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Influence of Cement Dose on the Durability of Structures in Stabilized Compressed Earth Blocks

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Abstract: Structures in stabilized Compressed Earth Blocks (CEB), and more precisely the exterior walls (exposed to rainwater) or interior walls (exposed to spray water room, e.g.: bathroom) constructed with sand clay of class 2, suffer from decrepitude and crumbling, which are degradations due to environmental stresses. In order to solve this problem of degradations, it is necessary to find a minimum dosage level of cement that ensures the resistance to rupture and environmental stresses, in particular the aggression from rainwater and/or rise in moisture by capillarity, penetration by gravity, by suction or internal condensation. Two tests of durability have been conducted to simulate the two phenomena. These are a cyclic test of alternated wetting and drying to simulate the phenomenon of rise in moisture and a spray test to simulate the aggression from rainwater. The results of these tests show that a minimum dosage of 10% is sufficient to strengthen durably the walls against environmental stresses.

Keywords: Compressed earth blocks, crumbling, cycle of wetting and drying, spray test, decrepitude

1. Introduction

The use of earth as a building material is a very old tradition. Nowadays, the need to protect the environment is no longer new. Yet, the knowledge about the minimum environmental requirements of construction using the earth throughout its life cycle is still sketchy. Earthen construction has several advantages on different levels including social, economic, environmental and cultural. The availability of the material, its low cost and its ability to adapt to most complex architectural forms are the main reasons of its extensive use. However, because of the low resistance to simple compression and the low durability of this material (Banakinao et al., 2017), it is then necessary to improve these characteristics to make earthen structures to resist durably against loads and severe weather.

To improve the mechanical performance of earthen constructions, the earth material is stabilized with caustic lime of cement to produce stabilized Compressed Earth Blocks (CEB). In Togo, defects such as decrepitude and crumbling that appear over time on wall faces in CEB induce durability problem of the material, despite these structures having good resistance to mechanical shocks. Mechanical tests are generally conducted to assess the resistance to rupture of CEB and to find a minimum dosage of cement. However, there is a lack of mechanical tests to assess the durability of CEB. The purpose of this study is to determine the minimum dosage of cement in CEB manufactured with coastal clay sand of Togo to be used as exterior walls in constructions subjected to severe weather or interior walls in bathrooms. This

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minimum dosage will ensure the ultimate limit state of rupture as well as the limit state of durability and thus will bring a solution to the problems of decrepitude and crumbling that ruins stabilized earth structures.

In the literature, many researches have been conducted on the durability of earth material, with several tests either in simulated laboratory in conditions (e.g. Ogunye and Boussabaine (2002) with the *rainfall test* or Hall (2007) with his *climatic simulation chamber*) or on site in real conditions (Guettala et al. (2006) with small walls left for four years on site without protection, or Heathcote (1995) with his house in small scale, or Bui et al. (2009) with rammed earth walls exposed for 20 years to natural weathering). The measurement of erosion of earthen walls was also carried out by the stereophotogrammetry method (Bui, 2008) based on the knowledge of the geometrical characteristics of an object from two images taken from two different angles (Desrues and Duthilleul, 1984). Houben and Guillaud (1989) proposed moisture content of humidity ratio of the stabilized compressed earthen blocks and fixed specifications values of 2.4 MPa for the minimum compressive strength to the compression in dry state and 1.2 MPa for the minimal compressive strength in the saturated state with the ratio of strength in dry state on the strength in saturated state greater than 0.5. Heathcote (1995) proposed a *spray test* to test the durability of stabilized CEB. Many authors considered the *wire brush test* of standard ASTM 559-1989, as typical test to test the cement stabilized CEB. Fitzmaurice (1958) proposed limit values in cement dosage of 5% for buildings in urban area with rainfall less than 500 mm and of 10% if rainfall are greater than 500 mm.

1.1 Decrepitude and Crumbling

The decrepitude of earthen constructions is a phenomenon that is observed on exterior walls subjected to rainfall (exterior walls of buildings or walls of earthen fences). It is a slow degradation that occurs over time (Fig. 1); the thickness of the wall becomes thinner gradually (Fig. 2) and the wall ends up generally drilled without cracking (Fig. 3). This phenomenon is caused by kinetic energy of rain drops (Heathcote, 1995). To study the behavior of stabilized CEB towards this phenomenon, the *spray test* is chosen to simulate the kinetic energy of rain drops on the wall.

The crumbling of earthen constructions is a phenomenon that is observed on exterior and interior walls of buildings as well as on walls of earthen fences. It is caused by water. Under moisture, the wall crumbles (Fig. 4) and ends up thinner or becomes ugly (degraded face). To study this phenomenon, the cyclic test of alternated wetting and drying is chosen.

Fig. 1 - Example of decrepitude wall

Fig. 2 - Decrepit and thinned wall

Fig. 3 - Example of wall decrepit and drilled

Fig. 4 - Example of crumbling wall

2. Material and Methods

2.1 Tests, Equipment and Material

In addition to conventional geotechnical soil identification tests (granulometric analysis, Atterberg limit), mechanical tests for the manufacturing of CEB and simple compression tests, durability tests (cyclic tests of wetting and drying and spray test) have been conducted. The equipment used for the tests includes: tears, sieves of standard AFNOR (French Standard Association), electric sieve, electronic balance, Casagrande cup, groove tool, smooth marble plate, drying oven, dryer, press *Terstaram®*, 3000 KN press of standard NF P18-411, hydraulic press to manufacture 10 cm × 10 cm × 10 cm bricks, tarpaulin, device for projecting water at a pressure of 50 KPa. A clay sand commonly known as Togolese coastal land bar generally used to manufacture stabilized CEB with CPJ35 cement and drinking water were used as materials for the tests.

2.2 Manufacture of CEB

Six series of stabilized bricks at 3 to 12% (by successive steps of 1%) of dosage of cement were manufactured. Beyond 12%, the stabilization is no longer economic. For each dosage, two types of bricks are manufactured with different dimensions: bricks of dimensions 22 cm × 14 cm × 9.5 cm for the *spray test* and bricks of dimensions 10 cm × 10 cm × 10 cm for the cyclic test of alternated wetting and drying.

2.3 Methodology of the Spray Test

Several bricks (numbered and weighed) of 22 cm × 14 cm × 9.5 cm were used to construct an experimental wall of dimensions 120 cm × 120 cm (Fig. 5). The wall is placed at a distance of 47 cm from a water pipe. The diameter of the water pipe is 63 cm and it projected jet of water at a pressure of 50 KPa. The impact of the jet on the wall forms a circle of 15 cm in diameter (Fig. 6). The maximum thickness of erosion is measured after one hour of exposure and the sample is checked to determine the extent of moisture penetration. Failure is effective when the maximum thickness of the decrepitude exceeds 60 mm or if the thickness of the moisture gets through the wall. The loss of the mass can be approximated by differentiating between the mass of the bricks in the circle impacted by the jet before and after the test.

Fig. 5 – Small experimental walls

Fig. 6 – Spray test

2.4 Cyclic Test of Alternated Wetting and Drying

To perform this test, thirty bricks of dimensions 10 cm × 10 cm × 10 cm were manufactured with dosages of cement from 3 to 12%. These bricks are subjected to five cycles of wetting and drying. To complete a cycle, the bricks must be dried in an oven for 48 hours at a temperature of 105 degree Celsius. At the output of the oven, the bricks are weighed, three of them are crushed and the remainders are immersed in water for another 48 hours. At the output of the water, the bricks are weighed and three of them are crushed. The test is then repeated for five cycles.

- The resistance to compression at saturated state (σ_{sat}) is given by the following relation:

$$\sigma_{sat} = \frac{F_{ms}}{S} \tag{1}$$

Where S is the section of the sample and F_{ms} the maximal charge at rupture of the bricks after the fifth cycle of immersion.

- The resistance to compression at dry state (σ_{dry}) is given by the following relation:

$$\sigma_{dry} = \frac{F_{md}}{S} \tag{2}$$

With F_{md} the maximal charge at rupture after drying.

- The coefficient of resistance to moisture (C_{rh}) is defined by the ration of σ_{sat} over σ_{dry}.

$$C_{rh} = \frac{\sigma_{sat}}{\sigma_{dry}} \tag{3}$$

If $C_{rh} \geq 1$, the material is insensitive to water and the water has no influence on the material.
If $C_{rh} = 0$, the material does not resist to water and can collapse before saturation.
If $C_{rh} < 1$, the material resist to water.

2.5 Imbibition and Drying

The imbibition time is the time it takes for the immersed earthen bricks to be completely saturated. To determine this duration, three bricks are initially weighed and then immersed in water (Fig. 7). Every 24 hours, the immersed bricks are weighed. The saturated state occurs when their weight does not vary anymore or when the variation does not exceed 0.05%.

The duration of the drying is the time needed for the immersed earthen brick to be completely dry. To determine this duration, three bricks are initially weighed and then put in an oven (Fig. 8). Every 24 hours, they are weighed. The bricks are dry when their weight does not vary anymore or when this variation does not exceed 0.05%.

Fig. 7 - Immersion of the bricks

Fig. 8 - Drying of the bricks

3. Results and Discussions

3.1 Identification of the Soil Used

The granulometric distribution of the clay sand used is represented by the curve in Fig. 9. This soil has a limit of liquidity of 30,74% and a limit of plasticity of 14,33% with an index of plasticity of 16,41%. It is then a soil of class 2 according to the Guide to Roadworks (GTR) classification: a clay sand of average plasticity.

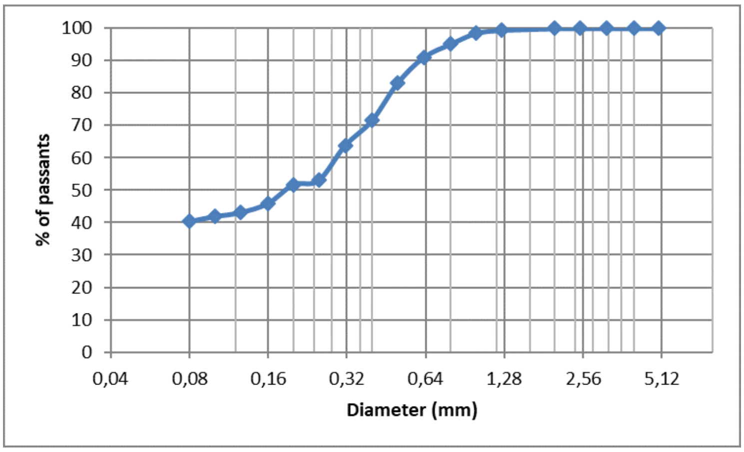

Fig. 9 - Granulometric curve of the soil

3.2 Duration of Imbibition

The different weights measured each 24 hours of the immersed bricks are shown in Table 1. The variation of the weight as a function of the time is plotted in Fig. 10. The curve does not grow after 48 hours. It can be deduced that the duration of immersion is 48 hours.

Table 1 - Mass of immersed bricks as a function of time

Duration of imbibition (*hours*)	**Mass (*g*)**
0	1673
24	1855
48	1856
72	1855
96	1855
120	1855

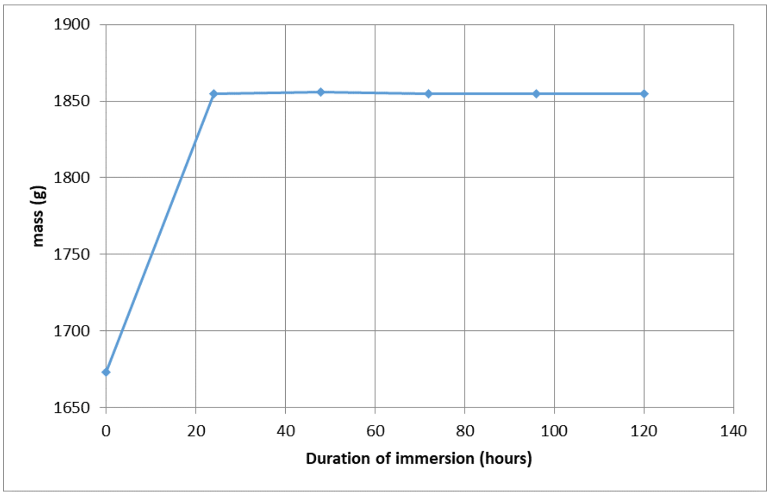

Fig. 10 - Curve of variation of the mass of the immersed bricks as a function of time

3.3 Duration of Drying

The steamed bricks are weighed each twenty-four hours and the results are shown in Table 2. The variation of the weight as a function of the time is plotted in Fig. 11. The curve does not grow after forty-eight hours. It can be deduced that the duration of immersion is forty-eight hours.

Table 2 - Mass of dry bricks as a function of time

Duration of drying (*hours*)	**Mass (*g*)**
0	1723
24	1703
48	1696
72	1696
96	1696
120	1696

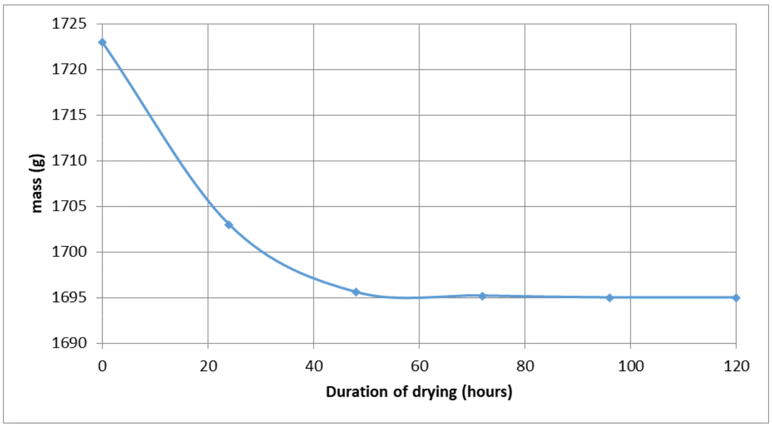

Fig. 11 - Curve of variation of the mass of the dry bricks as a function of time

3.4 Spray Test

The visual inspection of the ten experimental walls revealed the following information:

- For walls constructed with stabilized bricks from 3 to 4% of cement, the jet of water has drilled the wall forty-nine minutes for 4% (Fig. 12).
- For 5% and 6% of dosage of cement, the jet of water has deeply penetrated the wall and the surface of projection presents quite marked effects of decrepitude (Fig. 13).
- For 7, 8 and 9% of dosage of cement, the surface of projection presents very low effects of decrepitude (Fig. 14).
- From 10% of dosage of cement, the walls do not present any trace of decrepitude (Fig. 15).

Fig. 12 - Drilling of the wall by the jet of water (dosage of 3 and 4%)

Fig. 14 - Low effects of decrepitude (dosage of 7, 8 and 9%)

Fig. 13 - Quite marked effect of decrepitude of the wall (dosage of 5 and 6%)

Fig. 15 - Very low effects of decrepitude (dosage of 10 and 12%)

3.5 Durability Test

The cyclic test of alternated wetting and drying on the manufactured CEB from different dosage of cement have given results of resistance to compression at the saturated state (σ_{sat}), dry state (σ_{dry}) and coefficients of resistance to moisture (C_{rh}). These results are resumed in Table 3. The variation of these parameters as a function of dosage of cement is shown in Figs. 16 and 17.

From these results, it can be seen that the increase of the dosage of cement in the earthen material makes it more resistant and therefore more durable, which results in an increase of the coefficient of resistance to moisture from 0.078 for a dosage of 3% to 0.775 for a dosage of 12% (Table 3 and Fig. 17). When referring to the specifications by Houben and Guillaud (1989), which requires a coefficient of resistance to moisture greater than 0.5, dosages of cement greater or equal to 5% fulfill our expectations. By coupling this parameter with the loss of mass (which is mandatory when the crumbling is to be avoided), loss of mass for dosages from 5 to 9% are very important (2.504% for dosage of 5% and 0.606% for dosage of 9%). It would be inappropriate to use these dosages for exteriors walls subjected to rainfall and interior walls of spray water room (bathroom). When the dosage of cement is greater than 10%, the loss of mass are negligible (0.018% for dosage of 10% and 0.002% for dosage of 12%). A minimum dosage of 10% is then advised which can guarantee the resistance to rupture as well as the resistance to environmental stresses, especially aggressiveness of rainwater and rise in moisture by capillarity, penetration by gravity, by suction or internal condensation.

Table 3 - Results of the durability test

Dosage (%)	σ_{sat} (MPa)	σ_{dry} (MPa)	C_{rh}	Loss of mass (%)
3	0.3	3.83	0.078	7.963
4	1.5	5.2	0.288	6.543
5	4.23	6	0.705	2.504
6	4.8	6.6	0.727	1.565
7	5.1	6.8	0.750	1.206
8	5.6	7.5	0.747	0.905
9	6.2	8.2	0.756	0.606
10	6.8	8.8	0.773	0.018
11	7.2	9.3	0.774	0.005
12	7.9	10.2	0.775	0.002

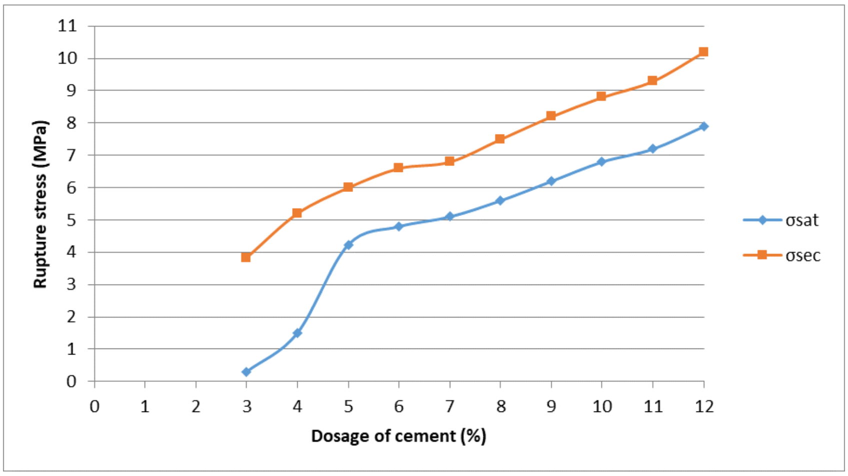

Fig. 16 - Variation of the σ_{sat} and σ_{dry} as a function of dosage of cement

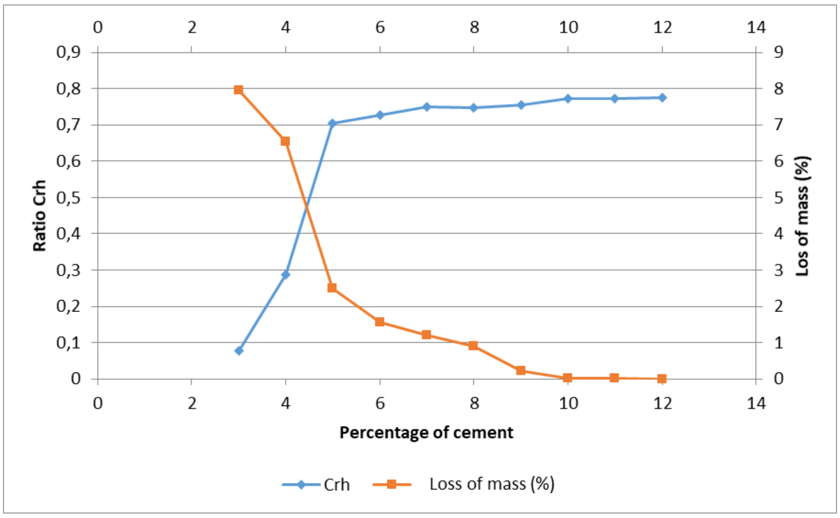

Fig. 17 - Variation of C_{rh} and loss of mass as a function of dosage of cement

4. Conclusion

To find a minimum dosage to ensure resistance to rupture and to environmental stresses, in particular aggressiveness of rainwater and rise in moisture on exterior and interior walls, two tests of durability have been conducted: the cyclic test of alternated wetting and drying and the spray test. The results show that a minimum dosage of 10% is sufficient to strengthen durably these walls against environmental stresses.

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