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Assessment of Cement-Lime as Stabilizer on Mud Bricks

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Abstract

The aim of this study was to evaluate the compressive strength of clay bricks and their stability to water absorption by inserting stabilizers such as lime and cement of 0%, 4%, 6%, 8%, 10%, 12% to 14%. Spectrometric analysis was used to characterize the various stabilizers and the clay used, and tests of resistance and water absorption were also carried out. The clay was found to be an aluminosilicate (15.55% to 17.17% Al_2O_3 and 42.12% to 44.15% SiO_2). The lime contains 90.84% CaO and the cement has 17.80% SiO_2, 3.46% Al_2O_3, 2.43% Fe_2O_3 and 58.47% CaO in the combined form of tricalcium silicate, dicalcium silicate, tricalcium aluminate and ferro-tetra calcium aluminate. The results showed that the insertion of locally available stabilizers (lime and cement) improved the strength of the material by almost 80% when the lime was increased from 0% to 14% for 14 days. For compressed cement, a 65% increase in strength was observed under the same conditions. Strength increases with drying time, with a 52% increase in strength at 28 days compared to 14 days. Furthermore, compressed cement bricks have a more compact structure, absorbing very little water (32%). In view of all these results, cement appears to be the best stabilizer, and compression improves compressive strength and reduces water absorption.

Keywords

Cement-Stabilized Earth, Lime-Stabilized Earth, Compressed Earth Brick, Compressive Strength, Water Absorption Test

1. Introduction

Earth bricks are one of the main building materials used on our planet. More than a third of the world's inhabitants now live in rammed earth dwellings [1]. However, when rammed earth is left in the open air, it is particularly sensitive to climatic conditions such as rain, wind and frost [2].

What's more, the deterioration of housing and construction in Cameroon, especially in the far north, has been observed as a result of the precarious nature of building bricks, most of which use mud bricks [3]. The bricks currently manufactured are not very sturdy, breaking during transport and failing to withstand heavy rains [3]. To compensate for this, numerous construction techniques have been developed: adobes, pisé, torchis, shaping, bauge, cut blocks (....). However, these different techniques require load-bearing elements for their implementation, notably the use of stabilizers such as cement, lime, bitumen and natural or synthetic fibbers [4]. However, manual or artisanal earth brick production techniques do not confer good mechanical strength properties to these bricks [5]. Good compaction of the brick in the mold is important to obtain a good-quality product. The aim of this work is to evaluate the mechanical strength properties of earth bricks stabilized by the cement and lime.

2. Material and Methods

2.1. Material

The clay material, which is the main raw material, was collected in the Yonkolé (MRE01) and Florina (MRE02) districts in the town of Maroua, at two clay sampling points with GPS coordinates (MRE01) Latitude = 10.55224417, Longitude = 14.28163833, Altitude = 431.70 m and (MRE02), Latitude = 10.62132733, Longitude = 14.30811933, Altitude = 426.46 m respectively; Lime and Cement come from Figuil.

2.2. Experimental Protocols

Chemical and physicomechanical analyses were carried out on clay and lime samples oven-dried for 24 hours at 45˚C, and on cement. The main constituents of these materials were determined using an x-ray fluorescence spectrometer. This involves irradiating the sample to be analyzed with X-rays emitted by the spectrometer tube. The bombarded pearl-like sample then emits X-rays (fluorescence) characteristic of the sample's chemical composition. This allows us to determine the different values of oxides, including calcium, silica, phosphorus, titanium, aluminium and iron oxides.

Stabilized earth bricks are made by homogeneously mixing clay constituents, water and stabilizer. The earth bricks presented in **Table 1** are formulated by mixing clay and a stabilizer, which can be either lime or cement, in the presence of water.

Table 1. Formulation of clay bricks with stabilizers.

Clay	Cement or	Water	Clay	Compressed cement	Water
70%	/	30%	80%	/	20%

Continued

66%	4%	30%	76%	4%	20%
64%	6%	30%	74%	6%	20%
62%	8%	30%	72%	8%	20%
60%	10%	30%	70%	10%	20%
58%	12%	30%	68%	12%	20%
56%	14%	30%	66%	14%	20%

Clay and stabilizers are mixed and water is added by gradual spraying, while mixing continues until a homogeneous mixture (paste) is obtained. The paste obtained is then introduced into a standardized mold used for cement mortar testing, with specimen dimensions of 4 cm × 4 cm × 16 cm as per standard EN-196-3 (**Figure 1(a)**). The mold filled with cement- or lime-stabilized clay paste is then placed and clamped in an impact table, whose role is to pack and compact the paste and eliminate any air bubbles in the paste that may ultimately render the brick porous.

The aim of compaction is to densify the soil. The moisture content of the soil at the time of compaction is crucial. There is an optimum moisture content for compaction, which after drying produces the best density. If compaction is carried out at the wrong moisture content, the final dry density can be greatly reduced: too much water prevents compaction (energy absorption by pressurization of water molecules); not enough water generates friction between grains, which absorbs compaction energy.

The shock table (**Figure 1(a)**) knocks the mold by lifting it up and letting it fall back onto an anvil, which constitutes a blow. The impact table is standardized for 60 ± 3 blows per minute according to EN-196-1, 2005. The height of fall of the mold + mass of mixture on the anvil is 15 ± 0.3 mm.

After molding, the mold containing the clay is stored for 48 hours in a room at room temperature and covered with plastic film to prevent rapid surface drying. The clay bricks are removed from the moulds and stored in the room, covered with plastic film to prevent rapid drying, which would be detrimental to hardening.

A 0 - 200 kN Herzog hydraulic press was used to manufacture the compressed clay bricks. The cement-stabilized clay bricks are pressed at a force of 50 kN and then immediately demolded.

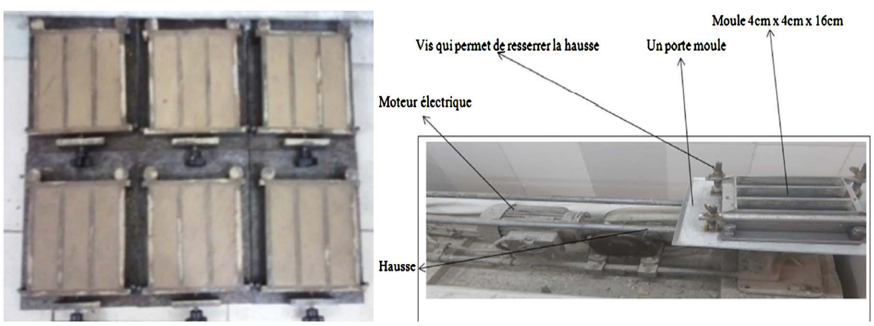

Figure 1. Brick moulds and shock table.

Stabilized clay bricks covered with a plastic film were stored in a room sheltered from sun and wind at an average temperature of 25˚C for 14, 21 and 28 days before being subjected to compression crushing tests.

Compressive crushing tests are used to assess the impact resistance of bricks. Compression tests are carried out on bricks, and the value of the breaking load (the load that must be applied to break the brick (**Figure 2**) is noted. The brick is pressed in a flat position, *i.e*. at a low pressing height (**Figure 3**). In this configuration, a large pressing surface is obtained [6] [7].

Figure 2. Compression test with hydraulic press.

Figure 3. Brick in flat position.

Figure 4. Humidity cabinet with temperature control at 25˚C and 90% relative humidity.

Water absorption tests were also carried out. The absorption test is also carried out on 5 clay bricks which have been previously oven-dried to obtain a constant weight. The bricks are placed on a porous surface permanently saturated with water, in a humid atmosphere at 25˚C with a relative humidity of over 85% (**Figure 4**). After 7 days, the increase in sample weight is measured. This is expressed as a percentage of dry weight. The average of the 5 results is calculated: this is the absorption value of the soil studied [8]. The absorption rate is expressed using the formula:

$$\%\text{water absorption} = \frac{m_1 - m_0}{m_0} \times 100$$

m_0 = mass at oven outlet.

m_1 = mass obtained after 7 days in the wet cabinet.

Each experiment was carried out in triplicate. The obtained data were analyzed by using Microsoft Excel 2007 and statgraphics plus software.

3. Results and Discussion

3.1. Material Characterization

The results obtained from the chemical analysis of clay, lime and cement samples by X-ray fluorescence spectrometry are presented in **Table 2** below.

Table 2. Elemental composition of materials.

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	P_2O_5	PAF (950˚C)
MRE01	42.12	15.55	9.60	10.01	1.53	1.42	2.20	1.38	0.02	12.55
MRE02	44.15	17.17	12.95	6.00	1.54	0.77	0.41	0.69	0.04	6.53
Lime	0.98	0.37	0.18	90.84	0.53	0.60	0.04	0.01	0.01	3.57
Cement	17.60	3.46	2.43	58.47	2.34	2.04	1.9	0.20	0.10	13.95

The table shows that most clays (over 70%) are composed of the metal oxides SiO_2 (42.12 - 44.15), Al_2O_3 (15.55 - 17.17), Fe_2O_3 (9.60 - 12.95), CaO (10.01 - 6.00) capable under certain conditions or when mixed with certain compounds of releasing Si^{2+}, Al^{3+} and Ca^{2+} cations and agglomerating, bonding and forming complexes (Si-OH, Ca-OH) capable of developing mechanical properties (binding, elasticity, strength) [9]. We also note the presence of alkaline oxides (MgO, Na_2O, K_2O, P_2O_5).

There is a difference in the composition of the clays, which can be explained by their origin, and these clays may have different properties when used to make clay bricks.

In addition, lime consists mainly of calcium oxide (CaO = 90.84%). This gives it its hydraulic properties, recognized as a binder or stabilizer in the manufacture of clay bricks [10].

Cement, on the other hand, is predominantly made up of calcium oxide (CaO = 58.47%) and silica (17.60). Unlike the chemical composition of clays and lime, these compounds (metal oxides) are found in cement in the combined forms of multi-calcium silicates or aluminates. Once in contact with water, multi-calcium silicates combine with water molecules to form hydrated silicates.

3.2. Brick Drying Kinetics

In order to determine a timeframe for the start of compressive strength testing, it was important to know the evolution of the drying kinetics of the manufactured clay brick. Earth bricks with low levels of stabilizer (4%) were used to verify the timeframes for compressive strength tests, which will be carried out at a time when the earth brick has dried to develop strength; the control brick having no stabilizer. The drying kinetics curves are shown in **Figure 5**.

The drying curves of the bricks all show the same pattern, consisting of two phases. A first phase of rapid water elimination in the first 14 days and a second phase of very slow water elimination with mass stability after 21 days. It should be noted that after the first 6 days, there is a mass loss of around 4% to 5% for all bricks. This reflects the loss of water from the bricks by advection created by air circulation in the material [11] [12]. Overall mass loss was greater for bricks without stabilizer (10% to 12%) than for bricks with stabilizer added (6% to 8%).

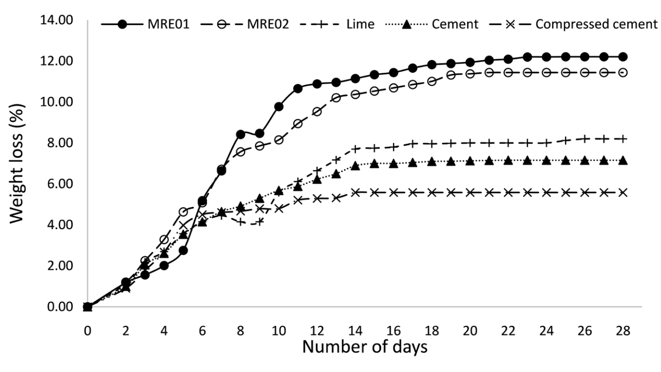

Figure 5. Drying kinetics of MRE1 control and stabilized earth bricks.

Mass loss rises to 11.33 and 10.53% respectively for MRE01 and MRE02 clays, and to 5.58, 6.58 and 7.70% respectively for cement-stabilized and compressed, cement-stabilized and lime-stabilized clays.

The cement-stabilized and compressed clay brick had a lower mass loss (5.58%) than all other stabilized and unstabilized bricks. There was a difference of almost 35% in mass loss between clays without stabilizer and clays with stabilizer, and of almost 50% between clays without stabilizer and clays with stabilizer and compression. This shows that compressing the bricks and adding the stabilizer reduces the mass loss of the clay brick after storage and drying.

These results on the drying kinetics of clay bricks indicate that drying times of 14 days, 21 days and 28 days are appropriate for compression testing, as the mass loss of the brick becomes constant. These results are similar to those of OTI [13] and Meukam [14].

3.3. Influence of Stabilizer on the Strength of Earth Bricks

The evaluation of compressive strength after 14 days of drying as a function of the stabilizer used and the quantity of stabilizer is shown in **Figure 6**.

From this figure, it can be seen that regardless of the stabilizer insertion rate and whether or not the clay is compressed, MRE2 clay is on average 20% stronger than MRE1 clay, whether without stabilizer or with stabilizer.

Brick strengths increase with the stabilizer insertion rate, regardless of the matrix used. Uncompressed earth bricks without stabilizer have the lowest strengths, at 0.70 MPa (MRE1) and 0.90 MPa (MRE2). The strength of earth bricks increases almost progressively with the amount of stabilizer added. In fact, brick strengths reach 3.30 MPa (MRE1) and 4.20 MPa (MRE2) for the 14% lime proportion on the one hand, and 6.70 MPa (MRE1) and 7.80 MPa (MRE2) with cement as stabilizer on the other.

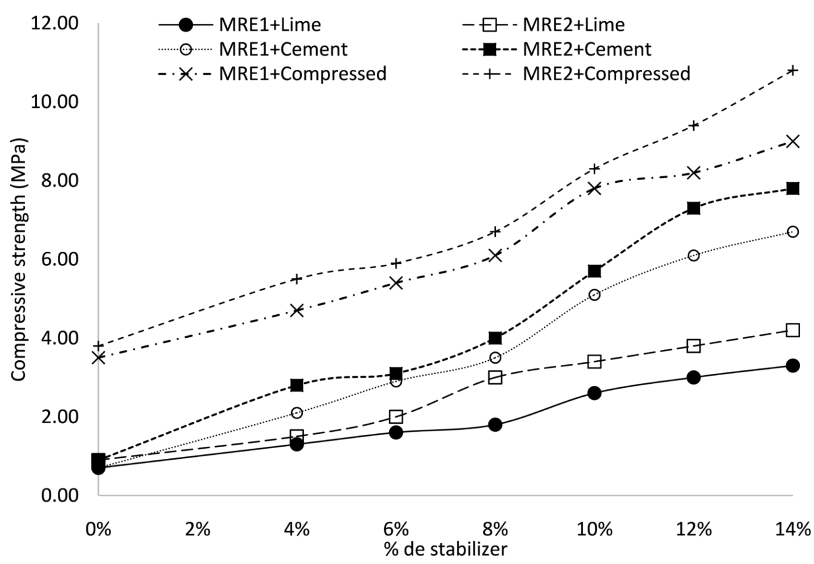

Figure 6. Evolution of the strengths of earth bricks in function of different stabilizers.

On the other hand, compression further increases the strength of bricks with and without stabilizer. Compressed brick without stabilizer has a strength value of 3.50 MPa (MRE1) and 3.80 MPa (MRE2), which are higher than uncompressed brick stabilized with 14% lime (MRE1 = 3.30 MPa) and uncompressed brick stabilized with 8% cement (MRE1 = 3.50 MPa). The addition of stabilizer combined with compression further improves brick strength. Thus, the strength of compressed bricks will reach 9.0 MPa (MRE1) and 10.80 MPa (MRE2) for a stabilizer insertion rate of 14%. The strength of cement-stabilized and compressed bricks is 34.3% and 38.5% higher respectively for MRE1 and MRE2 than for bricks stabilized without compression.

The low strength observed for MRE1 clays is thought to be due to the presence of organic matter in the soil (indicated by a high loss on ignition in the clay characterization) and is less problematic than in the case of cement stabilization [15]. This difference in strengths could also be linked to the high content (SiO_2, Al_2O_3, Fe_2O_3, CaO) in MRE2, which are capable under certain conditions or when mixed with certain compounds of releasing the cations Si^{2+}, Al^{3+} and Ca^{2+} and agglomerating, binding and forming complexes (Si-OH, Ca-OH) capable of developing mechanical properties (binder, elasticity, strength) [9].

In addition, silica and alumina in clays recombine with calcium to form calcium aluminum silicates, which cement the grains together. Lime stabilization therefore requires a clay soil containing mainly alumina silicates, silica or iron hydroxides [15] (Guillaud & Houben, 1995).

The strength of the brick increases with the insertion rate of the stabilizers and this is in agreement with a study of the mechanical characteristics of an earth brick stabilized with sugarcane molasses carried out by [16] which showed an increase in strengths with the insertion rate ranging from 2.5 to 4.5 MPa at 14 days. The results obtained with MRE1 and MRE2 clays are superior to those found by Malanda [16], this difference may come from the fact that lime and cement are hydraulic binders of mineral nature whereas molasses is a binder of organic type.

In addition, compressing the brick increases its strength as it promotes better cohesion between the particles. In fact, work carried out by [17] has shown that the compression process (25, 50 and 100 MPa) improves the mechanical behavior of the material and in particular, compressive stiffness and strength increase with a more than linear trend as a function of dry density.

3.4. Influence of Drying Time on the Strength of Clay Bricks

The evaluation of compressive strength in function of drying time is shown in **Figure 7**.

This figure shows that drying time is a factor influencing brick strength, whatever the clay matrix used. Indeed, we can see that the strength of bricks with lime as stabilizer at 14 days is much lower (29.95% less) than that at 21 days, and much higher (77.79%) than that at 28 days. The same is true of bricks with cement as stabilizer, as well as compressed cement bricks. The greater the drying time, the greater the strength of mud bricks.

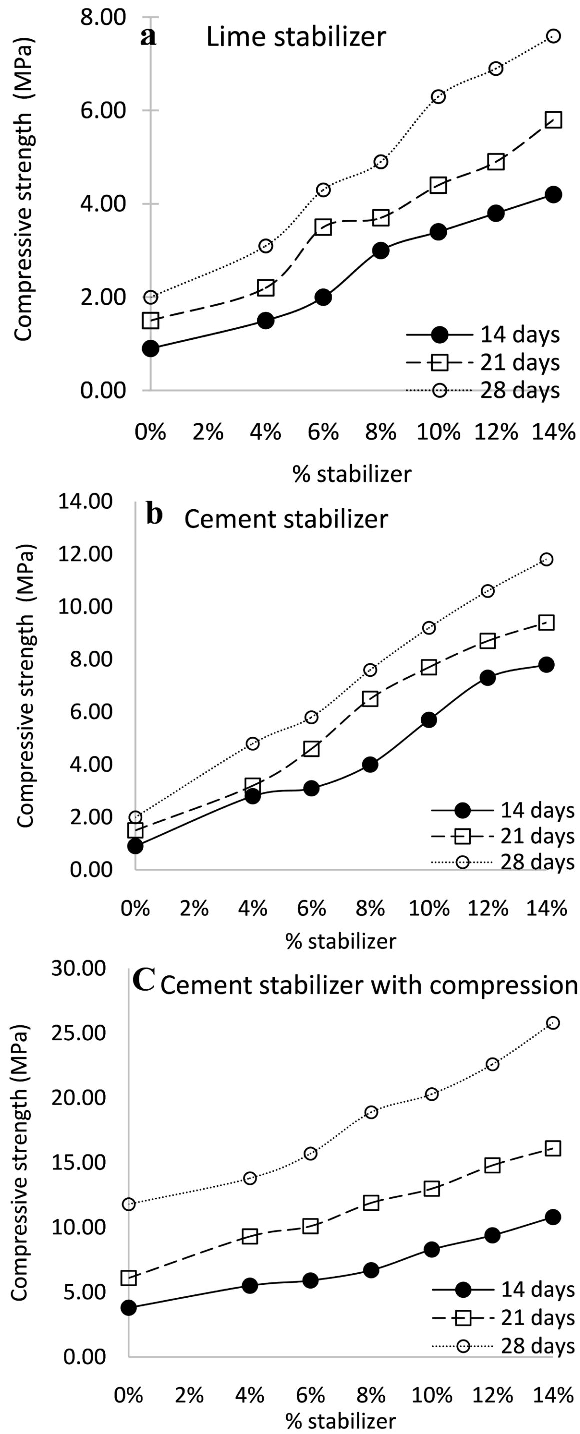

Figure 7. Resistance of MRE1 clay bricks as a function of drying time with (a) lime stabilizer, (b) cement stabilizer and (c) cement stabilizer plus compression.

The strength of earth bricks continues to increase with the number of days and the increasing rate of stabilizers. The significant increase in strength on compressed earth bricks is a combined effect of compression, which improves particle cohesion, and the cement insertion rate, which provides additional strength thanks to the hydrated silicates.

3.5. Assessment of Water Absorption by Mud Bricks

Figure 8 shows the percentage of water absorbed by earth bricks.

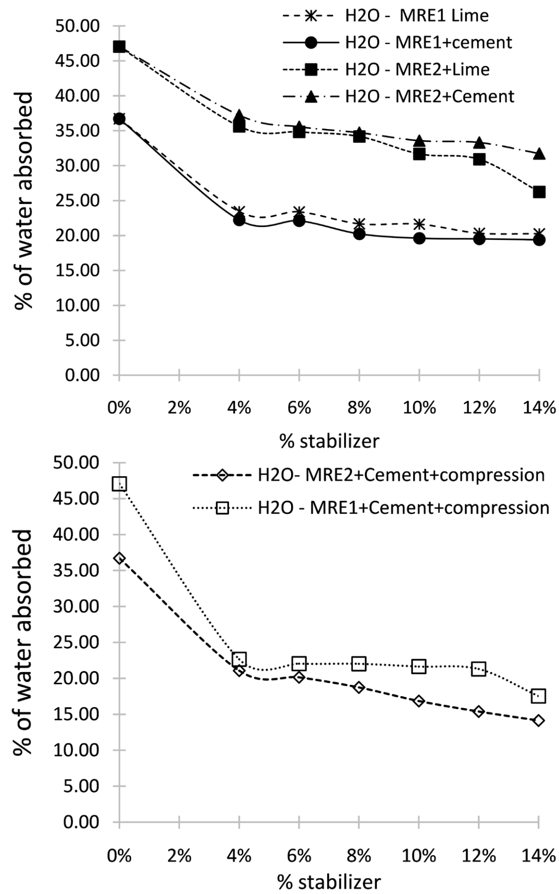

Figure 8. Evolution of water absorption by earth bricks.

Water absorption decreases with stabilizer insertion rate, whatever the matrix used. Compressed earth bricks stabilized with cement show the lowest percentages of water absorbed, starting from 36.71% for unstabilized earth bricks (0% stabilizer), and decreasing to 17.53% (MRE1) and 14.15 (MRE2) for the 14% cement proportion.

We also note that uncompressed and stabilized clay bricks using the MRE2 clay source present higher absorption percentages than the MRE1 clay source, as the absorption rate starts at 47.06% for uncompressed and stabilized clay bricks (0% stabilizer), and decreases to 31.75% with cement and 26.25% with lime stabilization at 14% stabilizer insertion. This higher water absorption with the MRE2 clay source can be explained by the porosity and permeability which are generally linked to a higher (coarser) particle size than the MRE1 source, the high presence of silica (SiO_2 = 44.15%) in the MRE2 source indicating more quartz particles (sand) whose size is generally coarser than the much finer clay particles. This explanation is confirmed on compressed earth bricks which, despite the improvement in particle cohesion by pressure, still show higher water absorption values with the MRE2 source than with the MRE1 source.

A number of studies have shown that each type of soil has its own stabilizer to improve porosity, permeability, durability, volume variations and mechanical strength. In general, a dosage of between 8% and 12% is used. Bricks obtained with a cement content of between 0 and 3% will have a higher porosity than non-stabilized bricks. For cement percentages between 4 and 8, porosity decreases: pore size becomes smaller and more homogenous. For cement contents above 8%, pores are completely closed. To obtain blocks that can withstand alternating rain and sun, a minimum of 8% cement should therefore be considered [18]-[20].

Air lime stabilization reduces the soil's sensitivity to water, slightly reduces its plasticity, increases its compressive strength (depending on dosage) and reduces shrinkage and swelling. It is mainly used on clay soils with rather high water content, as it mainly reacts with clays and not with sands. Soils with a clay content of 20% to 40% will be the most effective with lime. This is why lime is less widely used than cement for compressed earth bricks, given the sandy soils and low water content required for their production [18] [20].

4. Conclusions

At the end of our study, it observes that mud brick construction, although several millennia old and universally used, currently seems to be the target of rejection by the local population. They are turning away from earthen materials in favour of concrete and sheet metal, which are so ill-suited to our climate. This work was therefore carried out with the aim of improving the mechanical performance and water absorption stability of earth bricks.

Spectrometric analysis was used to characterise the various stabilisers and the clay used, and tests of compressive strength and water absorption were also carried out. The clay was found to be an aluminosilicate (15.55% to 17.17% Al_2O_3 and 42.12% to 44.15% SiO_2). The lime contains 90.84% CaO and the cement has 17.80% SiO_2, 3.46% Al_2O_3, 2.43% Fe_2O_3 and 58.47% CaO in the combined form of tricalcium silicate, dicalcium silicate, tricalcium aluminate and ferro-tetra calcium aluminate. The evaluation of the strength revealed that the longer the curing time, the better the strength, whatever the material used as stabiliser, and the best strength was observed with compressed cement for a maximum rate of 14% stabiliser insertion (resp 4.80 MPa lime, 7.80 MPa cement and 10.80 MPa compressed at 14 days), (resp 5.80 MPa lime, 9.40 MPa cement and 16.10 MPa compressed at 21 days) and (resp 7.60 MPa lime, 11.80 MPa cement and 25.80 MPa compressed at 28 days). Water absorption tests carried out in a climatic chamber (25˚C, 90% relative humidity) for 7 days on bricks previously oven-dried to constant mass showed that water absorption was much lower in 14.15% compressed cement than in the other stabilisers. High mechanical performance was achieved by inserting the cement and compressing it at a high pressure of 50 KN. This has removed one of the main obstacles to the use of raw earth as a construction material.

Looking ahead, in order to continue to improve this work and succeed in making mud bricks more attractive and more widely used by our populations, it can be interesting to:

- Evaluate the population's perception of this product;
- Evaluate the resistance and permeability of lime-stabilised bricks after firing;
- Study the effect of grain size on the mechanical performance and moisture stability of mud bricks.

Conflicts of Interest

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

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