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Construction and Building Materials 20 (2006) 119–127
Construction and Building MATERIALS
www.elsevier.com/locate/conbuildmat

Durability study of stabilized earth concrete under both laboratory and climatic conditions exposure

A. Guettala [a,*], A. Abibsi [a], H. Houari [b]

[a] Faculty of Engineering, Biskra University, 07000 Biskra, Algeria
[b] Civil Engineering Department, Constantine University, Algeria

Received 23 March 2004; received in revised form 29 October 2004; accepted 2 February 2005
Available online 8 March 2005

Abstract

The strength and durability of the earth can be improved considerably by the addition of different stabilizers. In this work, four stabilizers have been used: cement, lime, cement plus lime and cement plus resin and then evaluated by various laboratory tests as well as in real climatic conditions. In general, it has been noted that all treated walls showed no signs of deterioration after 4 years exposure in real climatic conditions even though the laboratory test conditions are more severe compared to the natural climatic conditions of the region of Biskra where this present work has been carried out. Among the 4 stabilizers tested, the cement plus resin showed the best durability behavior.

Keywords: Earth; Stabilizers; Laboratory durability tests; Climatic conditions exposure

1. Introduction

Undoubtedly, earth is the first building material used by man. Dethier [1] has indicated that at least 50% of the world's population still live in earth houses. Traditionally, earth has been extensively used for building in Algeria mainly in the south of the country where it's very hot and dry and the rain is very rare.

However, the main earth drawback is its deterioration under the action of the climatic conditions. The main deterioration causes are: shrinkage cracking, erosion, the undermining at the basis and mechanical deterioration [2,3]. The entire villages constructed by earth have been destroyed completely during the 1970 inundations; Nsutam village near Bunso (Ghana) is an example [4].

At present, there is a growing market for earth walled buildings, with commercial building companies tending to more durable stabilized materials, particularly in the area of cement stabilized pressed earth bricks and rammed earth. Various works have been carried out in order to evaluate different stabilizers [5–9] as well as to improve the material properties [10–12].

Houben [13] recommends the utilization of an earth that does not contain an excess of big elements and an exposure of a sufficiently smooth face on which water will have less action in order to get a good resistance with time.

The various accelerated ageing tests are means of comparing different stabilizers performances used under laboratory exposure conditions. These tests are fast but are subject to controversy as one cannot simulate in the laboratory the complex succession of the multiple climatic phenomenon: rain, sun, temperature, humidity, wind. However, little work has been done correlating the performance of samples under conditions similar to that of real buildings [3,14–17].

* Corresponding author. Tel.: +33 86 58 40; fax: +33 73 89 86.
E-mail address: abibsi_a@yahoo.fr (A. Abibsi).

0950-0618/$ - see front matter
doi:10.1016/j.conbuildmat.2005.02.001

The present work presents a program aiming at the realization of experimental walls carried out in the laboratory of materials at Biskra University, Algeria. This program consists of comparing the performances of different additives: cement, lime, cement + lime and cement + resin.

The project consists of constructing 8 walls on the University roof using different stabilized bricks and then evaluating their performance in real climatic conditions. The bricks have been also evaluated in laboratory conditions in order to establish a correlation between the two different methods of evaluation.

2. Materials

The different materials used in this work are: soil, sand, cement, lime and resin.

2.1. Soil

Soil samples of the region of Biskra (South East of Algeria) have been chosen among three different soils studied in a previous work by the same authors [9,18]. The soil was subjected to several laboratory tests as specified by ASTM standards [19]. The soil characteristics are given in Table 1. It is composed mainly of kaolin (a non-expansive and non-absorbent clay) and illites. According to Michel [20], the best earth soils for stabilization are those with low plasticity index (PI) and the product (PI × *M*) in the vicinity of 500–800, where *M* is the percentage of the mortar. In this case, PI × *M* = 644.

Table 1
Soil Characteristics

Constituents/properties	Values	Constituents/properties	Values
Textural composition, % by weight		Mineralogical constituents	
		Kaolin	45
Sand	64	Illites	40
Silt	18	Interstratifiers	15
Clay	18	Quartz	05
		Calcite	10
Atterberg limits		Physico-chemical characteristics	
Liquid limit, %	31		
Plastic limit, %	17	pH	7.1
Shrinkage limit	10	Methylene blue	0.2
Plasticity index, PI	14	Organic matter, %	0.15
Water content, %	9.5	Optimum (W_c), %	11.75
Activity coefficient	0.77	Max. dry density (γ), kg/m^3	1877
Product (PI × *M*)	644		

Table 2
Soil chemical composition (content, %)

SiO_2	AL_2O_3	Fe_2O_3	MgO	CaO	SO_3
32.22	2.24	0.53	0.03	31.8	5.81
K_2O	Na_2O	Cl	TiO_2	MnO	FW*
0.15	0.03	0.005	0.2	0.02	26.9

* Weight loss due to fire.

2.1.1. Chemical analysis

Clay analysis has been accomplished in the cement factory of Hamma Bouziane (Constantine, East of Algeria) using X-ray diffraction, in accordance with NF6 P 15-467 [21]. The obtained soil constituents results are given in Table 2.

2.2. Sand

Using AFNOR [21] regulations, the sand samples have been tested and the following results were found:

- Disturbed apparent density (ρ_0) = 1520 kg/m^3.
- Specific mass (γ) = 2640 kg/m^3.
- Fineness modulus (FM) = 2.33.
- Sand equivalence value by sight (SE) = 70.
- Sand equivalence value by test (SE_t) = 64.

2.3. Cement

The cement used is manufactured locally under the commercial label C.P.J 45 and has been tested in respect to the AFNOR regulations [21] in order to determine its real class. The tests carried out on mortar cubes have shown that the strength at 28 days is 46 MPa.

2.4. Resin

The resin used for this work has a commercial name of 'MEDALATEX', supplied by Granitex; private Algerian company making additives. MEDALATEX is an aqueous dispersion of resin of white color. It's compatible with most of cement as well as lime. In general, the latex content varies between 10% and 20% in respect to the cement mass. The latex addition gives a good adherence to the support. It gives also the impermeability, the durability and the improvement in protection of the reinforcement, thus resistance to chemical attacks.

3. Experimental work

For this part of the present work, two different tests were programmed: laboratory and real life exposure tests. All the bricks samples used throughout this work were fabricated under the same conditions using a prismatic steel mould. These have been prepared using an earth corrected by 30% sand and compacted using 15 MPa stresses.

3.1. Bricks fabrication

3.1.1. Sand content

According to Houben et al. [13] and Doat et al. [22], the clayey small elements must be dissociated and not agglomerated as nodules. The presence of 50% of nodules more than 5 mm in size is susceptible to reduce by half the compression resistance.

After soil sieving through 5 mm mesh, the presence of clay nodules was noticed. The preliminary tests have shown that these nodules have an effect on the stabilized earth concrete (SEC) structure (very poor compression resistance). On the other hand, according to the ideal granulometric curves [22], 72% of the grains must be less than 1 mm. This needs a sieving through 1 mm mesh instead of 5 mm and a sand granulometric correction.

3.1.2. Mixtures preparation

In this present work, the soil was dried for 24 h at 63 °C. The materials (soil + sand + stabilizer) were mixed in dry state for 3 min then mixed with water at 139 rev/min in a rotating 5 l malaxer during 2 min. The mixture was then placed immediately in the mould and compacted. Four different treatments were made:

1. Cement with two different contents: 5% and 8%.
2. Lime with two different contents: 8% and 12%.
3. Cement + Lime with two different contents: 5% cement + 3% lime and 8% cement + 4% lime.
4. Cement + Resin (MEDALATEX) with two different contents: 5% cement + 50% resin (of the compacting water weight) and 8% cement + 50% resin.

3.1.3. Samples compaction

The compaction is of the static and simple effect type. The 5 elements steel mould of 2.5 mm thick and $10 \times 10 \times 20$ cm volume was assembled by 8 bolts (Fig. 1). The mixed materials used were approximately 2 kg for each brick and a compressive force of 15 MPa. The formed bricks were then removed from the moulds and cured accordingly.

3.1.4. Curing

In this study, two methods of curing were used: a humid atmosphere and a humid atmosphere plus immersion in water.

3.1.4.1. Humid atmosphere. After confection, the samples were put on a tray, covered by a plastic sheet and then kept in a humid atmosphere (air relative humidity

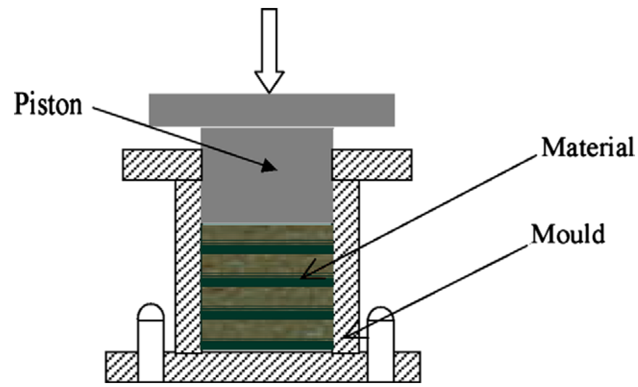

Fig. 1. Mould used for bricks making.

>70%) in order to assure a maximum hydration of the used stabilizer.

3.1.4.2. Humid atmosphere plus immersion in water. In order to determine the behavior of SEC when in contact with water, samples have been conserved for 27 days in a humid atmosphere then immersed completely in water for 24 h at 20 °C. The tests were then carried out on the 28th day.

3.2. Laboratory tests

The stabilized bricks have undergone different laboratory tests: Compressive strength in the dry and wet sates, Absorption (Capillary and Total), Wetting–Drying, Freezing–Thawing and Spraying.

3.2.1. Compressive strength

These tests were carried out according to a test developed by l'Ecole Nationale des Travaux Publiques de l'Etat (ENTPE) [23] which was then adapted by the Normes Françaises [24].

3.2.2. Capillary absorption

Capillary absorption test consists of placing the soil sample on a humid surface with voids, constantly water saturated, and measuring its weight after 7 days. Absorption is evaluated in percentage of dry weight.

3.2.3. Total absorption

The present test consists of immersing the soil samples in water and measuring the increase in weight during 24 h. The absorption is evaluated in dry weight percentage.

3.2.4. Wetting and drying test

This test is carried out according to the ASTM D 559-57 [19]; it consists of immersing the soil samples in water for a period of 5 h and then removed to be dried in an oven at 71 °C for a period of 42 h. The procedure is repeated for 12 cycles; samples are brushed every cycle to remove the fragment of the material affected by the wetting and drying cycles. For every sample, the variation in weight is computed after the 12 cycles [13]. The requirements for the limits on weight loss have been conveniently modified/specified by different researchers to suit the local environmental conditions and requirements [25,26].

3.2.5. Freezing and thawing

Following the procedure described by ASTM D560 [19], the Freezing and Thawing test consists of placing a soil sample on an absorbent water saturated material in a refrigerator at a temperature of −23 °C for a period of 24 h and then removed. The sample is then thawed in a moist environment at a temperature of 21 °C for a period of 23 h and then removed and brushed. The test is repeated for 12 freezing–thawing cycles and then dried in an oven to obtain a constant weight [13].

3.2.6. Spray test

Doat et al. [23] proposed a test whereby an earth block is placed on a grid facing a spray jet. The brick is vertical, 17 cm away from a horizontal jet of 1.6 kg/m^2 pressure, during two hours. The erosion resistance is evaluated by measuring the holes depth or the brick weight loss. Most of the time, results of this test are only indicative. The erosion maximum rate (mm/h) is given simply by the maximum depth of the erosion. In the case of the sample eroding completely in less than one hour, the depth is given by the ratio of the brick thickness to the spraying time.

3.2.7. Water strength coefficient

This coefficient characterizes materials stability to water. It's determined from the compressive strength ratio for dry and humid states. The use of a ratio between "dry" and "wet" strengths as a way of controlling the durability of earth walls is implicit to CraTerre specifications for stabilized earth bricks [27].

3.3. Climatic conditions exposure

8 walls (15 cm thick) have been constructed on the Biskra University roof, arranged in a row and sufficiently remote from one another in order to avoid mutual protection. They were oriented South and North so that one of their North main faces is exposed to the dominant rains. The wall joints were of a cement mortar. Usually the test wall top is covered by a hat as it would be in reality. However, this is not the case in this present work as to evaluate the direct effect of the rainfall. A general view of the built walls is given in Fig. 2.

A general check up has been made after the construction in order to detect any defects or damages caused during the construction. Then, two month periodical visits and inspections were programmed for a period of 48 months.

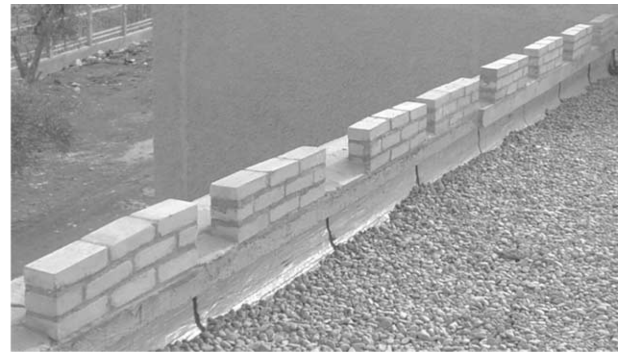

Fig. 2. General view of the built walls.

3.4. Climatic information

The collected climatic data were spread over four consecutive years 1999, 2000, 2001 and 2002. They reflect a very rigorous, cold and dry semi-arid climate in winter, hot and dry in summer, whose features are as follows:

The relative humidity also fluctuates. It can vary from 90% in winter (maximum value in January) to a minimum value of 10% in July and August; a value that sometimes can spread over the 4 to 5 hot months.

The main agents of earth wall erosion are principally rain and frost, apparently little present in Biskra region. This does not prevent to neglect the deep damages that can be caused by rain dripping and that falls occasionally. During the month of the January 2003, a huge quantity of rain fell during 7 days; about 73 mm, a quantity which represents three quarters of what usually falls in one year.

The quantity of precipitation during the years 1999, 2000, 2001 and 2002 were 190, 81, 93 and 95 mm, respectively.

There are two types of seasonal dominating winds in the region of Biskra. The cold winds of winter blowing from north-west with an average speed of 35 km/h and the hot and dusty winds of the south-east and the south-west during spring and fall seasons. The winds reach the speed of 80 km/h provoking disasters in the region. The region also knows the dry and hot winds that blow during summer that can reach a maximum value of 47 km/h.

4. Results and discussion

4.1. Laboratory tests

It can be seen from the different laboratory test results (Table 3 and Figs. 3–7) that the durability improves considerably with the stabilizers addition. All the values of the compressive strength (Fig. 3) are well superior

Table 3
Test results

Bricks characteristics	Different walls treatment							
	Cement (%)		lime (%)		Cement (%) + Lime (%)		Cement (%) + Resin (%)	
	5	8	8	12	5 + 3	8 + 4	5 + 50	8 + 50
Compressive strength in dry state, MPa	15.4	18.4	15.9	17.8	17.5	21.5	17.2	19.5
Compressive strength in wet state, MPa	9	12.7	10.1	11.7	12.3	15.6	11.5	14
Water strength coefficient	0.58	0.69	0.64	0.66	0.63	0.7	0.67	0.72
Capillary absorption, %	2.35	2.2	3.7	2.9	2.3	2	2.3	2.1
Total absorption, %	8.27	7.35	9.8	9.02	8.1	7.9	5.9	5.3
Weight loss (wet–dry), %	1.4	1.25	2.3	2.1	1.2	1.0	0.9	0.9
Weight loss (freezing and thawing), %	2.35	2.23	3.7	2.9	2.3	2.0	2.3	1.8
Hole depth, mm – After spray test	1.0	0.5	2.2	1.0	1.0	0.5	0.25	0.2
Hole depth,[a] mm – Real life exposure	–	–	1.0	0.5	–	–	–	–

[a] Values obtained using a comparator.

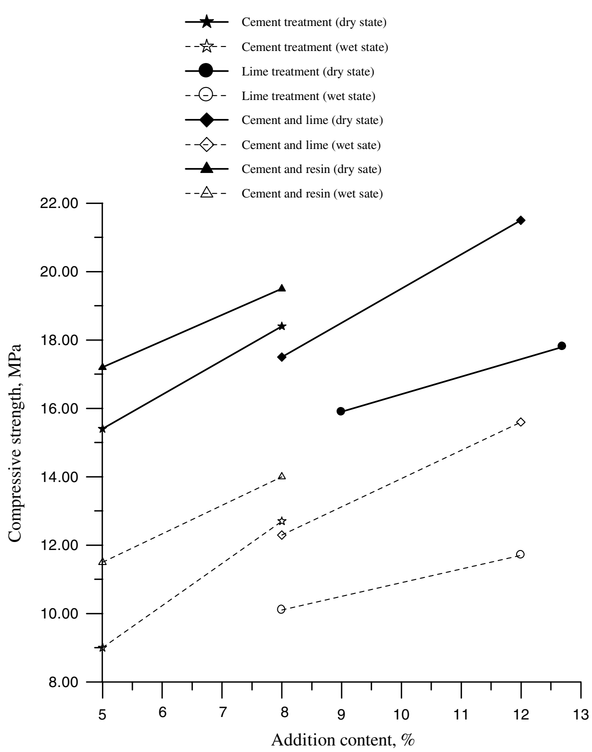

Fig. 3. Effect of additions on the compressive strength.

(2–3-fold) to those indicated by the norms which are 6 and 3 MPa as dry and wet states, respectively [26]. Kerali [12] found the same results using microsilica as addition. With 9% cement plus microsilica addition and a compacting stress of 10 MPa, the compressive strength values are of the order of 14 MPa as dry state and 16 MPa as wet state.

Again, for the water strength coefficient, the values obtained in this present work (Fig. 4) are well above the value limit fixed by AFNOR [24] which is 0.5. However, Kerali [12] found a more improved value for the water strength coefficient with microsilica addition, a value of the order of 0.9.

Almost all bricks can absorb water by capillarity [28]. The total amount of water absorbed is a useful measure of bulk quality. Generally, the less water a block absorbs and retains, the better is its performance likely to be [29]. There was a general decrease in water absorption (WA) with the different additions as shown in Fig. 5 and this is in a good accordance with the water strength coefficient values which increase with the increase of the addition content (Fig. 4). The values found as a result of the present work for total absorption (5.3–9.8%) are well within the recommended maximum value which is 15%. The recommended value limit for the capillary absorption is 2.5% as specified by the Uniform Building Code, USA [13]. Ngowi [30] showed that the WA decreases with increase in cement content while the lime had the opposite effect. On the other hand, the addition of microsilica reduces considerably the WA, as shown by Kerali [12].

According to ASTM standards D-559 [19], the weight loss limit in regions with annual rainfall less than 500 mm (150–200 mm for Biskra region where this work has been carried out) is 10%. The maximum weight loss value observed in this work is 2.3% corresponding to the 8% lime addition while the best performance was given by the addition of cement plus resin as illustrated in Fig. 6.

The values for the spray test results (Fig. 7) are somewhat small which reflect the excellent performance of the tested bricks when considering the severity of the test used in this present work. The test consisted in spraying the bricks vertically, 17 cm away from a horizontal jet of 1.6 kg/m^2 pressure, during two hours. Grezel [31] had studied the cement effect on the hole depth using the same test. He found that for the cement content of the 5–8%, the holes depth remains of the order of 1 mm. Other researchers use less severe tests [32,33]. In this present work, the authors have used a water pressure of 1.6 kg/m^2 and duration of 2 h in a region characterized by a very rare rainfall (150–200 mm per year).

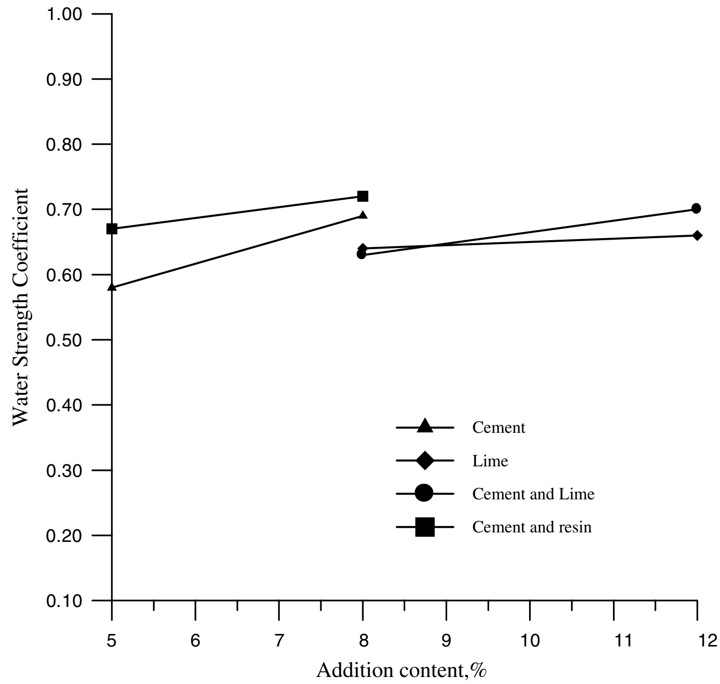

Fig. 4. Effect of additions on the water strength coefficient.

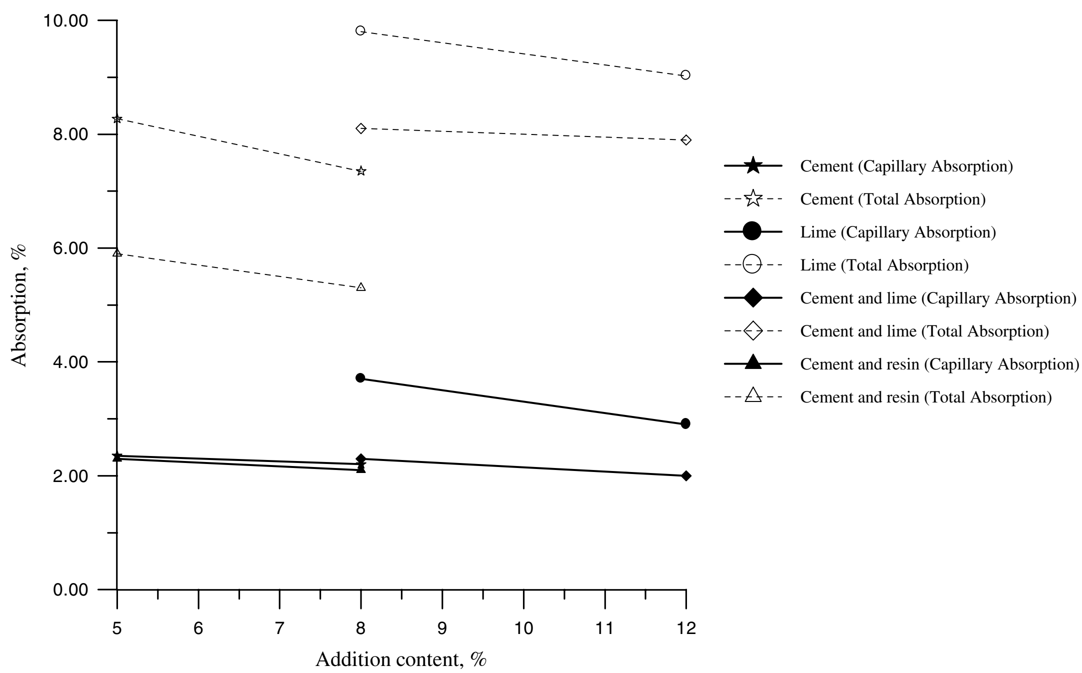

Fig. 5. Effect of additions on the absorption.

Again, there is a good correlation between the weight loss, the hole depth and the water strength coefficient results. The weight loss and the hole depth values decrease with the increase of the addition content whereas the values for the water strength coefficient increase; the hole depth and the weight loss are more important for a weak water strength coefficient.

4.2. Climatic conditions exposure

It is important to observe degradation with a maximum quantifiable criteria: degradation type, number, shape and dimensions of cracks; depth of the erosion. All of these will be recorded on cards for each wall and the degradation evolution will be noted. Photographs were also taken.

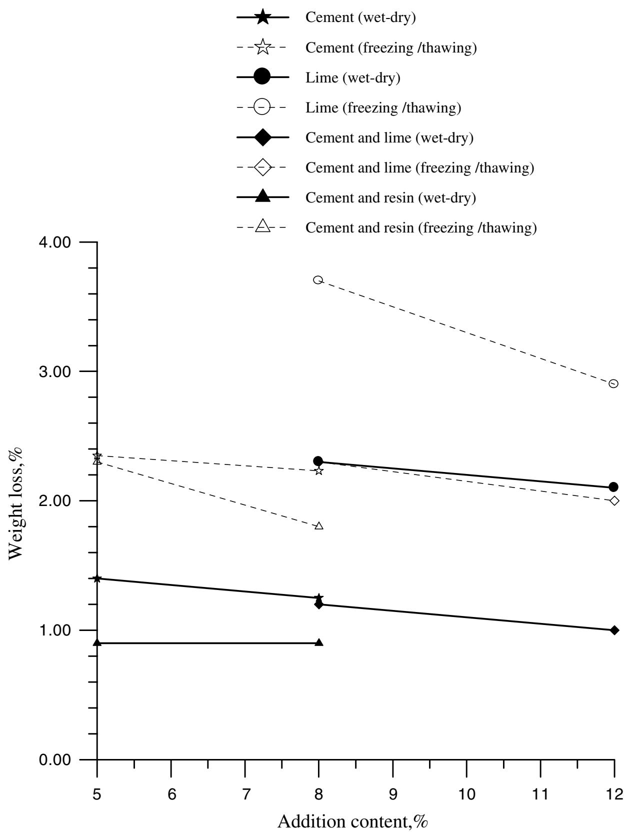

Fig. 6. Effect of additions on the weight loss.

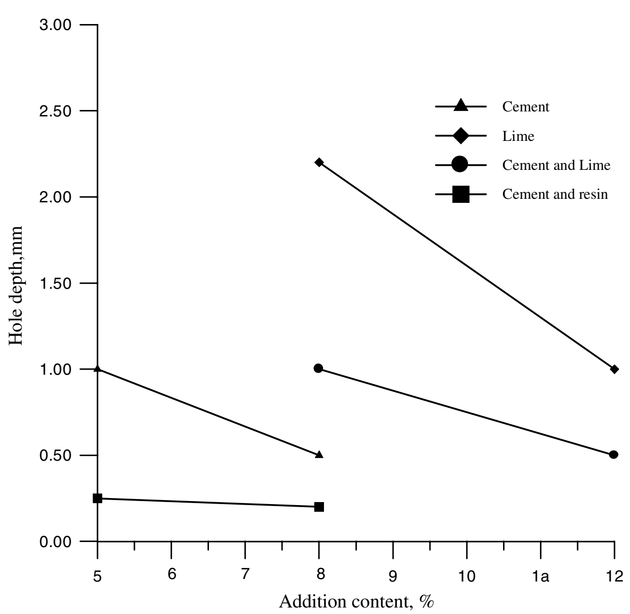

Fig. 7. Effect of additions on the hole depth – Spray test.

4.2.1. Stabilization using lime

In general, all the walls treated behaved satisfactorily after 48 months exposure, except those treated with lime which have shown a slight erosion degradation. It has been observed for the walls treated with 8% lime a partial crumbling at the north face level of the first and the second row, after 48 months exposure, as shown clearly in Fig. 8. This deterioration provoked an erosion reaching a maximum depth of 1 mm (Fig. 9) and over an area of about 40% of the exposed block surface. On the other south face, no deterioration was observed. Apparently, this is due to the effect of the dominant wind direction.

For the walls treated with 12% lime, no erosion has been recorded but a disappearance of small pieces of the brick of the first row has been noted. At left and right angle levels on the north face, Fig. 10. It has also to be noted that during the winter period, the walls have all the efflorescence at the base level but in more important manner for the case of the walls treated with lime.

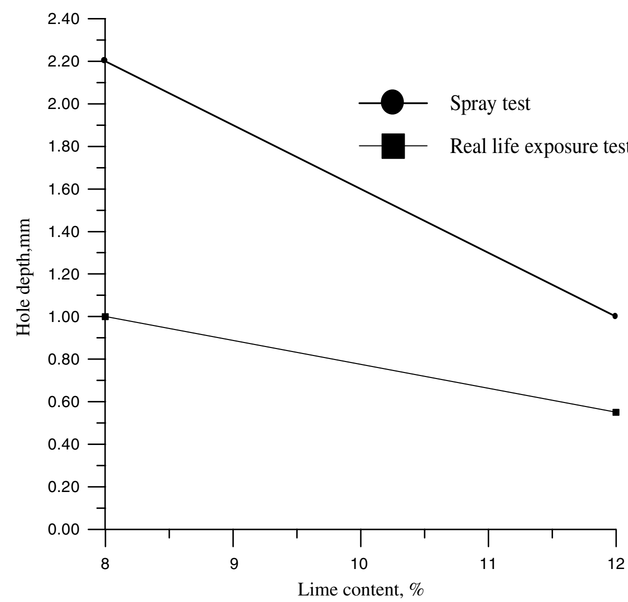

Fig. 8. Effect of lime content on the hole depth.

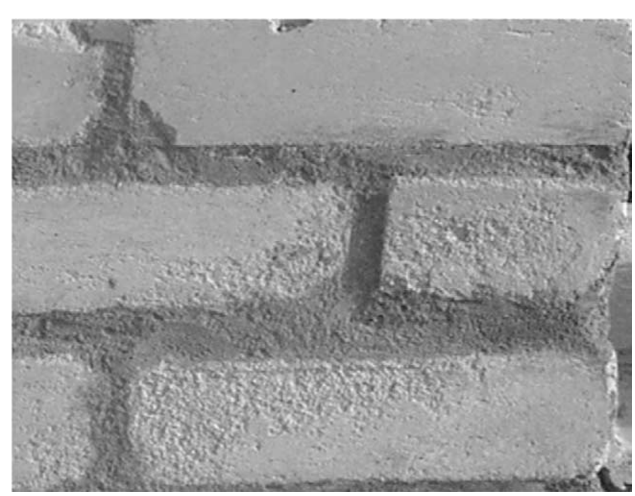

Fig. 9. 8% lime stabilized wall. Erosion deterioration after 48 months exposure.

4.2.2. Stabilization using cement

For the walls constructed with 5% cement bricks, no deterioration has been observed a part from the light leaching of the joints (Fig. 11). The walls prepared with the 8% cement bricks showed no sign of deterioration.

4.2.3. Stabilization using cement and lime

Two experimental walls have been prepared using mixed additives, cement and lime. It has been noted that the treatment by 5% cement plus 3% lime has shown a very good behavior.

Exactly, the same remarks can be made about the second treatment concerning the 8% cement plus 4% lime case. No degradation has been observed.

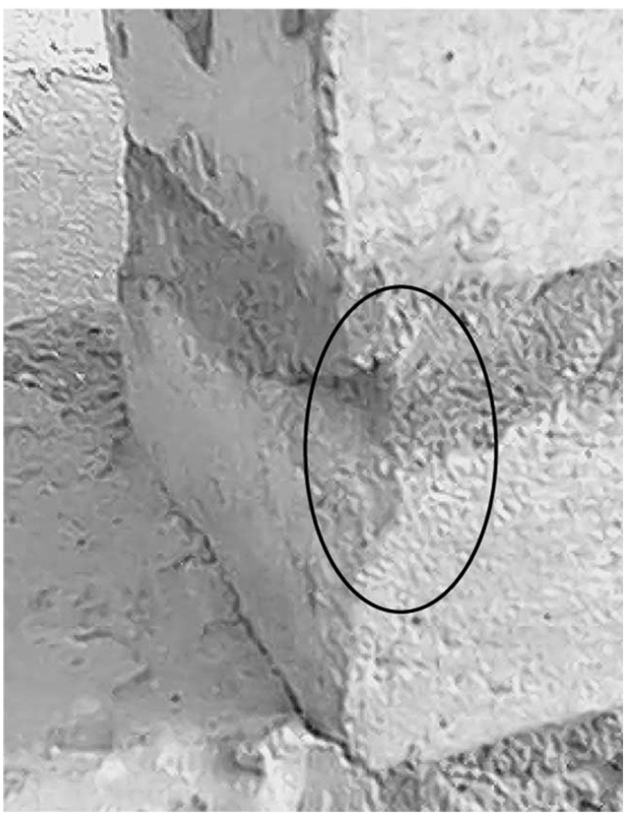

Fig. 10. 12% lime treated wall. North-face disappearance of small pieces.

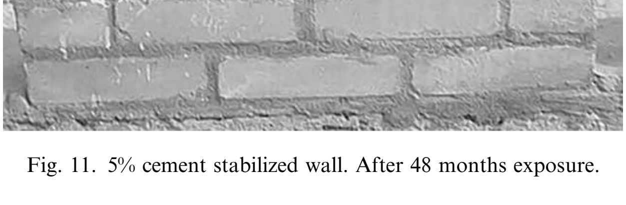

Fig. 11. 5% cement stabilized wall. After 48 months exposure.

4.2.4. Stabilization using cement and resin

Again, two walls have been prepared using two different mixtures of cement and resin. It has been noted that a treatment by the 5% cement + 50% resin in compacting water gave excellent results with a slight signs of leaching. The same observations can be made for the second treatment type; 8% cement + 50% resin in compacting water.

4.3. Validation of accelerated ageing tests

According to Gresillon [6], the wall bricks without protection exposed to rain and wind would be soaked with water. After immersion, Spraying, Wetting and Drying, Freezing and Thawing and Crushing tests are necessary. However, one might wonder on the validity of such tests in the region where the present work has been done.

The immersion of blocks during 24 h appears very severe. No rain is equivalent to such a regime in the region of Biskra. The spraying is very violent; in this case; we tend to replace the spraying period by the violence of the jet.

The wetting–drying test appears also very severe because the exposed bricks have not undergone a total immersion. The Freezing–thawing test appears also very severe because the bricks have not been exposed to temperatures below zero.

Among these accelerated ageing tests used to study the performance of the earth treated in mass, one can only keep the spraying test. This latter could establish a correlation effectively with the natural ageing test because the experimental walls have undergone neither a total nor a partial immersion.

The accelerated ageing tests (laboratory tests) are very severe compared to the natural ageing tests carried out in this present work. This explains the good behavior of the walls after 48 months exposure to natural conditions of the region of Biskra. Houses in this region constructed in raw earth with the Adobe technique without any outside protection stayed in an acceptable state for more than 60 years of their existence.

5. Conclusions

Durability improves considerably with the addition of stabilizers. It is also worth noting that the laboratory tests conditions seem very severe compared to the natural climatic conditions of the region of Biskra. This explains partly the good behavior of the stabilized walls after four years exposure. A good correlation between the two different test results as well as between the different laboratory tests was observed.

The exposure conditions have been characterized by a weak quantity of rainfall of about 120 mm/year. However, the walls have been exposed to an important and unusual rain during the month of the January 2003 for seven days, of the order of 73 mm.

In general, It has been noted that all treated walls showed no signs of deterioration after 4 years exposure in real climatic conditions. However, a light degradation has been recorded in the case of 8% lime sample. This deterioration provoked an erosion reaching a maximum depth of 1 mm and covering up to 40% of the surface of the exposed brick.

As a result of the present work, the following classification of the different products used as earth stabilizers can be made; according to their good durability:

- cement + resin
- cement
- cement + lime
- lime

It is also important to note that the utilization of the resin as a protection material is not economic. It is practically eight times more expensive than the treatment by cement.

For the type of soil (sandy clayey) used for this work; it is recommended to manufacture bricks stabilized with cement (5%) using a compacting stress of the order of 10 MPa. With these manufacturing conditions, one can assure an acceptable durability.

Acknowledgement

As we did not have any equipment for measuring the meteoroligical parameters on site, we used Biskra region station data. Their generous contribution is most gratefully acknowledged.

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