the presence of organic matter. For our study, the soil was extracted from various quarries in the town of Moundou in Chad (Ecole Normale, Lac Wey and Koutou).

2) Characterisation of materials

Montmorillonite clay: high plasticity, swelling, requires rigorous stabilisation.

Sand: reduces shrinkage, improves compactness.

Laterite: gives cohesion, improves compressive strength.

Cement: main stabiliser for mechanical strength.

3) Preparation

The aim of preparation is to combine the different materials used to make the blocks into a single homogeneous material. The preparation stage allows us to crush and sieve out elements larger than 5 mm. The operations involved in preparing the material determine the final quality of the blocks. The material prepared in this way must be kept free from any impurities that could cause it to become polluted, as pollution can cause the material to lose its physical and chemical characteristics. It is therefore important to dry the material before subjecting it to mixing. Preparation is an essential stage in obtaining quality products.

4) Mixing

The prepared material must be mixed homogeneously with the stabiliser (cement) and water. This mixture is initially dry (earth + cement), and the water is added to this dry mixture by spreading. The water is added gradually until a homogeneous mixture is obtained with the optimum water content of the blocks determined from the mixing of the earth fractions.

5) Pressing

This is a technique used to tighten the grains. It can be mechanical, hydraulic, frictional, impact or isostatic. Pressing densifies the material and the tightening of the solid grains gives the resulting products good compressive strength. For this study, we used a light manual press with a pressing force of 5 to 10 tonnes.

6) Curing

The curing of blocks over time plays a very important role in their resistance. The precautions taken during manufacture and storage can mitigate disorders in the behaviour of the products. It is essential to keep the blocks moist, as this allows the cement's reagents to react to achieve maximum strength during the curing period.

In our case, the manufactured blocks are kept in a humid atmosphere at room temperature in the laboratory and are covered by a cure bag to maintain the humidity. The maximum curing time for our blocks is 28 days.

7) Quality control

- Compressive strength test: at 3, 7 and 28 days.
- Water stability: compressive strength after immersion, absorption by capillary action.

Figure 2. Mixing of the material.

Figure 3. Filling of the mold.

Figure 4. Brick pressing.

Figure 5. Demolding bricks.

Figure 6. Curing bricks.

2.6. Mechanical Properties

2.6.1. Dry and Wet Compressive Strength: Standard XP 13-901

Compressive strength is the most important mechanical property for the choice of construction materials [19]. The dry compressive strength test was developed from tests on cylindrical specimens. These consist of placing a block on a press fitted with a hydraulic compression ram and loading it until it breaks (**Figure 7**). Compressive strength tests were carried out on blocks measuring 13 × 15 × 30 cm^3. The maximum load reached was recorded and the compressive strength was calculated according to the following relationship:

$$R_c = \frac{F}{A} \tag{6}$$

R_c : Compressive strength (MPa); F: Compressive breaking load (N) and A: area of load application (mm^2).

Given that buildings are frequently exposed to the risk of deterioration caused by rainwater, rising capillaries and even immersion in the event of flooding, it is essential to know how they behave when wet, in order to determine their minimum characteristics under the most unfavorable conditions. This test is identical to the dry compressive strength test, except that on this occasion, a sample of each dosage aged 28 days was soaked in water for 24 hours before being subjected to compression (**Figure 8**) [20].

2.6.2. Capillary Absorption Test: Standard NF P 554

This test is used to determine the behaviour of bricks with respect to humidity conditions. The principle of the test is to dry the blocks in an oven at a temperature of 105˚C. On leaving the oven and after cooling, they are weighed, *i.e.* M_1; after this operation they are immersed on the underside to a depth of 5 mm. Ten (10) minutes later, it is taken out of the water to be weighed, *i.e.* M_2, and the immersed surface is measured [21]. The absorption coefficient is calculated by the relationship:

$$C_b = \frac{M_2 - M_1}{S \times \sqrt{t}} \times 100 \tag{7}$$

C_b: absorption coefficient (g/cm²·s$^{1/2}$); M_1 and M_2: masses (g); S: immersed surface area (cm²) and t: time in seconds.

Figure 7. Compression testing.

Figure 8. Immersion of (CCEB).

3. Results and Discussion

3.1. Characteristic Properties of Clay, Laterite and Sand Used

The results of preliminary investigations on the untreated soils being studied are presented in Table 2.

Table 2. Summary of the characteristics of clay, laterite and sand.

Materials	Apparent density	Analysis particle size				Atterberg limits			Proctor test		ES
	$\rho_a\left(g/cm^3\right)$	<2 mm	<80 µm	C_u	C_c	W_L	W_P	I_p	γ_d	W_{opt}	E_S
Clay	1.22	99.64	77.08	3.4	0.443	63.8	32.39	31.41	17.52	16.9	-
Laterite	1.36	96.61	45.7	96.4-	0.002-	33	16.55	16.45	20	11.8	-
Sand	1.6	98.54	49.7	2	1.2-	-	-	-	-	-	90

The particle size analysis showed that the three soils each had a percentage of 0.080 mm sieve passages greater than 35% (Table 2). According to standard NF P 11 - 300, the soils used are fine soils. The uniformity and curvature coefficients obtained from the curves, presented in Table 2, show that the sand has a spread and well-calibrated grain size compared to the laterite and clay. The latter are spread out and poorly graded.

The results of the Atterberg Limits obtained (Table 2) show that the plasticity index (I_p) is equal to 31.41% and 16.45% for the clay and laterite, respectively. These values show that the clay and laterite used have a very plastic behaviour.

We note that for sand $E_S = 90$, which allows us to give the following assessment according to standard NF EN 933-8: very clean sand containing no fine clay.

The particle size distribution curves shown in Figure 9 are those for clay, laterite and sand obtained from particle size analysis tests, as well as those for the standard particle size distribution curves for materials used in the manufacture of compressed earth bricks (CEB) and adobes [22] [23]. According to the recommendations of standard NF XP P13-901 [24], the particle size curves of the materials used to manufacture (CEB) must not deviate from these reference particle size distributions [25]. However, it is generally accepted that many soils that do not fall within the recommended range can in practice give acceptable results [26]. In the case of our study, the particle size distribution of the materials is well within the range (over 70%).

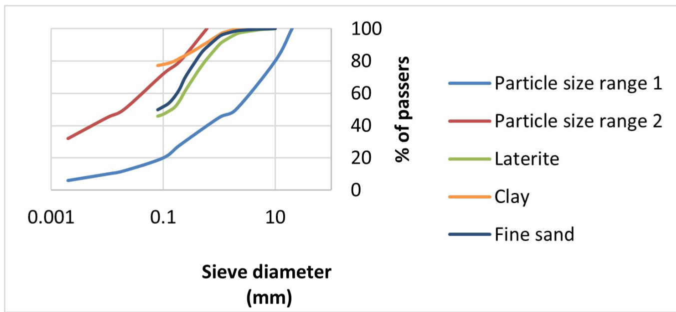

Figure 9. Sieve size curves and reference particle size range.

The incorporation of montmorillonite into stabilised earth brick compositions requires special care because of its high plasticity, its ability to retain water and its swelling characteristics. Nevertheless, it is expected to have good dry strength and more stable behaviour depending on the percentage of cement used. In addition, thanks to laterite and stabilisation, it is less sensitive to water, and together with sand, shrinks less during drying.

3.2. Modified Proctor Test

Mixing the materials with a quantity of water close to the optimum moisture content of 16.9 (Table 1) enabled us to make a few bricks (around 4). The characteristics of each brick are summarized in Table 3.

Table 3. Modified proctor test of bricks.

Water content (%)	14	16	18	20
Dry soil weight (Kg)	7.31	8.03	8.31	7.66
Volume of mould (m^3)	0.01	0.01	0.01	0.01

Continued

Density (Kg/m³)	1249.57	1373.33	1420.51	1309.40
Weight of bricks	6.32	6.43	7.00	6.12
Dry density (KN/m³)	1.25	1.37	1.42	1.31

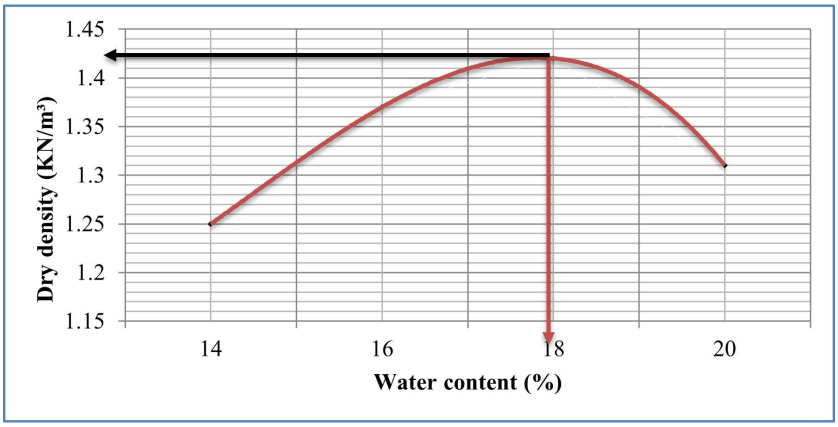

Figure 10. Modified proctor curve.

Based on this graph, the optimum water content for the clay-laterite-fine sand material is 18% (**Figure 10**).

3.3. Compressive Strength Characteristics

Table 4 and **Figure 11** show the results of the dry compression tests. These results are based on at least 18 brick samples, including: 6 aged 3 days and dosed with 4%, 6% and 8% cement, 6 aged 7 days and dosed with 4%, 6% and 8% cement and 6 aged 28 days and dosed with 4%, 6% and 8% cement. They are determined by applying formula (6). These data show that compressive strength increases with curing age and cement content. Indeed Montmorillonite, being a swelling clay, can reduce the compressive strength of CCEB if present in large quantities. However, the appropriate use of 8% cement mitigated this impact and improved the compressive strength to 6.08 MPa. Comparable research indicated that CCEB stabilised with 5% cement and containing 20% sand had ideal physico-mechanical characteristics [27]. In addition, the incorporation of laterite (16%, 14%, 12%) and sand (20%) also improved the compactness and strength of CCEB. [28] have obtained similar results.

Table 4. Summary of dry compressive strengths at different cement dosages.

	4%	6%	8%
3 days	1.77	2.34	3.03
7 days	2.48	2.8	3.21
28 days	3.51	4.44	6.08

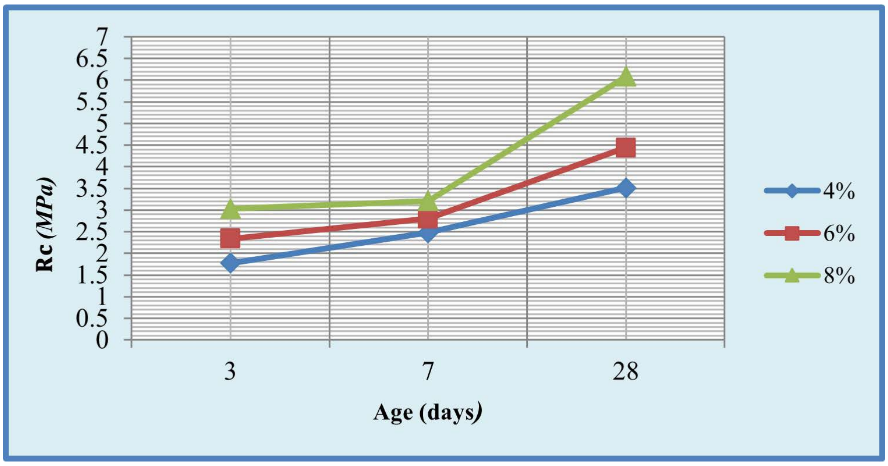

Figure 11. Curing strength-age curve of (CCEB).

With regard to compressive strength in a wet environment, there was a decrease depending on the quantity of cement used, ranging from 19.64% to 22.52%. Despite this reduction, the strengths remain tolerable (above 4 MPa) (**Table 5**). This reduction is attributed to the presence of montmorillonite, a type of clay that readily absorbs water and can lead to an increase in the moisture content of bricks, reducing their compressive strength. By incorporating cement, we are able to increase water resistance and stabilise compressive strength. Introducing sand into the clay contributes to granularity by reducing its plasticity and shrinkage during drying. Laterite, which contains a high concentration of iron and alumina, provides strength and resistance to erosion. It also helps to reduce water sensitivity. These results are similar to those of other researchers [29]-[31].

Table 5. Wet compressive strength.

Dosage	Dry mass (g)	Wet mass (g)	Load (KN)	Area (cm²)	Wet R_c (MPa)	Dry R_c (MPa)	Loss (%)
4%	6958.5	8278	116,000	427.74	2.71	3.50	22.52
6%	6372.5	7508.5	150,000	427.74	3.51	4.44	21.02
8%	6486.5	7572.5	209,000	427.74	4.89	6.08	19.64

According to standards NF XP P13-901, there are two categories of compressed earth bricks: those with compressive strengths greater than 4 MPa for dry R_c and 2 MPa for wet R_c, intended for load-bearing walls, and those with compressive strengths less than 4 and 2 MPa, used for non-load-bearing walls. Based on both dry and wet compressive strengths, cement-stabilized and compressed earth bricks (CCEB) with at least 8% cement are suitable for load-bearing walls, while (CCEB) with 6% cement can be used for non-load-bearing walls.

3.4. Absorption by Capillary Action

The durability of bricks is strongly influenced by their water absorption capacity

[32]. Bricks with a low absorption capacity are more durable and resistant to weathering [33]. The results of the absorption test presented in **Table 6** show water absorption of between 4.21 and 3.71 g/cm^2·s$^{1/2}$. They are determined by applying formula (7). All these measurements remain below the threshold imposed by standard NF P 554, which is set at 20 g/cm^2·s$^{1/2}$ for blocks with low capillarity.

Normally, the presence of montmorillonite can increase water absorption capacity due to its porous structure. However, the addition of cement, laterite and sand has reduced this capacity by filling the pores, thereby reducing water absorption. Research carried out by [34] [35] led to the same results.

Table 6. Absorption by capillary action.

Dosage	Dry mass (g)	Wet mass (g)	Area (cm^2)	Cb (g/cm^2·s$^{1/2}$)
4%	5056	5497.5	427.74	4.21
6%	5313.5	5739	427.74	4.06
8%	5923	6311.5	427.74	3.71

4. Conclusion

This study explores the manufacture of compressed earth bricks using local materials, in particular montmorillonite-type clays, laterite, sand and cement. Two types of stabilisation were carried out in this study. The dry and wet compressive strengths and capillary absorption of these bricks were analysed to assess their suitability for construction. The results showed that CCEB composed of clay, laterite, sand and cement have mechanical properties and water absorption that vary according to their composition and stabilisation. A formulation with 60% clay, 16%, 14%, 12% laterite, depending on the cement dosage (4%, 6%, 8%) and 20% sand, can offer a dry compressive strength ranging from 3.50 to 6.08 MPa after 28 days curing. For the same formulation, a wet strength of between 2.71 and 4.89 MPa can be obtained after 28 days curing. Absorption by capillary action for these bricks remains between 1.53 et 4.21 g/cm^2·s$^{1/2}$. The presence of montmorillonite clay can increase water absorption capacity due to its porous structure. However, the addition of cement, laterite and sand reduces this capacity by filling the pores, thus reducing water absorption. On the basis of the compressive strengths obtained, both dry and wet, and in accordance with standard NF XP P13-901, CCEB containing at least 8% cement are suitable for the construction of load-bearing walls, while CCEB stabilised at 6% cement can be used for the construction of non-load-bearing walls.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Dao, K., Ouedraogo, M., Millogo, Y., Aubert, J. and Gomina, M. (2018) Thermal,

Hydric and Mechanical Behaviours of Adobes Stabilized with Cement. *Construction and Building Materials*, **158**, 84-96. https://doi.org/10.1016/j.conbuildmat.2017.10.001

[2] Kabre, S., Ouedraogo, F., Naon, B., Messan, A., Benet, J.-C. and Zougmore, F. (2019) Assessment of the Thermo-Hydro-Mechanical Properties of Compressed Earth Bricks (CEB) from the Matourkou Quarry in Burkina Faso. *Afrique Science*, **15**, 12-22.

[3] Ali, A. (2018) Mechanical and Thermal Characteristics of Clay Stabilized by Gum Arabic and Reinforced by Rice Straw. PhD Thesis, University of Lorraine, 204 p.

[4] Barbero-Barrera, M.M., Jové-Sandoval, F. and González Iglesias, S. (2020) Assessment of the Effect of Natural Hydraulic Lime on the Stabilisation of Compressed Earth Blocks. *Construction and Building Materials*, **260**, Article ID: 119877. https://doi.org/10.1016/j.conbuildmat.2020.119877

[5] Kouakou, C.H. (2005) Valorization of Côte d'Ivoire Clays: Study of the Stabilization of Compressed and Cement-Stabilized Clay Blocks Using Hydraulic Binders. PhD in Earth Sciences, University of Cocody, 186 p.

[6] Meukam, P., Noumowe, A., Jannot, Y. and Duval, R. (2003) Thermophysical and Mechanical Characterization of Stabilized Earth Bricks for Thermal Insulation of Buildings. *Materials and Structures*, **36**, 453-460. https://doi.org/10.1007/bf02481525

[7] Stéphane, H. (1956) Classification of Clay Minerals. *Bulletin of the French Clay Group*, **8**, 35.

[8] Mesbah, A., Morel, J.C. and Olivier, M. (1997) Behaviour of Fine Clay Soils during a Static Compaction Test: Determination of Relevant Parameters.

[9] François, H. (2016) Clay, Its Use Unofficially. PhD Thesis, University of Angers, 139.

[10] Djonkamla, Y. (2010) Characterization and Numerical Simulation of the Volumetric Behaviour of N'Djamena Clay Soils. Memoir 2010, 115.

[11] Michel, C. (1997) Materials and Components. Gros œuvres, Delagrave.

[12] Houben, H. and Guillaud, H. (1995) Treaty of Earth Construction. Edition Parenthesis, 355 p.

[13] Gana, A.L. (2014) Characterisation of Indurated Lateritic Materials for Improved Use in Housing in Africa. Joint Thesis for the Award of the Degree of Doctor of the University, University of Havre and International Institute of Water and Environmental Engineering, 262 p.

[14] Ouedraogo, E., Coulibaly, O., Ouedraogo, A. and Messan, A. (2015) Mechanical and Thermo-Physical Characterization of Compressed Earth Blocks Stabilized with Paper (Cellulose) and/or Cement. *Journal of Materials and Engineering Structures*, **2**, 68-76.

[15] Yves, C. (2010) Properties and Characteristics of Building Materials. 2nd Edition, Betting (FR), Monitor.

[16] Cordary, D. (1994) Soil Mechanics. Street Lavoisier, 359.

[17] Rao, S.M. (2024) Novel Approach to Identify Soil Compositional Factors That Control the Compressive Strength of Unstabilized Adobes and Earth Mortars. *Discover Civil Engineering*, **1**, Article No. 138. https://doi.org/10.1007/s44290-024-00144-1

[18] Akintola, G.O., Dacosta, F.A., Mhlongo, S.E. and Matsiketa, K.E. (2020) Geotechnical Evaluation of Clayey Materials for Quality Burnt Bricks. *Heliyon*, **6**, e05626. https://doi.org/10.1016/j.heliyon.2020.e05626

[19] Ndione, J., Gaye, S., Sambou, V., Adj, M., Azilinon, D. and Vianou, A. (2006) Opti-

mising the Thermal and Mechanical Properties of Pumice-Based Concrete. *Journal of Engineering Sciences*, **6**, 25-30.

[20] Brahim, M. (2022) Valorization of Dredged Sediments in the Manufacture of Compressed Earth Blocks Stabilized by Geopolymeric Binders. PhD Thesis, CY Cergy Paris University, 143 p.

[21] Bozabe, R., Ouinra, K. and Fulbert, T. (2020) Comparative Study of the Mechanical Characteristics of Cement-Stabilized Sand and Compressed Laterite Mortar Bricks. *International Journal of Innovation and Applied Studies*, **28**, 438-451.

[22] Jiménez Delgado, M.C. and Guerrero, I.C. (2007) The Selection of Soils for Unstabilised Earth Building: A Normative Review. *Construction and Building Materials*, **21**, 237-251. https://doi.org/10.1016/j.conbuildmat.2005.08.006

[23] Elenga, R.G., Ahouet, L., Kimbatsa, T.F., Kinga, M. and Goma, M.J. (2018) Brick Earth from Congo. *Yearbook of the University Marien N'GOUABI, Sciences and Techniques*, **18**, 13-20.

[24] NF XP P13-901 (2001) Ed. Compressed Earth Blocks for Walls and Partitions. Nor 01. French Standards Association, Paris, AFNOR, 35 p.

[25] Lavie Arsène, M.I. (2019) Valorization of Clay Deposits for the Manufacture of Compressed Earth Blocks. PhD Thesis, University of Liege, 157 p.

[26] Olivier, M. and Mesbah, M. (1986) The Earth Material—The Static Compaction Test for the Manufacture of Compressed Raw Earth Bricks. *Liaison Bulletin for Road and Bridge Laboratories*, **146**, 34-37.

[27] Fall, M., Sarr, D., Cissé, E.M. and Konaté, D. (2021) Physico-Mechanical Characterization of Clay and Laterite Bricks Stabilized or Not with Cement. *Open Journal of Civil Engineering*, **11**, 60-69. https://doi.org/10.4236/ojce.2021.111004

[28] Wade, M., Thiam, M., Ba, M. and Ndiaye, M. (2025) Influence of Sand on the Mechanical Strengths of Compressed Earth Blocks Based on Sindia Laterite Stabilized with Cement. *American Journal of Civil Engineering and Architecture*, **13**, 1-4. https://doi.org/10.12691/ajcea-13-1-1

[29] Meukam, P. (2004) Upgrading of Stabilized Earth Bricks with a View to the Thermal Insulation of Buildings. PhD Thesis, 3rd Cycle, University of Yaoundé I, 140 p.

[30] Yacoub, M.S.I. (2010) Comparative Study between the Improvement of Compressed Earth Bricks Stabilised by Cement and Slaked Lime. Dissertation for the Master's Degree in Water and Environmental Engineering, International Institute of Water and Environmental Engineering, 71 p.

[31] Darman, J.T., Tchouata, J.H.K., Ngôn, G.F.N., *et al.* (2022) Evaluation of Lateritic Soils of Mbé for Use as Compressed Earth Bricks (CEB). *Heliyon*, **8**, e10147. https://doi.org/10.1016/j.heliyon.2022.e10147

[32] Gencel, O., Kazmi, S.M.S., Munir, M.J., Sutcu, M., Erdogmus, E. and Yaras, A. (2021) Feasibility of Using Clay-Free Bricks Manufactured from Water Treatment Sludge, Glass, and Marble Wastes: An Exploratory Study. *Construction and Building Materials*, **298**, Article ID: 123843. https://doi.org/10.1016/j.conbuildmat.2021.123843

[33] Benlalla, A., Elmoussaouiti, M., Dahhou, M. and Assafi, M. (2015) Utilization of Water Treatment Plant Sludge in Structural Ceramics Bricks. *Applied Clay Science*, **118**, 171-177. https://doi.org/10.1016/j.clay.2015.09.012

[34] Teixeira, E.R., Machado, G., Junior, P.A.d., Guarnier, C., Fernandes, J., Silva, S.M., *et al.* (2020) Mechanical and Thermal Performance Characterisation of Compressed Earth Blocks. *Energies*, **13**, Article No. 2978. https://doi.org/10.3390/en13112978

[35] Zhang, Y., Jiang, S., Quan, D., Fang, K., Wang, B. and Ma, Z. (2024) Properties of Sustainable Earth Construction Materials: A State-of-the-Art Review. *Sustainability*, **16**, Article No. 670. https://doi.org/10.3390/su16020670