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HYDROMECHANICAL CHARACTERIZATION OF RAW EARTH MORTAR – STABILIZING CEMENT AND LIME

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ABSTRACT:

Earth-based mortars are again taking their place as building materials for plastering, rendering and repairing earth walls, not only in a sustainable context but also in terms of efficiency. Nevertheless, scientific understanding of these mortars is still scarce. This present paper reports on an experimental study, conducted at the laboratory of the university center of El-Bayadh, concerning the study of the hydro-mechanical characteristics of mortars based raw and stabilized earth. In doing so, mortars prepared with clay-sand soil, treated with cement (C) (6%, 8% and 10%), lime (L) (4%, 6% and 8%) and mortars treated with both binders (4% C+2% L, 5% C +4% L, 8% C+6% L) taking into account control mortars of raw earth, are investigated. Compressive and tensile percentage strengths, total absorption, and swelling are determined. Therefore, the obtained results in the case of total absorption test, showed significant erosion in the mortars specimens weakly stabilized with cement and those without added stabilizer. Indeed, it was observed during the swelling test that the mortars specimens weakly stabilized with cement were fragile to the erosive water and showed deterioration, especially at the edges. Furthermore, increasing the cement content from 6% to 10%, the water absorption percentage was reduced by 30%. It appears that the composition that led to a better behavior towards water is the mixed combination (8% cement + 6% lime). However, stabilization with cement confers a higher strength compared to lime powder. In fact, the maximum resistances were obtained for high cement dosages (8 and 10% respectively) and the 4% lime dosage.

1. INTRODUCTION

Historically, Earth remains, one of the main building materials. It is available in abundance, and its transformation into building material needs. Low energy consumption and ecological qualities have made it a material of choice for construction throughout the centuries. However, the industrialization in developed countries has favored the massive use of breeze blocks, concretes and other hydraulic binders to the detriment of raw earth. Nevertheless, with the environmental drawbacks of these materials, raw earth construction is now gaining interest in developing countries and even in industrialized countries. Despite the weaknesses that it presents in its current state (high sensitivity to water, low durability) the raw earth construction presents, in its stabilized form and depending on the used technique, tremendous environmental advantages as an ecological solution (Houben, Rigassi, and Garnier 1996). On the other hand, masonry walls are made up of mortar and masonry units. A variety of mortars and masonry units are used for the purpose of masonry construction. Morever, earth mortar was commonly used for masonry construction in the past, especially for low-rise structures with thicker walls. Lime mortar was popular, especially for palace construction. For the improvement of soil properties by applying different mechanical or chemical methods, this process is known as soil stabilization. Deep soil compaction (Moseley and Kirsch, 2004; Slocombe, Bell, and Baez, 2000), preloading (Alonso, Gens, and Lloret, 2000), vacuum consolidation (de Almeida, Marques, and Baroni, 2010), grouting (Croce and Flora, 2000), drainage (Al-Khafaji and Craig, 2000) and chemical soil stabilization are important and most preferred in soil treatment (Bell and Coulthard, 1990; Ghobadi, Abdilor, and Babazadeh, 2014). Recently, a number of scientific techniques for soil stabilization have been initiated (Rogers, Glendinning, and Roff, 1997, Al-Rawas and Goosen, 2006). Extensive studies have been done on the stabilization of soft soils using various additions such as lime and cement (Muntohar, 2011; P'Kla, 2002).

Cementitious material (Kemer, Bouras, Mesboua, et al. 2021, Kemer, Bouras, Sonebi, et al. 2021; Mesboua et al., 2021) such as lime, fines such as pozzolanic material, etc. in conjunction with cement. Commonly used composite mortars such as cement-lime mortars have a good workability, excellent water retention and better adhesion compared to pure cement mortars. Soil stabilization by lime in such mortars gives lime-soil mortars which are economical, compared to cement mortars with improved properties. On the other hand, the prediction of durability and mechanical benefits of earthen mortars is again a controversial subject. Therefore, some investigations such as the examination of the influence of some preparation parameters

such as the percentage of cement on the physical/mechanical characteristics of rammed earth by Venkatarama et al. (Reddy and Kumar, 2010) where it is highlighted that an optimum cement percentage of around 8% is sufficient to obtain cost effectiveness of earth mortars. Additionally, the increase in cement percentage over a range of 6% and 10% induces an increase in compressive strength from 5.32 to 8.05 MPa and from 1.13 to 2.52 MPa for the tensile strength. Regarding the study of the hydromechanical behavior of the earth material, we can report the work of Guettala et al (Guettala, Abibsi, and Houari, 2006), to investigate the effectiveness of some adopted chemical treatments (cement, resin) compared to other ones (lime, cement / lime) on the mechanical behavior and accelerated aging by spray test of earth mortars of stabilized earth from the region of Biskra-Algeria. Indeed, the results showed that the loss of material decreases with the increasing of the stabilizer content.

In the case of this work, the present study focuses on the hydro-mechanical behavior of earth mortar manufactured with a clay-sand soil, stabilized with cement, lime (and/or their combinations). The parameters controlling the mechanical behavior and the aging accelerated in the laboratory by the cycle of wetting/drying with water of these earth mortars are studied. In addition, the effect of stabilizers on the hydric and mechanical behavior of the manufactured earth mortar and the accelerated aging are also investigated.

2. EXPERIMENTAL PROGRAM

2.1 Materials used and specimen's preparations

Low clay soil from a plot of land in the province of El-bayadh (Algeria), which was selected due to its accessibility and quantity in the area, was used in this project to produce mortars. It was dug up to a depth of 70 cm. The cement adopted for this present paper again for chemical stabilization of mortars is class CPA-CEM I 42.5-ES (CRS-sulfate resistant cement), which has an excellent durability due to its composition of 95% clinker. and 5% gypsum. Additionally, it must be used with dry soil as a binder since cement begins to hydrate when it comes into encounter with water. Furthermore, quicklime, which is a calcium oxide made by heating lime stone rocks to a temperature of 1000°C.Indeed, it's hold be mentioned that mortars stabilized with lime require an additional three months (approximately) to acquire their optimum strength percentage than mortars stabilized with cement (Guide and Recommendations CNERIB) (Saadia, 2014).

2.2 Soil Composition

The soil was subjected to several laboratory tests to determine the constituents. The chemical analysis has been accomplished by using Fluorescence X ray, in accordance to NF6 P 15-467 standard. The obtained results are shown in Table 1.

Chemical Element	Percentage (%)
SiO2	53.25
AL2O3	25.60
Fe2O3	4.60

Table 1. Chemical composition of the soil

The mineralogical analysis has been performed by using diffractometer (X-rays) and the results were directly collected from the computer. The mineral characteristics are given in Table 2.

Mineral Element	Percentage (%)
Quartz SiO_2	56.25
Calcite $CaCO_3$	03.00
Albite $NaAlSi_3O_8$	02.00
Feldspaths K (Orthoclase) ($K_2O_6SiO_2Al_2O_3$)	03.00
Illite $2K_2OAl_2O_{32}4SiO_{22}H_2O$	04.50
Kaolinite $Al_2Si_2O5(OH)_4$	20.60
Minérauxferrugineux+Autres	08.65

Table 2. Mineralogical constituents of the soil

2.3 Stabilizer compositions and contents

This investigation consists of applying the stabilizers and their combinations according to the dosages given in Table 3.

	Materials used	Stabilizer percentage (%)
Homogeneous composition	Raw earth	0
	Cement	6- 8- 10
	Lime	4- 6- 8
Mixed composition	Cement + lime	4 c+2 L, 5 c +4L , 8 c+6 L

Table 3. Stabilizer content in the mortars specimens

According to Michel (1976), the most favorable mixing conditions are obtained when the soil has dried. This requires a preliminary drying process of the soil. Once the soil has been dried in the oven for 24 hours at 63°C, the materials (soil + lime + cement) are first mixed in a dry state and subsequently mixed with water in a 5-litre cement mixer at a rate of 139 rpm. The dry mixtures are homogenized during five minutes as well as mixing with water was carried out for approximately two minutes, the amount of water is 10% in the dry mix.

2.4 Shaping mortars specimens and testing

The Prismatic specimens ($4x4x16cm^3$) used for the determination of the various tests established by the program object of our present research, the de-molding of prismatic mould is carried out by opening the mould (unscrewing the bolts). On the other hand the resistance of a soil-bonding increases with age. Not all soils have the same behavior, but acquiring period of 28 days is required. During this period, the materials hold be kept in a humid atmosphere, away from the sun, taking care of the wind; this will avoid a too fast drying. Under real conservation conditions, the mortars specimens must be covered with plastic film for the first few days before being used. After de-molding, the mortars specimens is taken by hand carefully, avoiding contact with the edges due to its fragility, then covered with a plastic film to ensure its impermeability (photos 1, 2).




Photo 1. Mortars specimens



Photo 2. Mortars specimens covered with plastic film

2.5 Hydric tests

The total absorption (photo 3) test consists of putting specimens in a water tray for 24 h and the increase in the mass of the specimens (Ph) is measured. The index A of total water absorption of each specimen is commonly expressed as:
$A\% = (Ph\text{-}Ps)/ps$.

- Ph: weight of the sample in the wet condition.
- Ps: weight of the sample in the dry condition.



Photo 3. The total absorption test

The capillary water absorption was measured according to the detailed test described in the NF XP 13-901 experimental standard.

- Weigh the specimens in the dry condition: Md
- Immerse the smooth face of the facing at a height of 5 mm as shown in Photo 4.



Photo 4.The capillary absorption test

The absorption coefficient Cb is the absorption rate following a time of 10 minutes. This coefficient is expressed by the following equation's=100x(Mh – Ms)/SyT
With :

- Mh - Md : is the mass of water, in grams, absorbed by the block during the test.
- S: Surface of the immersed face, in square centimetres.
- T: is the immersion time of the specimens in minutes.

Moreover, the measurement of the swelling is performed according to the following procedure (standard XP 13- 901) (photo 5):

- Seal on each specimen with an epoxy resin -two measuring studs
- Measure the distance between epoxy resin -two: L0
- Place the specimens in a water tank

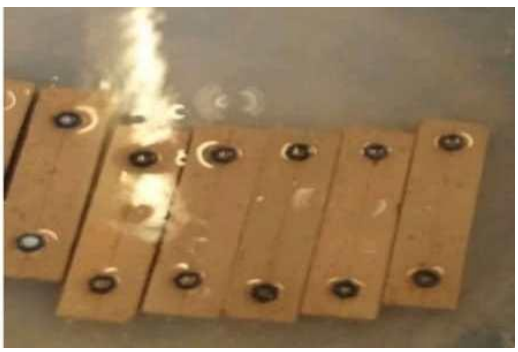


Photo 5.The swelling test

When the specimens have been immersed over 48 hours, let them drain for 10 minutes, then measure the distance between epoxy resin-two: L1

- The swelling amplitude of each block is given by the following equation:

Dlg (mm/m) = (L1-L0)/ L0
L0: the distance before immersion.
L1: the distance after immersion

3. EXPERIMENTAL RESULTS

3. 1 Results and discussion

Compressive and tensile strength test results on raw and stabilized earth mortars specimens with different binder percentage (cement, lime and their combinations) are reported in Table 4.

Cement %				Lime %				Cement+Lime %			
Compressive strength (MPa)											
0	6	8	10	0	4	6	8	0	4C+2L	5C+4cL	8C+6L
2,09	5,32	7,04	8,05	2,09	3,37	2,97	2,55	2,09	4,20	4,52	5,09
Tensile strength (MPa)											
0	6	8	10	0	4	6	8	0	4C+2L	5C+4L	8C+6L
0,75	1,13	1,42	2,52	0,75	1,01	0,80	0.60	0,75	1,01	1,03	1,05

Table 4. Compressive and tensile strengths carried out on the blocks

Cement stabilization confers a steady increase in compressive strength for all the mortars specimens respectively 83.48%, 142.75% and 177.57% compared to the control block never the less a higher strength compared to lime and this is due to the pozzolanic effect requiring a prolonged curing time. The maximum strengths percentage (more than 7 and 8 MPa) were obtained for high cement content (8 and 10%, respectively), which is probably due to the amount of C3S and C2S calcium silicates following the increase in anhydrous cement content on the one hand and the formation of hydrates such as calcium aluminates and calcium alumino silicate hydrates on the other hand. Therefore, these main hydrates are produced during the hydration of cement and participate in the filling of the pores of the cementitious matrix while improving the rigidity of the structure by creating a large number of rigid bonds between the particles of the soil mixture (Bahar, Benazzoug, and Kenai, 2004).

For mixed binders, the maximum mortars specimens' compressive strength (5.04 MPa) was achieved for a combination of stabilizers (8% cement + 6% lime). The results show that a mixed treatment of cement and lime can also lead to the improvement of the earth mortars specimens' compressive strength.

For the tensile test carried out on the mortars specimens stabilized with different binders, we noticed a continued increase of the strength depending on the variation of the cement content which reaches a value of 2.52 MPa, hence an over all increase of 236% compared to the control block for the blocks stabilized with 10% cement, and a value of strength of 1.01 MPa where an increase of 34.66% for that which is stabilized with 4% of lime. On the other hand we notice a significant drop about 20% regarding the blocks stabilized by 6% and 8% of lime. The evolution of the strengths remains constant for the whole of the blocks based on mixed treatment this last is owed to the pozzolanic action which requires longer cure duration.

The compressive and tensile strengths of stabilized earth blocks at 28 days are shown in Figure 1 and Figure 2 respectively, so that the strength of the mortars specimens tends to improve as the binder content increases.

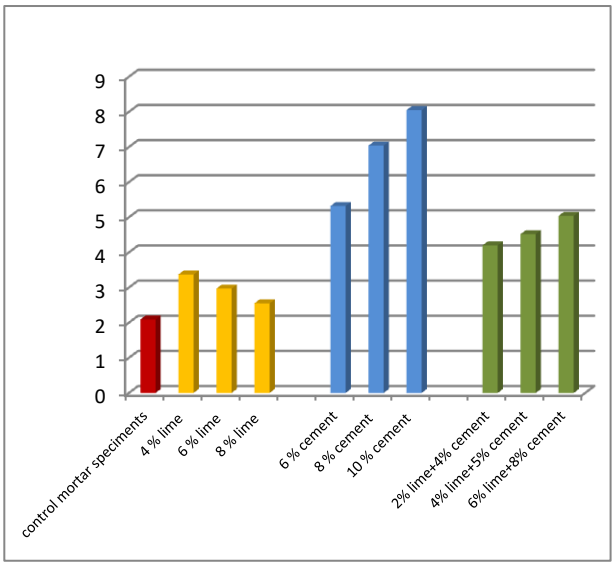


Figure 1. Compressive strength of Mortar specimens (MPa)

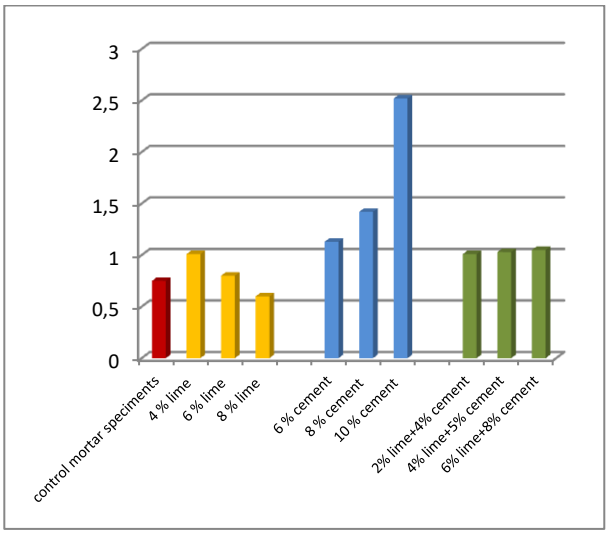


Figure 2. Tensile strength of Mortar specimens (MPa)

The results of the hydric tests on the raw and stabilized earth mortars specimens with different binder percentage (cement, lime and their combinations) are presented in Table 5.

Cement %				Lime %				Cement+Lime %			
Total absorption A%											
0	6	8	10	0	4	6	8	0	4c+2Ch	5c+4ch	8c+6ch
0,30	0,24	0,22	0,21	0,3	0,17	0,21	0,21	0,30	0,24	0,21	0,19
Absorption by capillarity Cb %											
0	6	8	10	0	4	6	8	0	4c+2Ch	5c+4ch	8c+6ch
19,50	19,26	10,38	7,17	19,50	9,89	15,89	16,07	19,50	17,80	15,57	11,13
Swelling Dlg (mm/m)											
0	6	8	10	0	4	6	8	0	4c+2Ch	5c+4ch	8c+6ch
70	60	50	40	70	40	50	60	70	60	50	40

Table 5. Results of water tests carried out on the blocks

The total absorption test performed on the mortars specimens produced significant adverse effects manifested by disintegration at the edges (Figure 3), especially when the stabilizer content was low. It should be noted that a significant degradation was observed for the blocks without addition of stabilizer, and this since the first minutes of immersion. Figure 3 illustrates the evolution of the total absorption level as a function of the stabilizer content for a 24-hour immersion phase. In fact, a significant degradation was noted in the weakly stabilized mortars specimens, from the first hours of immersion.

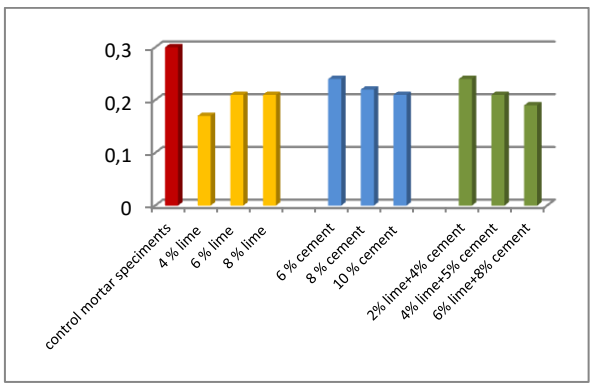


Figure 3. Total absorption of Mortar specimens (%)

The value of weight loss recorded in the stabilized mortars specimens (homogeneous composition) corresponding to the addition of 4% of lime, whereas a best erosion resistance of the stabilized mortars specimens was noticed for the mixed compositions with addition of cement, and lime. Nevertheless, the percentage of absorbed water decreases as the cement content in the mortars specimens' increases. The cement proportioning in the mortars specimens (6%, 8%, and 10%) reduces the material losses. This phenomena on can be due to the fact that the hydrated cement contributes to reducing the porosity and filling the voids (pores) thanks to its low specific mass. Furthermore, for mixed composition mortars specimens stabilized with the added cement and lime, it was reported that the water absorption percentage was low, particularly for mortars specimens having the following composition (8% cement + 6% lime) and. The same study was carried out by Venkatarama et al. (Venkatarama Reddy and Gupta, 2005) on cement stabilized earth mortars specimens, in which it was found that the water absorption percentage decreased considerably with the increase of the cement content of the mortars specimens (6%, 8%, 12%). The pore size decreased with increasing cement content. The total amount of absorbed water by capillary (Figure 4) action with in the mortars specimens stabilized by cement (6%, 8% and 10%) is in the range of 19.26% and 7.17%, which suggests a more water resistant material with a high cement level.

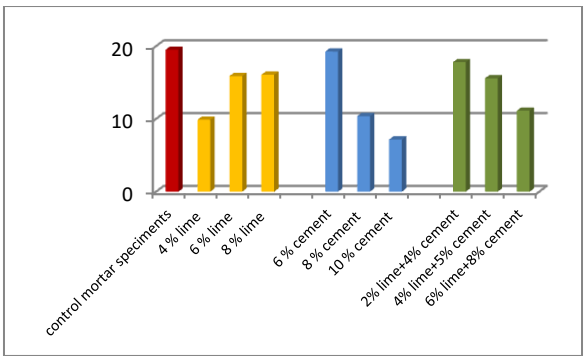


Figure 4. Capillary absorption of Mortar specimens (%)

Moreover, it is noted that the mortars specimens stabilized with mixed combinations of stabilizers (cement + lime) presented a better resistance to the wetting / drying cycle, with a loss in weight of the mortars specimens ranging from 8.12%.The water resistance of mortars specimens, increases with the high cement percentage especially for a 10% cement content. The lime treatment only is not suitable, since even with high percentage (8%), the strength of the mortars specimens after wetting drying is altered. In fact, mortars specimens stabilized with the added cement and lime have a practically low water absorption rate, especially the mix (8% cement + 6% lime). On the other hand, figure 5 shows the effect of the percentage of stabilizers on the swelling of mortars specimens. According to this illustration, it can be seen that the swelling by emersion is decreased with the increasing of the cement proportioning.

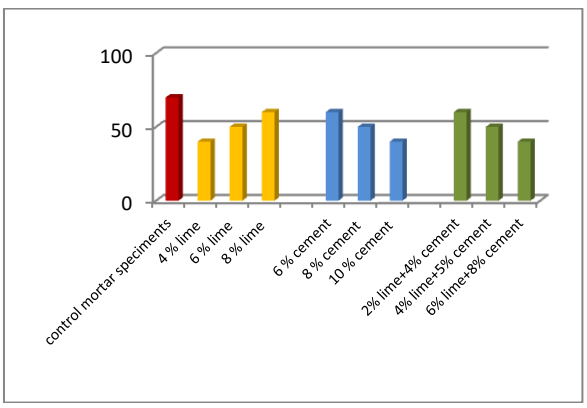


Figure 5. The swelling rate of Mortar specimens (mm/m)

After 28 days, the swelling rate of the lime-stabilized mortars specimens is lower than that of the control mortars specimens. In terms of values, this decrease is 42.86% for the addition of 4% lime. The highest values of swelling are at 6% and 8%. Swelling decreases immediately when sufficient lime is added to the clay soil. In fact, this behaviour is due to the exchange of inter-foliar cations by calcium cations. This cation exchange contributes to the reduction of water by the clays. The mixed combination in stabilizers (cement + lime) showed a better resistance to the stabilized mortars specimens of (8% cement + 6% lime).

4. CONCLUSION

The study's findings indicate that stabilized earth mortars with higher binder percentage demonstrated better mechanical and hydric performance. With increasing binder percentage alone, the mortars' compressive and tensile strengths tended to rise. With 10% cement percentage, the highest compressive strengths (around 8 MPa) were attained (but significantly lower with lime as binder). The compressive strength of the earth mortars significantly increased as a result of stabilization using mixed combinations (cement/lime). Nearly identical tendencies to those for the mechanical testing were seen in the hydric tests. In the case of the entire absorption test, mortars stabilized with a 4 percent lime dosage and the combination showed an acceptable resistance to the erosive action of water (8 percent cement and 6 percent lime).

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