INSTITUTO SUPERIOR TÉCNICO
Universidade Técnica de Lisboa

Rendering mortars for old building with pozzolanic materials

Maria Inês Nascimento dos Santos

Extended Abstract

Orientador: Prof. Doutora Ana Paula Teixeira Ferreira Pinto França de Santana

Co-orientador: Prof. Doutor Augusto Martins Gomes

October 2009

1. Abstract

The replacement of old mortars is a procedure that has become a matter of interest to the study of aerial lime mortars that contain pozzolanic additions. Therefore, this study aims at contributing to a better understanding of the use of these types of mortars as replacement mortars of old buildings.

Several formulations of mortars were studied so that an analysis of the influence of natural and artificial pozzolanic additions, its percentage in the formulation and its performance evolution through time when compared to an aerial lime mortar settled as reference mortar, could be made. The pozzolan used were the Cape Verde pozzolan and fly ash and the binder-aggregate was aerial lime, keeping the same quantity and type of sand in all formulations. Two parameters to define the relations water/binder-aggregate used in the formulation of mortars were settled, that is, mortars with a consistency of approximately 65% were studied, as well as mortars with a water/lime relation of 1.62.

This study entitled a mechanical and physical characterization of mortars at different ages (14, 60 and 90 days) with the aim of evaluating their use as mortars for replacement coatings of old buildings. Therefore, a characterization of prismatic samples and of the mortars applied as coating layers in bricks through *in situ* test techniques was done.

This study allowed to demonstrate the influence of pozzolans and their percentage in aerial lime mortars, with more evidence in the additions of natural pozzolan. The addition of the Cape Verde Pozzolan changed the mechanical and physical characteristics, as well as its behaviour in relation to water in the formulation of the aerial lime mortar. The fly ash, on its turn, was responsible for the change of the physical characteristics of the lime mortar, showing, therefore, a clearer action as filler, rather than as a pozzolanic addition.

***Key Words*:** Replacement mortars; Aerial lime; Pozzolan; Fly ash; Performance evolution; Pozzolanic addition

2. Introduction

The use of rendering mortars is an old practice, however it has been the target of several changes in time. The need to rebuild buildings has increased the importance of studying old mortars as well as its components, to analyse its compatibility. This has become a matter of interest due to low chemical, mechanical and physical affinity between old mortars and the cement based mortars currently used. For the selection of substitution renders for old buildings, it is necessary to combine several characteristics, such as good durability in humid and aggressive environment as well as a good water resistance. Therefore, the study of aerial lime mortars has become a matter of interest in the last few years, in order to improve their properties by the addition of pozzolanic materials namely to give them some hydraulic features. Pozzolans have been used since ancient times. They are composed by silicates and aluminates, that don't play the role of binder-aggregate alone, however together with humidity and temperature chemically react with calcium hydroxide, forming composites with hydraulic properties and giving the mortar an high resistance and durability, [1].

The main objective of this study is to evaluate the influence of natural and artificial pozzolanic additions in lime mortars and determine their performance when different proportions are used, as well as analyse the evolution of the hardening phenomena in the characteristics analysed.

3. Experimental

3.1. Mortar Composition

In this experimental study, several formulations of mortars were used, with different water/lime ratios and amount of addition. These populations were defined considering a specific aerial line mortars as reference (c). It was used is the same sand for all mortars, as well as the lime which is hydrated lime powder. The pozzolans used were the Cape Verde pozzolan and fly ashes.

Table 1 presents the studied populations.

Table 1- Mortars in study

Pozzolanic Additon	Mortar	Ratio by weight		Water/lime (in weight)	Flow Value [%]
	C	lime:sand	1:8	1,55	65
Fly ashes	**CV2**	lime:fly ash:sand	1:1:8	1,40	65
	CV4	lime:fly ash:sand	1:0,5:8	1,37	65
Natural pozzolan	**PZ2**	lime:natural pozolan:sand	1:1:8	1,55	65
	PZ4	lime:natural pozolan:sand	1:0,5:8	1,58	65

Mortars with natural addition are PZ2 and PZ4. They present the same flow volume and different amount of pozzolan. The same happens with mortars with additions of fly ashes, CV2 and CV4. The mortar specimens were kept under dry cure conditions since its production until their characterization, in a room at 25±2ºC and 45±5%.

3.2. Testing program and results

The following tests were carried out:

- Fresh mortar characterization: consistence by flow table, bulk density.
- Hardened mortar characterization:
  - *Mechanical tests:* ultrasound velocity, flexural and compressive strength.
  - *Physical characteristics:* water absorption by capillarity, water absorption by immersion (48h), porosity accessible to water, bulk and real density, drying kinetic, water absorption under low pressure and carbonation depth.

The hardened mortar characterization performed on prismatic specimens was made at 14, 60 and 90 days and at 14 and 90 days on the mortars applied on ceramic bricks

3.2.1.Fresh mortar caracterisation

The tests of flow value, bulk density were carried out following procedures that were adapted from EN1015:3 [2] and EN 12350-6:2002 (3) respectively. The results are presented in Table 2.

Table 2- Flow value and bulk density

Addition	Ratio by weight	Mortar	water/lime (in weight)	Flow value [%]	Bulk density [kg/m^3]
	1:8	C	1,55	65 ± 0,7	2061 ± 61
Natural pozzolan	1:8	PZ2	1,55	65 ± 1,0	1899 ± 23
	1:0,5:8	PZ4	1,58	65 ± 1,0	1959 ± 12
Fly ashes	1:8	CV2	1,40	66 ± 0,8	1986 ± 39
	1:0,5:8	CV4	1,37	65 ± 0,9	1902 ± 15

The values of the volume mass can be considered quite near, and the maximum value was seen in the aerial lime mortar.

3.2.2. Hardened mortar characterisation

- **Mechanical characteristic**

Table 3 presents the average values of the compressive and tensile strength and the velocity of ultrasound. The compressive tensile strength tests were performed following procedures adapted from EN1015-11:1999 [4].

The analysis of mechanical resistance shows that natural pozzolans significantly increased the lime mortar resistance, and this was even more evident for higher percentages of addition. Concerning the mortars with fly ashes, it is observed that its presence did not influence the mechanical characteristics of the lime mortar in a significant way.

Table 3- Resistance to flexion, compression, speed US speed, porosity and carbonation depth

Addition	Ratio	Mortar	Curing time (days)	$f_{cf\ (average)}$ [MPa]	$f_{c(average)}$ [MPa]	V (average) [m/s]	Porosity [%]	Carbonation depth [mm]
-	1:8	C	14	0,19 ± 0,03	0,31 ± 0,01	1043 ± 21	-	2,8 ± 0,3
			60	0,29 ± 0,02	0,66 ± 0,07	1431 ± 93	-	10,3 ± 0,4
			90	0,31 ± 0,03	0,80 ± 0,05	1490 ± 47	-	19,1 ± 1,4
Natural Pozzolans	1:1:8	PZ2	14	0,99 ± 0,07	4,68 ± 0,15	1874 ± 24	27,2 ± 0,3	3,0 ± 0,5
			60	0,47 ± 0,02	4,79 ± 0,34	1321 ± 31	-	6,3 ± 0,4
			90	0,71 ± 0,02	4,84 ± 0,22	1569 ± 17	-	7,0 ± 1,4
	1:0,5:8	PZ4	14	0,32 ± 0,03	2,01 ± 0,22	1139 ± 35	28,3 ± 0,2	3,0 ± 0,2
			60	0,37 ± 0,02	2,16 ± 0,13	1213 ± 39	-	8,1 ± 0,3
			90	0,44 ± 0,02	2,59 ± 0,20	1296 ± 63	-	13,4 ± 0,5
Fly ashes	1:1:8	CV2	14	0,05 ± 0,02	0,73 ± 0,16	1551 ± 62	24,4 ± 0,2	0,0 ± 0,0
			60	0,36 ± 0,04	1,30 ± 0,09	1600 ± 17	-	10,6 ± 4,2
			90	0,15 ± 0,07	1,44 ± 0,03	1613 ± 11	-	17,4 ± 1,2
	1:0,5:8	CV4	14	0,17 ± 0,07	0,50 ± 0,06	1153 ± 33	25,5 ± 0,2	3,8 ± 0,7
			60	0,28 ± 0,03	0,79 ± 0,03	1414 ± 22	-	10,9 ± 3,1
			90	0,31 ± 0,01	0,96 ± 0,06	1425 ± 39	-	17,4 ± 1,7

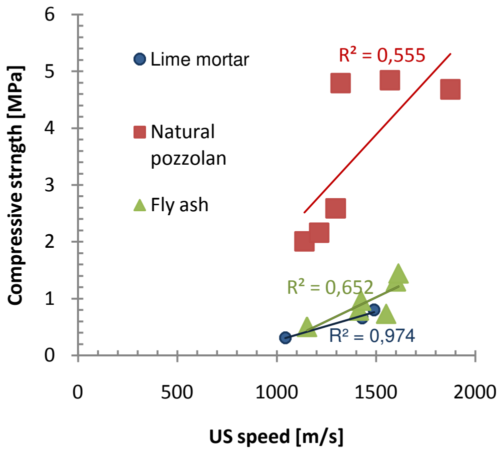
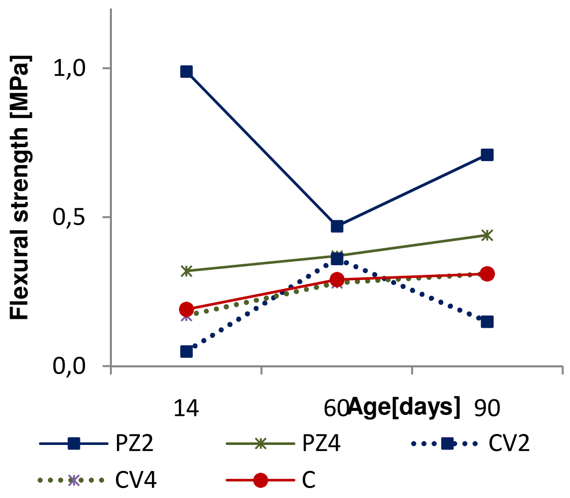


Fig. 1- Compressive strength vs. US speed (14, 60 and 90 days).

It was achieved satisfactory correlations between the values of compressive strength and velocity ultrasound for both additions. Mortars with higher resistance to compression present higher values of velocity.



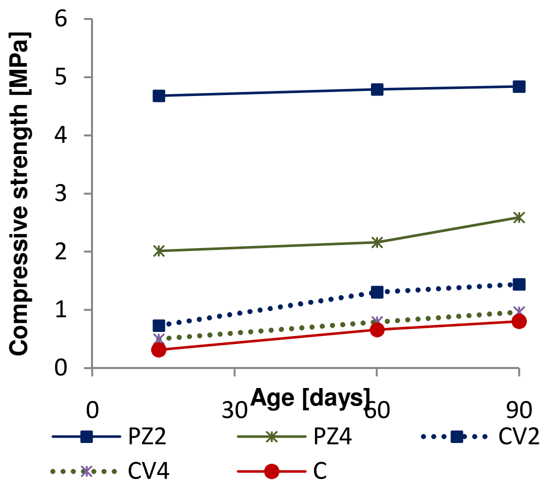


Fig. 2- Flexural and compressive strength (14, 60 and 90 days)

Concerning the values of compressive strength, all the mortars registered an increasing of these values through time, and highest results were achieved on the mortars formulated with natural pozzolan and higher percentage of this addition. The results of tensile strength were a bit inconclusive and higher values were noticed in all ages for mortars with natural pozzolan.

Mortars formulated with natural pozzolan presented a higher porosity in comparison with the mortars with fly ashes, and thus the mechanical resistance of the first is higher.

The carbonatation speed allows to evaluate the rhythm of the mortars carbonatation. The mortars with natural pozzolans showed less carbonatation speed, which decreased with the increase of the addition percentage. The behaviour of mortars with fly ashes is similar to the one of lime mortars, C, and there aren't significant changes in the carbonatation speed with the percentage of this addition.

The mechanical resistance evaluated through the indirect method, didn't reveal sensitive to variations of the mechanical resistance observed among the mortars. Although it was clear that there was an evolution of these characteristic in time. The values obtained with the rebound hammer test show tendency to increase in time for all mortars. The resistance of mortars with natural pozzolan increased taking in consideration the mechanical characteristic of lime mortar.

Table 4- Rebound and US speed results

Addition	Ratio	Mortar	Curing time (days)	V (average) [m/s]	R^2	Rebound
-	1:8	C	14	2006	0,94	11±6
			90	1502	0,96	20 ± 6
Natural Pozzolans	1:1:8	PZ2	14	240	0,94	24 ± 7
			90	1554	0,95	*Invalid*
	1:0,5:8	PZ4	14	*Invalid*		20 ± 4
			90			33 ± 3
Fly ashes	1:1:8	CV2	14	407	0,92	19 ± 4
			90	1634	0,96	20 ± 8
	1:0,5:8	CV4	14	390	0,98	10 ± 4
			90	1112	0,93	20 ± 8

- **Physical characterisation**

Water absorption by capillarity were performed following procedures adapted from EN 1015-18 (5).

Table 4- Coefficient of capillary absorption and asymptotic value

Addition	Ratio	Mortar	Curing time (days)	Coefficient of capillary absorption [$kg/m^2.s^{1/2}$]	R^2	Asymptotic absortion value	Water absortion by immersion (48h) [%]
-	1:8	C	14	0,12	0,98	15,3	9,1
			60	0,30	0,97	24,9	9,4
			90	0,34	0,98	27,8	12,7
Natural Pozzolans	1:1:8	PZ2	14	0,11	1,00	20,2	11,0
			60	0,16	1,00	23,4	12,5
			90	0,13	0,99	21,3	11,6
	1:0,5:8	PZ4	14	0,36	0,98	34,2	11,6
			60	0,22	1,00	22,3	11,5
			90	0,17	0,99	20,9	11,5
Fly ashes	1:1:8	CV2	14	0,12	1,00	19,4	10,0
			60	0,12	1,00	19,4	9,9
			90	0,13	1,00	19,0	9,7
	1:0,5:8	CV4	14	0,23	0,97	29,9	9,9
			60	0,13	1,00	19,4	9,6
			90	0,12	0,99	16,9	8,6

The coefficient of water absorption by capillarity gives information about the initial velocity of water absorption, whereas the asymptotic value gives us information related to the total amount of water absorbed. The water absorption on mortar for renders should not be very high and values lower than 0,2 $kg/m^2.s^{1/2}$, [6], for the coefficient of water absorption is recomended. In table 4 is possible to observe that all the mortars after 90 days accomplish this condition.

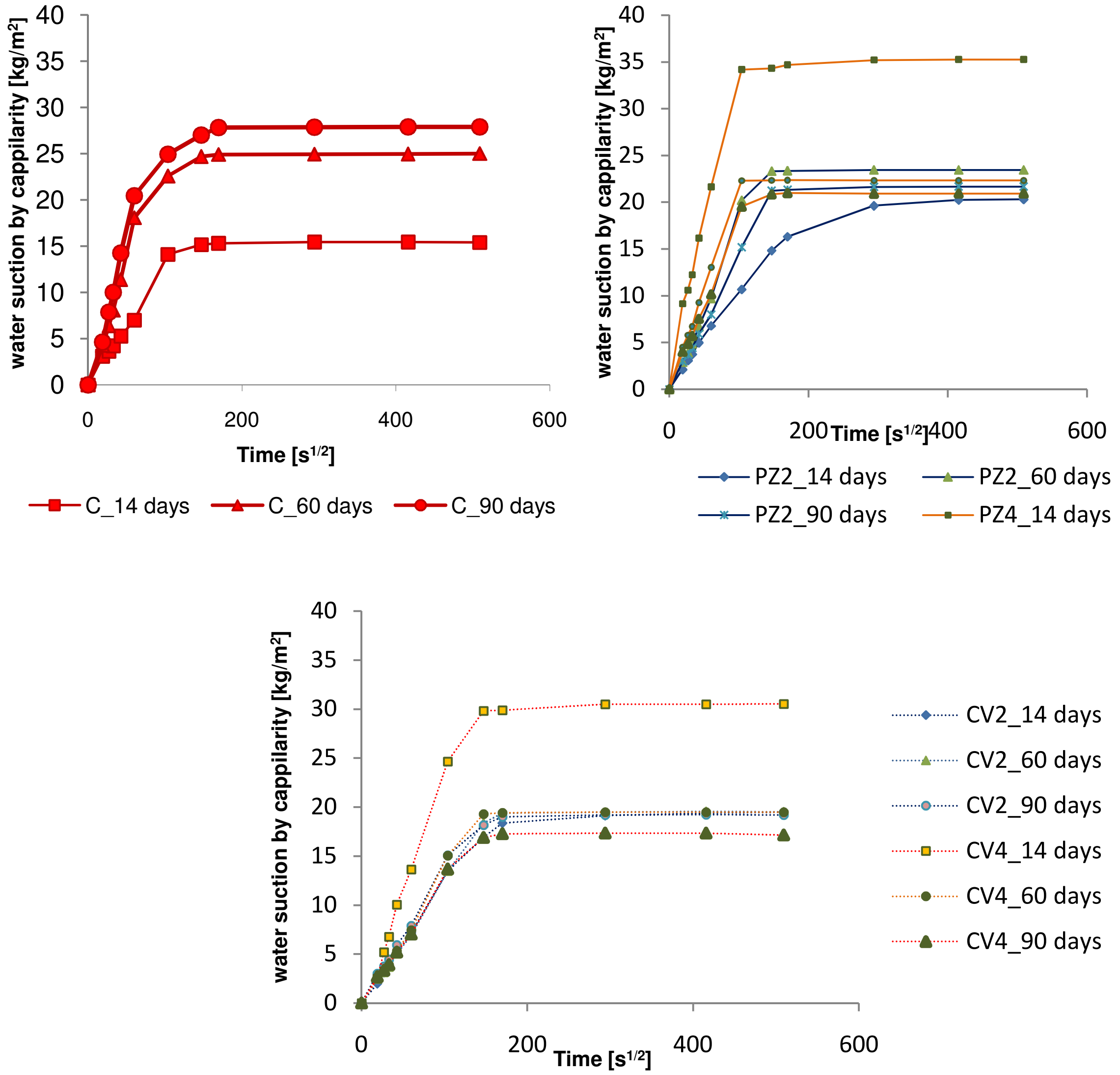


Fig. 3- Water suction by capillarity

The capacity of water absorption of mortars formulated with a binder-aggregate mixture composed by 50% of addition, didn't show any evolution with the mortars' age, whereas in the mortars with less content of additions there was a reduction in the absorption capacity. This might mean a reduction in the pores dimension and in the mortar porosity.

Bearing in mind the characteristics of the mortars' absorption with 90 days being studied, it is possible to conclude that the presence of additions was responsible for the reduction of the absorption capacity of the lime mortar, namely through the reduction of the water absorption coefficients by capillarity and of the asymptotic value.

The values of water content (48h) revealed stability in time with exception of lime mortars.

The drying test was performed following procedures based in [7]. The drying index, I.S., was determined based in the drying curves through:

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

t_f- final time of the test [h]; W_0- initial amount of water, expressed in percentage in what concerns to the drying mass [%]; $f(W_i)$ – amount of water inside the sample according to time, expressed in percentage in relation to drying mass.

Figure 4 presents the drying of water on all tested mortars with 14, 60 and 90 days of curing time.

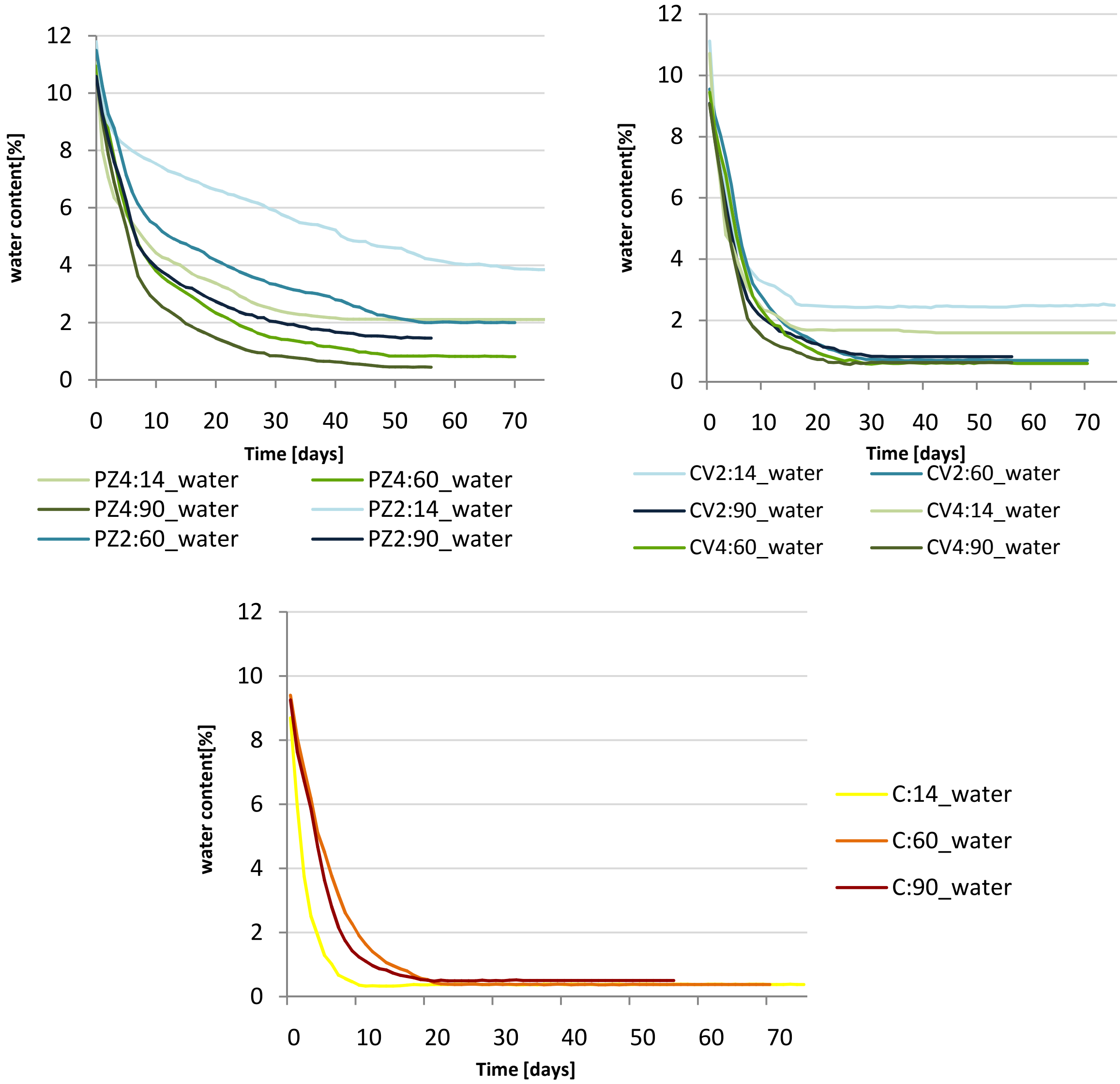


Fig. 4- Drying curves (14, 60 and 90 days)

The mortars with additions show a more complete drying with ageing. This is particularly clear in mortars formulated with Cape Verde Pozzolan. It is also observed that, for mortars formulated with fly ashes additions, the drying kinetic is not quite influenced with time evolution. Its behaviour is more similar to the one shown by the aerial lime mortar, C.

Table 5- Initial and final amount of water or saline, final test time and drying index

				Water Immersion					**Saline immersion**				
Addition	**Ratio**	**Mortar**	**Curing time (days)**	***W_i* [%]**	***W_f* [%]**	***W_f-W_i* [%]**	***final test time [days]***	***IS***	***W_i* [%]**	***W_f* [%]**	***W_f-W_i* [%]**	***final test time [days]***	***IS***
-	1:8	**C**	**14**	8,70	0,38	8,32	11	0,07	8,45	1,09	7,36	35	0,16
			60	9,40	0,38	9,02	23	0,12	9,64	1,23	8,41	> 65	0,32
			90	9,26	0,50	8,76	21	0,13	9,34	1,02	8,32	52	0,21
Pozolanas Naturais	1:1:8	**PZ2**	**14**	11,80	3,84	7,96	70	0,48	12,42	6,72	5,70	87	1,66
			60	11,49	2,00	9,49	55	0,32	11,98	3,44	8,54	66	0,43
			90	10,58	1,45	9,13	51	0,28	10,9	2,33	8,57	59	0,35
	1:0,5:8	**PZ4**	**14**	11,06	2,10	8,96	42	0,27	11,53	5,49	6,04	47	0,53
			60	10,94	0,81	10,13	49	0,20	11,58	1,82	9,76	64	0,31
			90	10,58	0,44	10,14	49	0,17	10,95	1,33	9,62	51	0,24
Cinzas Volantes	1:1:8	**CV2**	**14**	11,12	2,49	8,63	26	0,26	11,1	6,06	5,04	74	0,62
			60	9,55	0,70	8,85	32	0,17	9,85	2,08	7,77	> 68	0,40
			90	9,09	0,82	8,27	30	0,15	9,59	1,44	8,15	56	0,27
	1:0,5:8	**CV4**	**14**	10,72	1,60	9,12	36	0,19	11,1	4,20	6,90	62	0,44
			60	9,46	0,60	8,86	28	0,15	9,67	1,57	8,10	58	0,31
			90	9,06	0,63	8,43	22	0,15	9,11	1,14	7,97	25	0,20

There is a reduction of the drying kinetic when saline solution are being evaporate in comparison to the evaporation of water. The water content at the end of the test is higher when saline solution are being evaporated, meaning that the drying is less complete, due to the presence of retained salts inside or outside the mortars. The identified aspects decreases their importance after a curing period of 90 days.

The values obtained for each mortar in the test of water absorption under low pressure carried out according to RILEM [8] are shown in Figures. This test was done in mortars applied as renders of ceramic bricks. The mortars with highest percentages of additions, PZ2 and CV2, show different behaviours through time. Mortar with natural pozzolan showed an increase of water absorption, and the opposite happens for mortars formulated with fly ashes. It is also observed that mortars with less percentage of additions and the lime mortar revealed similar behaviour and there were not registered significant changes concerning the evolution of water absorption with the evolution of time.

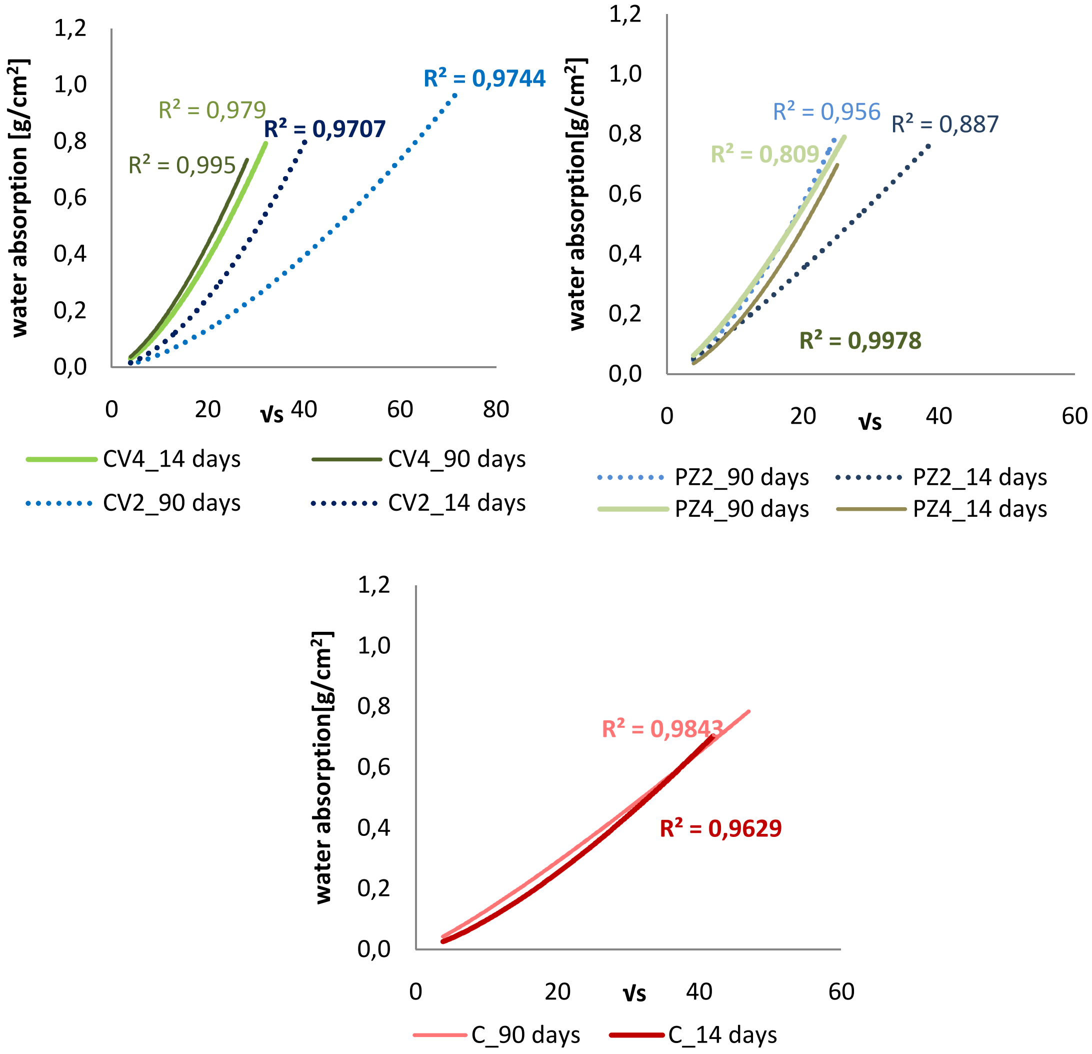


Fig. 5- Water absorption

4. Conclusions

The research was carried out with the aim of studying the action of pozzolanic additions in aerial lime mortars. Several mortars formulations with different additions (natural pozzolan and fly ash) and with different percentages of addition were made in order to assess the influence of these parameters on the characteristics of lime mortars.

Natural pozzolans had a significant influence on the mechanical characteristics, mainly in the compressive tensile values, when compared to lime mortar. The amount of this addition was responsible for the compressive and tensile increasing. It was not registered evolution in time on the mechanical properties of mortars formulated with natural pozzolan.

The values of porosity obtained after 14 days, show that mortars with the same percentage of additions, formulated with Cape Verde Pozzolan, present higher porosity in comparison to the one obtained when using fly ash.

In what concerns to the development of the water absorption characteristics through time the characterization of water absorption by capillarity done, show a reduction in the capacity of mortars' absorption formulated with a content of 33% of addition and there is a tendency to the stabilization of the characteristics assessed after 14 days for the mortars with 50% of addition. After 90 days the value of the capillarity coefficient registered in all mortars formulated with both additions is inferior to 0,2 $kg/m^2.s^{1/2}$. These are settled as a limit recommended by [6], since the use of mortars too absorbent in coverings is not recommended.

The lime mortars with pozzolanic additions show a lower drying speed than the lime mortar, observing that all mortars have a tendency to a more complete drying as time goes by, being quite close to the behaviour of the lime mortar. The mortars that showed a higher coefficient of capillarity, indicating faster water absorption, present a superior drying kinetic.

This study demonstrated the influence of the Cape Verde Pozzolan and of its content in the formulation of aerial lime mortars, since this addition was responsible for changes of the mechanical and physical characteristics, as well as of its behaviour in relation to water. The fly ashes, on the other hand, showed a reduced pozzolanic reactivity, proved by the reduced influence observed in the characteristics of the lime mortar. However, the presence of fly ash was responsible for the changes in the physical characteristics of the lime mortar, namely of the porosity reduction, of the capacity of water absorption and drying, showing that the changes introduced acted more like a filler, instead of acting as a pozzolanic addition.

5. References

1. **VELOSA, A. L. P. L.** *Argamassas de cal com pozolanas para revestimentos de paredes antigas.* Secção autónoma de engenharia civil, Universidade de Aveiro. 2006. Tese de Douturamento.

2. **EUROPEAN COMITTEE FOR STANDARDIZATION.** Methods of test for mortar masonry. Part3 Determination of consistence os fresh mortar. *EN 1015-3:1999.* Brussels : s.n., 1999.

3. **IPQ.** NP EN 12350 - 6 Ensaios do betão fresco. Parte 6: Massa volúmica. Lisboa : s.n., 2002.

4. **EUROPEAN COMMITTEE FOR STANDARDIZATION (CEN).** Methods of test for mortar masonry. *EN 1015 -Parts 3,6,8, 11 and 18:1999.* Brussels : s.n., February 1999.

5. **EUROPEAN COMMITTEE FOR STANDARDIZATION (CEN).** Methods of test for mortar masonry. Part 18: Determination of water absorption coefficient due to capillary action of hardened mortar. *EN 1015-18:2002.* Brussels : s.n., 2002.

6. **VEIGA, Maria do Rosário** *As argamassas na conservação.*Lisboa : LNEC, 1ªs Jornadas de Engenharia Civil da Universidade de Aveiro, Avaliação e Reabilitação das Construções existentes, Colecção Comunicações, pp. 1-26.

7. **CAVACO, Luís.** Técnicas de aplicação de argamassas de revestimento em edifícios antigos. Influência no desempenho. *Dissertação para obtenção do grau de Mestre em Construção.* 2005.

8. **RILEM- Réunion Internationale des Laboratoires el Experts des Matériaux.** Water absorption under low pressure. Pipe method. Test nº4 II.4. Paris : Recommendations provisoires RILEM, 1980.