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THE PERFORMANCE EVOLUTION OF AERIAL LIME MORTARS FORMULATED WITH DIFFERENT BINDERS

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ABSTRACT

Wall renderings replacement is a frequent action in interventions on old buildings rehabilitation.

The paper presents, the performance of evolution of two aerial lime mortars formulated with hydrated lime and lime putty (volumetric proportion 1:3), commonly used in buildings restoration, and analyses the influence of the type of aerial lime on render performance. For that purpose, the mortars were physically and mechanically characterized at different ages. Furthermore, this paper aims to contribute for the assessment of the potential interest of using *in situ* tests techniques to evaluate old buildings wall renderings degradation. Since salts crystallization is a major cause for materials degradation, the study of aerial lime mortars behaviour facing salts crystallization phenomenon is also presented.

The results obtained show the influence of the type of aerial lime mortar in the performance of the two mortars formulations and the interest of studying their performance at advanced ages.

Keywords: replacement mortars, aerial lime, performance evolution, carbonation, salt crystallization, *in situ* tests.

1 INTRODUCTION

Since wall rendering mortars are exposed to climatic and environmental actions they are usually the first elements to deteriorate. Thus, wall renderings replacement is very common in old buildings rehabilitation interventions.

Considering that nowadays most of materials and techniques are impossible to be reproduced, it is necessary to study and establish the main requirements and characteristics that mortars should have to be applied as replacing mortars, without causing major damages in pre-existing materials.

Several researches revealed that aerial lime mortars are the most compatible and present suitable performance when applied as wall rendering replacing mortars in old buildings. So, this study aims to contribute to increase the knowledge regarding aerial lime mortars behaviour when applied as replacing mortars through mechanical and physical characterization, at several ages, of two mortar formulations frequently applied in these situations. According to the results obtained from several tests, it might be possible to evaluate the influence of the type of aerial lime mortar in these two mortar formulations behaviour and performance.

In order to know the state of conservation of old buildings and evaluate the replacement needs, this study attempts to increase the use of *in situ* tests techniques to evaluate old buildings materials characteristics and their state of conservation. With this purpose, some characteristics evaluated through these techniques were compared with those obtained with tests frequently used in laboratory for mortars characterization.

Salts crystallization phenomenon frequently contributes to materials degradation. Given the porous nature of materials, salts penetrate and circulate through them in water solutions that crystallize when the water evaporates, and will be dissolved again depending on the temperature and relative humidity. These cycles of crystallization/dissolution are responsible for materials degradation. Thus, this research also aims to contribute to the establishment of laboratory testing methods to simulate the effect of salts crystallization in mortars, through two different test procedures.

To reach these objectives, two common formulations of aerial lime mortar were characterized by testing two sorts of specimens: prismatic specimens and brick specimens with one surface covered with mortar simulating render.

2 EXPERIMENTAL SECTION

2.1 AERIAL LIME MORTARS

The research tested one mortar formulated with hydrated lime (CaH) and other formulated with lime putty (CaP) with a slaking period of 1 month. Both mortars were made with natural sand from different origin (volumetric proportion 1:1,5:1,5), previously dried at 100 ± 5 ºC for 48 hours.

The amount of water used in each composition was determined by establishing a mortar flow of 65 ± 5 %. This flow was set according to the workability of the mixture.

For both compositions several prismatic specimens (16x4x4 cm) and brick specimens (30x11x2 cm) were prepared.

The mortars were mixed and the specimens were molded in laboratory at 18 ± 2 ºC. After molded, the specimens were kept in a chamber under temperature of 20 ± 2 ºC and relative humidity of 50 ± 5 %. They remained under these conditions until their characterization.

2.2 TESTS

For the purpose of this research, study the evolution of performance of two formulations of aerial lime mortars and the influence of the type of aerial lime mortar, the tests carried out covered some of the most important characteristics of aerial lime mortars, namely: flexural and compressive strength, ultrasonic pulse velocity, water absorption by capillarity, water absorption under low pressure, water absorption after 48 hours of immersion, drying kinetics, carbonation and mortars behaviour facing salts crystallization. The behaviour of the mortars was evaluated at the following ages: 14, 21, 28, 60 and 90 days. Drying kinetics and salts crystallization tests were performed at 90 days of age.

All the tests performed were based on procedures described in international specifications or in research works.

Since lime putty includes water in its composition, it was determined the amount of water in the lime putty, [11][12]. The test revealed that 55% of lime putty is water. Thus, the water-binder proportion of lime putty mortar is 1,73, and 1,62 for hydrated lime mortar.

Ultrasonic pulse velocity was evaluated following the procedure described in [12] and carried out on prismatic specimens before their characterization through flexural strength. This characterization was performed on 6 specimens for each age under study.

The compressive test was performed following the procedure described in [12] on the half samples that resulted from the flexural test. So, for each age, 6 prismatic specimens were submitted to flexural test and the resulting 12 halves were used in compressive test. However, before compressive test, the 12 halves were sprayed with phenolphthalein solution (0,2 % concentrated) to determine the evolution of carbonation [12].

The results are presented in Table 1.

Table 1 – Mortars mechanical characterization and carbonated depth

Mortar sample	Mortar flow [%]		Age [days]	Ultrasonic pulse velocity [m/s]		Flexural strength [MPa]		Compressive strength [MPa]		Carbonated depth [mm]	
	N	Average		N	Average	N	Average	N	Average	N	Average
CaP	10	63 ± 2,5	14	6	1360 ± 60	6	0,1 ± 0,03	12	0,5 ± 0,05	12	3
			21	6	1400 ± 40	6	0,2 ± 0,01	12	0,6 ± 0,02	12	6
			28	6	1480 ± 40	6	0,2 ± 0,02	12	0,6 ± 0,05	12	7
			60	6	1560 ± 10	6	0,3 ± 0,02	12	0,8 ± 0,04	12	19
			90	6	1620 ± 5	6	0,4 ± 0,01	6	0,9 ± 0,02	6	20
CaH	12	65 ± 2,0	14	6	1460 ± 35	6	0,2 ± 0,02	12	0,4 ± 0,04	12	1
			21	6	1520 ± 30	6	0,2 ± 0,02	12	0,5 ± 0,04	12	4
			28	6	1580 ± 60	6	0,3 ± 0,06	12	0,6 ± 0,03	12	6
			60	6	1630 ± 150	6	0,4 ± 0,01	12	1,0 ± 0,05	12	14
			90	6	1710 ± 20	6	0,4 ± 0,02	6	1,1 ± 0,15	6	20

N - Number of determinations

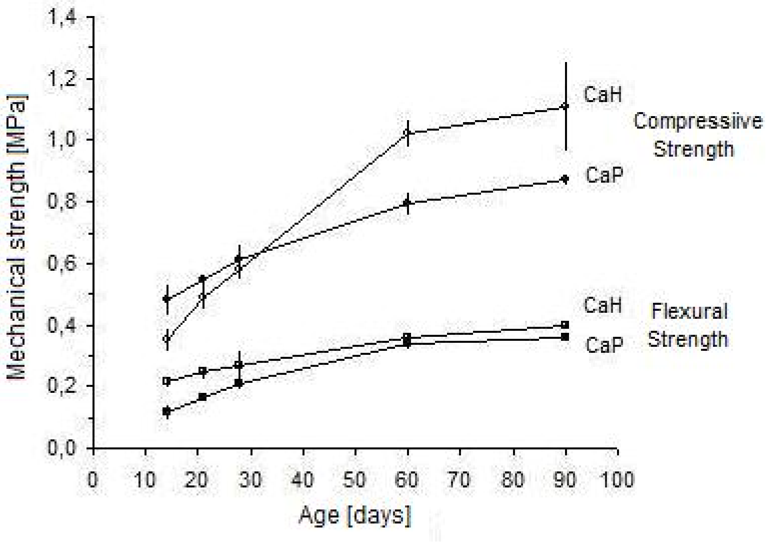

Fig. 1 – Evolution of mechanical strength

Capillary water absorption test was conducted by placing 2 prismatic specimens, previously dried at 60 ± 5 ºC for 3 days, in 2 mm of water inside a covered box for 72 hours, until the absorption reached an asymptotic value [12][5].

The determination of the water absorption after 48 hours of immersion was based on a classic procedure [12][6] on 1 specimen, previously dried at 60 ± 5 ºC for 3 days, for each age.

Results are presented in Table 2.

Table 2 – Water absorption

Mortar sample	Age [days]	Capillary water absorption at 60 min [$Kg/m^2.s^{1/2}$]		N	Water absorption after 48 hours of immersion [%]
		N	Average		
CaP	14	2	0,26	1	11,0
	21	2	0,31	1	11,7
	28	2	0,37	1	12,3
	60	2	0,41	1	11,2
	90	2	0,45	1	10,0
CaH	14	2	0,2	1	9,8
	21	2	0,24	1	10,1
	28	2	0,29	1	9,2
	60	2	0,32	1	9,3
	90	2	0,36	1	9,4

N - Number of determinations

The tests performed on the mortars applied as render on bricks were the ultrasonic pulse velocity test and the water absorption under low pressure. Ultrasonic pulse velocity test was determined according to [12] and water absorption under low pressure test was carried out as state in RILEM procedure [7]. Results are presented in Table 3.

Table 3 – Characteristics of mortars applied as brick rendering

Mortar sample	Mortar flow [%]	Age [days]	Ultrasonic pulse velocity [m/s]	N	Water absorption under low pressure at 2 min [kg/m^2]
CaP T	61	14	1890	3	0,66
		21	1910	3	0,45
		28	1950	3	0,48
		60	1990	3	0,35
		90	2010	3	0,32
CaH T	67	14	1790	3	0,66
		21	1870	3	0,41
		28	1880	3	0,32
		60	1910	3	0,37
		90	1970	3	0,30

N - Number of determinations

Drying kinetics experimental procedure was based on [1][3][12]. This test was performed using samples obtained from flexural test at 90 days of age, 4 halves of lime putty mortar columns and 5 halves of hydrated lime mortar samples, which 4 lateral surfaces were sealed with epoxy resin. The drying index is determined according to:

$$I.S. = \frac{\int_{t_0}^{t_f} f(w_i) \times dt}{W_0 \times t_f}$$

t_f – test final time [h];

W_0 – initial amount of water, expressed as a percentage of the dry weight [%];

$f(W_i)$ – amount of water inside the specimen as a function of time, expressed as a percentage of the dry weight.

The drying indexes obtained from this test are presented in Table 4.

Table 4 – Drying kinetics

Drying conditions	Mortar sample	Age [days]	N	Drying index
Water immersion	CaP	90	4	0,46
	CaH	90	5	0,59
Salt solution immersion (15% of sodium chloride)	CaP	90	4	0,59
	CaH	90	5	0,66

N - Number of determinations

Aerial mortars behaviour facing salts crystallization was evaluated through two different procedures at 90 days of age. The specimens used in the first procedure (I) Fig. 2 were the same previously used for the drying kinetics test and were immersed in salt solution (15% of sodium chloride) for 48 hours, and then weighted everyday until constant mass was reached [3][12].

Fig. 2 – Salts crystallization – Procedure 1

The second procedure (II) was based on [3][12][8]. Three specimens previously used on the capillary water absorption and water absorption after 48 hours of immersion tests at 90 days of age, previously dried at 60 ± 5 ºC for 72 hours, were placed in glass dish (9 cm of diameter and 2,5 cm high) with salt solution, Fig. 3. Paraffin wax was used to prevent evaporation and seal the system. During the first two weeks, salt solution was replaced every 48 hours. After the second week, distilled water was used instead of salt solution and it was replaced every seventh day.

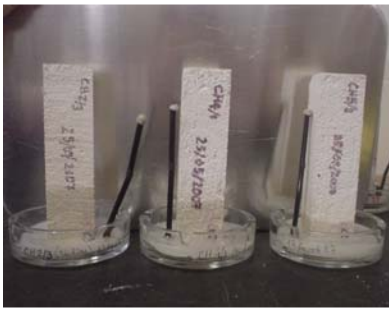

Fig. 3 – Salts crystallization – Procedure 2

After several weeks, mortar samples surfaces, from both procedures, were covered by salt and apparently degraded Fig. 4

Fig. 4 – Salts crystallization

Mortars behaviour facing salt crystallization was evaluated through mass loss, Table 5, and differences in water absorption before and after crystallization tests, Table 6 and Fig. 4.

Table 5 – Mass loss

Test procedure	Mortar sample	Mass loss [%]
I	CaP	0,18
	CaH	0,39
II	CaP	2,20
	CaH	23,09

Table 6 – Water absorption after 48 hours of immersion

Mortar sample	Initial water absorption [%]	Water absorption after salts crystallization test [%]
CaP	10,0	10,2
CaH	9,4	10,4

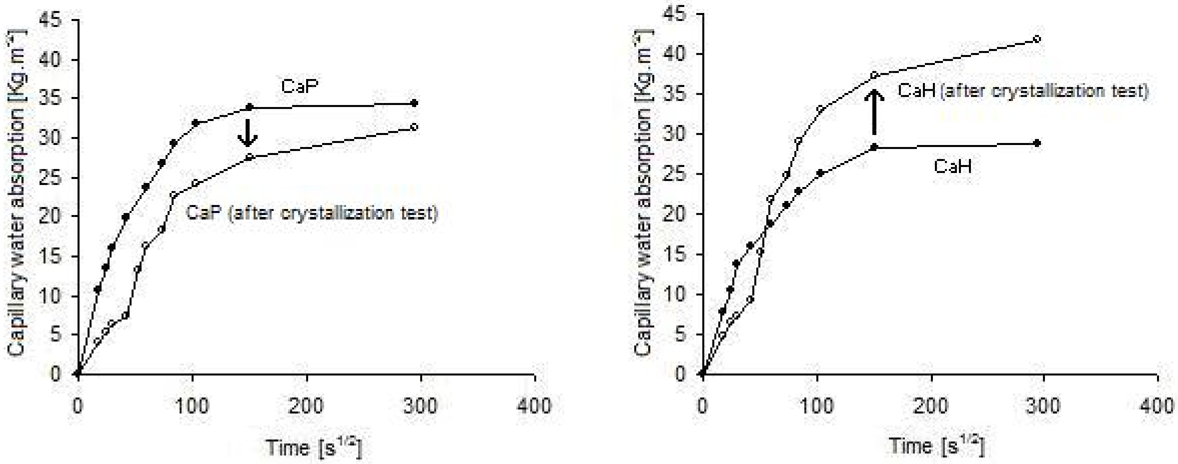

Fig. 5 – Capillary water absorption

3 DISCUSSION OF RESULTS

Both mortars presented mechanical characteristics compatible with the binder used [4][10], which means that the mechanical strength obtained is significantly lower than those achieved with hydraulic binders. According to the tests performed, hydrated lime mortar revealed higher values of flexural and compressive strength, Table 1. These results are in agreement with the water-binder proportion of each mortar formulation. The water-binder of the lime putty mortar was slightly higher (1,73) than the hydrated lime mortar (1,62).

Mortars mechanical resistance was also evaluated through ultrasonic pulse velocity. This test performed in prismatic proved to be sensitive to mechanical resistance variations and to the development of carbonation. The results obtained revealed that hydrated lime mortar is slightly more compact and resistant than lime putty mortar, Table 1, which is in agreement with the results obtained for flexural and compressive strength, Fig. 6.

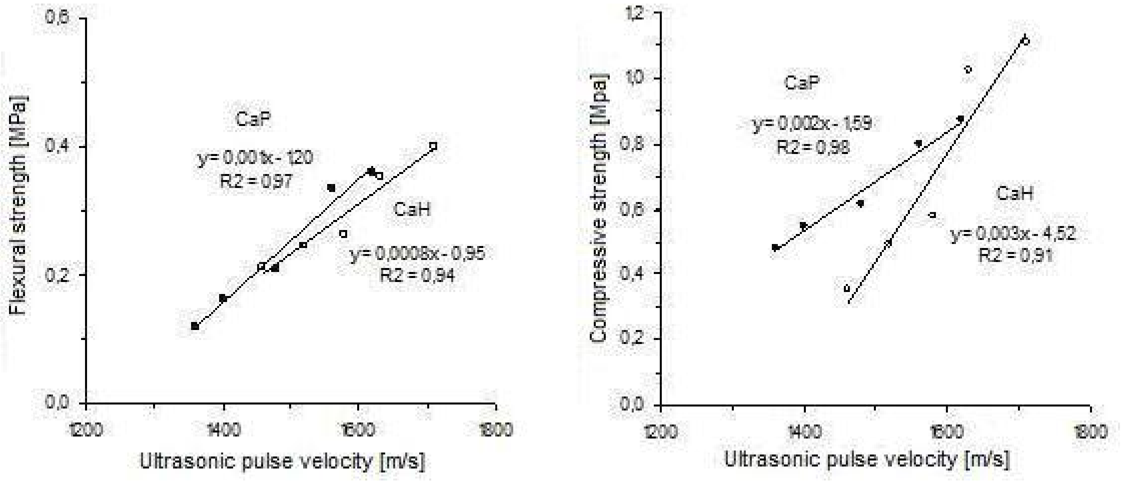

Fig. 6 – Relation between ultrasonic pulse velocity and mechanical strength

However, ultrasonic pulse velocity determined in mortars applied as render on brick specimens led to different results. The ultrasonic pulse velocity obtained with lime putty mortar was slightly higher than the velocity obtained with hydrated lime mortar, Table 3. This difference may be related with the influence of carbonation development due to the different thickness of specimens (prismatic and brick specimens), or related to the process of determination of ultrasonic pulse velocity not being sensitive enough to this variations.

The obtained results revealed the importance of the carbonation evolution in the mechanical resistance development. The flexural and compressive resistance increased until the process of carbonation finish. Despite hydrated lime mortar present higher values of mechanical resistance and the amount of water in mortars hinder the penetration of carbon dioxide in the porous structure of material, carbonation developed faster in lime putty mortar, Table 1. It might be related with the drying characteristics and the porous structure of each mortar. This process was responsible for the higher values of mechanical resistance obtained with lime putty mortar samples in the early ages. Also, phenolphthalein solution indicated total carbonation of mortar samples at 90 days of age. This is not in agreement with reality because carbonation is a slow process that wasn't finished at 90 days due to the growth of mechanical resistance.

Mortars behaviour towards water revealed that both mortars have high capacity for water absorption.

The coefficients determined for capillary water absorption are higher than the values recommended in bibliography for replacement mortars [4][10]. According to the tests carried out, lime putty mortar revealed increased capacity for water absorption, Table 2. This test shows that capillary water absorption increases with age, Figs. 5 and 6, which might be related with the development of carbonation.

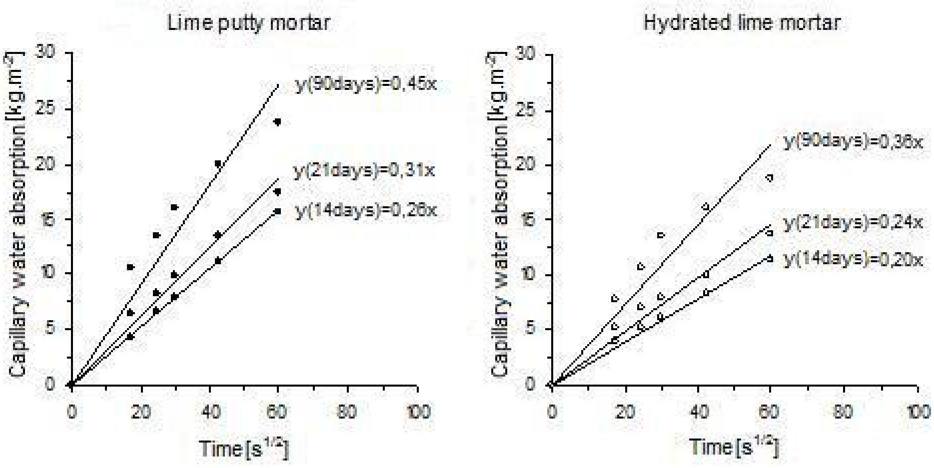

Fig. 7 – Capillary water absorption

Although, such behaviour was not identified by water absorption after 48 hours of immersion, Table 2, and water absorption under low pressure, Table 3. Tests carried out pointed to a reduction of water absorption over time, Fig.8. These differences are connected to the performed experimental methods and its sensibility to the evolution of carbonation in mortars.

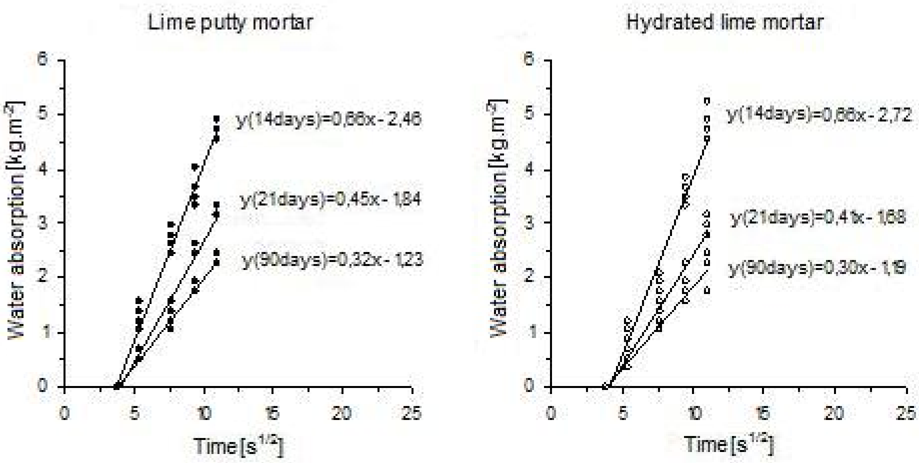

Fig. 8 – Water absorption under low pressure

Water absorption characteristics determined through capillary water absorption, water absorption after 48 hours of immersion and water absorption under low pressure led to similar conclusions: both mortars revealed high capacity of water absorption, and it was found to be higher in lime putty mortar.

Drying kinetics tests showed that both mortars have different drying kinetics. Lime putty mortar was found to dry faster in the beginning, revealing less tendency to retain water inside the material than hydrated lime mortar, Table 4 and Fig. 9.

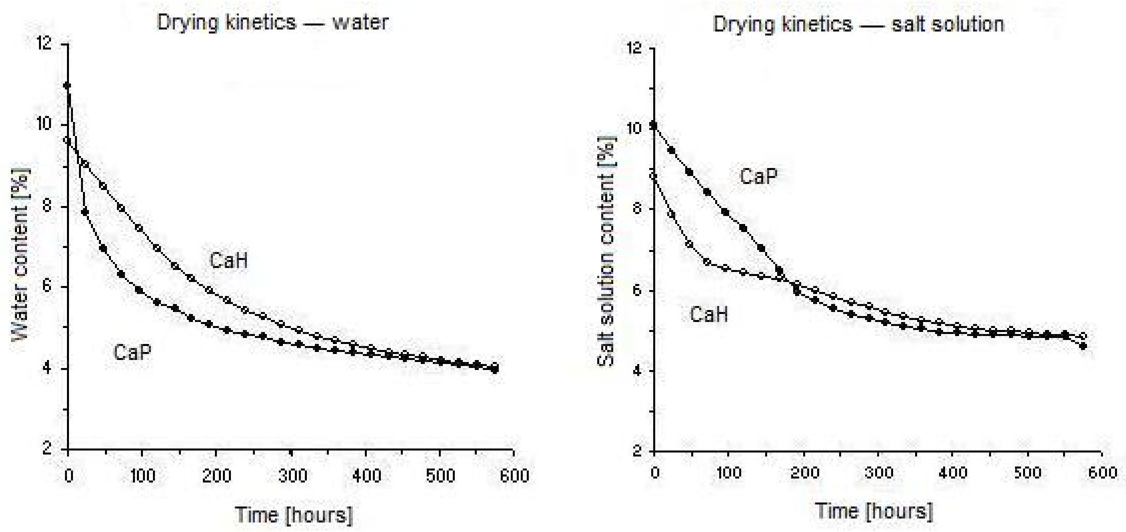

Fig. 9 – Drying kinetics

In order to evaluate the fluid influence in drying characteristics, tests were performed using water and salt solution (15% of sodium chloride). Drying process after salt solution immersion was found to be more difficult than with water, Fig. 9.

Regarding the influence of mortar characteristics in drying kinetics, results obtained revealed that lime putty mortar dry faster than hydrated lime mortar, which is responsible for a better behaviour facing salts crystallization.

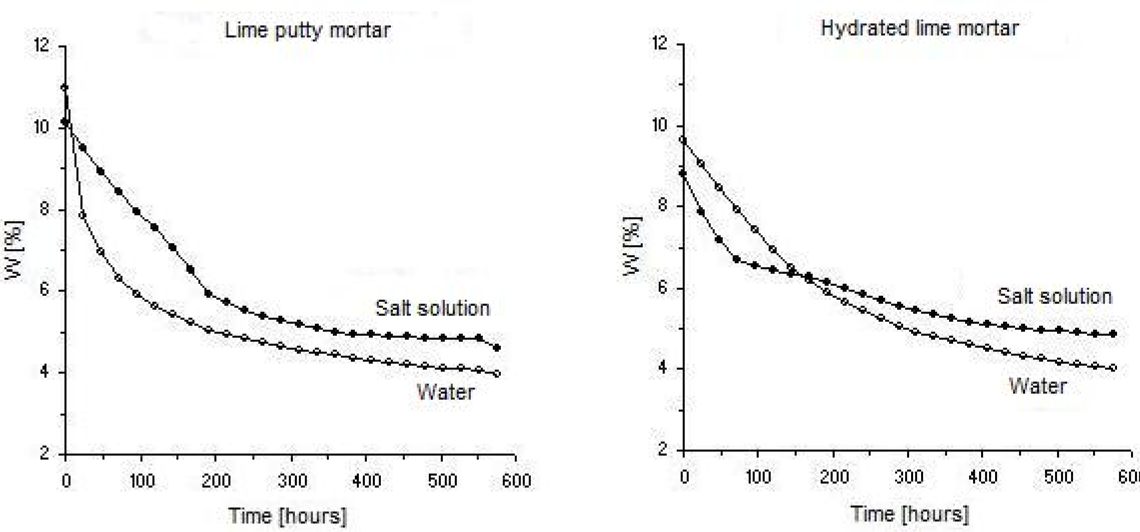

Fig. 10 – Fluid influence in drying kinetics

The evaluation of mortars behaviour facing salts crystallization revealed that hydrated lime mortar is the most sensitive to the actions simulated, Tables 5 and 6. After desalination, degradation was more obvious in hydrated lime mortar samples, Fig. 10.

Fig. 11 – Salts crystallization (Procedure 2)

These tests also revealed that procedure II was more efficient concerning the time required for development of degradation of mortar samples, Table 5. After the second week, when salt solution was replaced by water and drying cycles were longer, samples degradation became faster and more marked. Longer cycles provided salts circulation and crystallization in the porous structure of mortars.

According to the tests carried out, lime putty mortar was found to have a better performance and potential to be applied as replacement mortar. Lime putty mortar revealed higher capacity for water absorption and drying, a faster development of carbonation and a better behaviour facing salts crystallization.

4 CONCLUSIONS

According to the obtained results, the objectives set for the development of this study were achieved. The influence of the type of aerial lime in mortars behaviour was evaluated due to evolution of mechanical and physical characteristics over time. Lime putty mortar revealed a better performance than hydrated lime mortar, which shows a better potential to be applied as replacement mortar in old buildings rehabilitation interventions.

In situ test techniques were found to be reliable to evaluate mortars state of conservation and replacement needs. A comparative analysis between results obtained with this test and the ones obtained with tests frequently used in laboratory for mortars characterization shown a similar mortars behaviour.

The study also demonstrated the significant influence of salts crystallization in mortars and it contributed for the development of test procedures to simulate this action in mortars.

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