The use of pozzolans as additives in lime mortars for employment in building rehabilitation

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ABSTRACT: In order to assess their adequacy of mortar components for application in conservation renders, natural pozzolanic additives with different proveniences (Portugal and Cape Verde) were studied as additives in lime mortars. Tests were carried out for characterization of these materials and for mechanical, physical and chemical properties of hardened mortars. In order to assess durability to climatic conditions artificial ageing was performed and renders were executed on walls in the exterior. Results are presented and the adequacy of application of these mortars as renders, in old buildings subject to conservation actions, is discussed.

1. INTRODUCTION

Old buildings, which have not been subject to recent interventions, contain lime-based renders. Conservation practice implies the use of mortars that will ensure compatibility with old masonries and old remaining renders. For this purpose, and taking into account frailties posed by mortars in which the only binder is lime, additivated lime mortars have been studied. Pozzolans are a well known additive, frequently used in Roman times, with the purpose of ensuring greater durability, strength and hydraulicity of renders.

This study intends to examine, through laboratorial testing, the adequacy of different lime mortars, additivated with pozzolans, for the employment in renders for conservation purposes, in an attempt to recover the use of natural pozzolans.

2. POZZOLANS – CHARACTERISTICS

Portuguese (São Miguel, Azores) and Cape Verde (Santo Antão) pozzolans were used for this study and their initial characterization was made through sieve analysis, concluding that Azores pozzolans present a more continuous particle size distribution than Cape Verde pozzolans, and have a high percentage of very fine material and coarser particles (Figures 1 and 2). It is relevant, however that, unlike Azores pozzolans, Cape Verde pozzolans were not used in their natural state, as they had been previously grinded for industrial use.

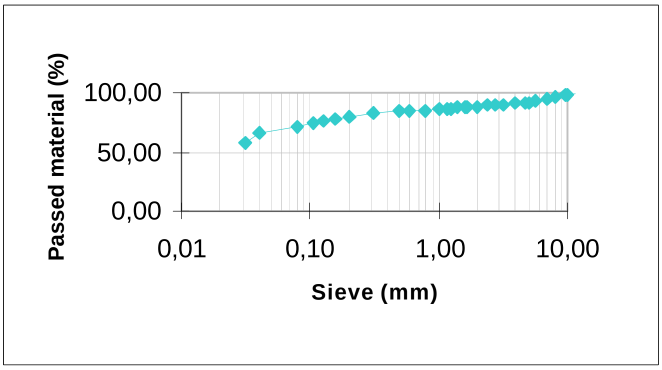

Figure 1 : Azores pozzolans – Particle Size Distribution

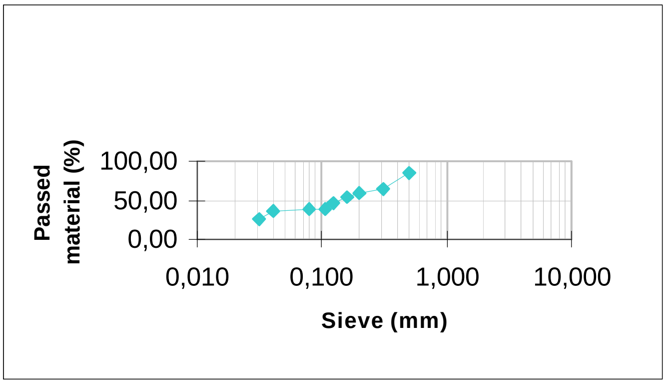

Figure 2 : Cape Verde pozzolans (grinded) – Particle Size Distribution

A study developed at LNEC by Castanheira das Neves (Castanheira das Neves 1907) includes the chemical composition of pozzolans from the islands of São Miguel and Santo Antão – the main compounds in both materials are silica and alumina, in this order; however, São Miguel pozzolans contain a higher percentage of silica (60%) and a lower percentage of alumina (18%) than Cape Verde pozzolans (50% SiO_2; 30% Al_2O_3).

The other characteristics that have an important influence on the performance of these additives are:

- Pozolanic Reactivity
- Blaine's Specific Surface

Testing for pozolanic reactivity was carried out according to Portuguese recommendations, 'Caderno de Encargos para o Fornecimento e Recepção de Pozolanas'(República Portuguesa 1960).

Table 1 : Pozolanic reactivity

	Minimum values 28 d. Type I pozzolans*	Minimum values 28 d. Type II pozzolans**	Cape Verde pozzolans	Azores pozzolans
Flexural strength	2,0 MPa	1,0 MPa	2,9 MPa	1,4 MPa
Compressive strength	6,0 MPa	3,0 MPa	7,7 MPa	2,8MPa

* - high reactivity pozzolans
** - weak pozzolans

Concerning pozolanic reactivity, which measures the speed of the reaction between pozzolans and lime, Azores pozzolans present values that classify them below the minimum requisites for 'type II pozzolans', following Portuguese regulations. On the other hand, Cape Verde pozzolans are classified as 'type I pozzolans'.

Table 2 : Blaine's Specific Surface

	Minimum values 28 d. Type I pozzolans*	Minimum values 28 d. Type II pozzolans*	Cape Verde pozzolans	Azores pozzolans
Blaine's Specific Surface	3000 cm^2g^{-1}	2000 cm^2g^{-1}	3250 cm^2g^{-1}	6870 cm^2g^{-1}

* - high reactivity pozzolans
** - weak pozzolans

A high specific surface has implications upon reactivity – higher specific surfaces contribute towards higher reactivity. Following this classification, both pozzolans possess high specific surfaces, above all minimum requisites. Azores pozzolans, with a higher percentage of fine material, as shown previously by particle size distribution analysis, achieve extremely high specific surfaces.

3. MORTAR COMPOSITION AND CURING CONDITIONS

Initially, a set of laboratory tests was established, based on three mortars – ML, MPA and MPC1, with the compositions specified in Table 3. ML, the mortar containing only lime and river sand serves the purpose of comparison. The other mortars posses the same volumetric ratio, but the pozolanic additive has a different provenience (Azores pozzolans for MPA and Cape Verde pozzolans for MPC1). Standardized specimens with size 40x40x160 mm^3 were used, under curing conditions consisting of a temperature range of 23ºC ± 2ºC and a relative humidity of 50% ± 5%.

Following this first set of tests and according to their results, expressed in the subsequent fields of this paper, two other mortars were prepared: MPC2, a mortar with the same composition as MPC1, but with a different cure, and MPC3, with a different volumetric ratio. Both mortars were prepared with Cape Verde pozzolans and curing conditions were changed to a temperature range of 23ºC ± 2ºC and a relative humidity of 50% ± 5%, sprinkled with 20cc of water every day, so as to simulate real atmospheric conditions. In fact, tests showed (Rosário Veiga 1997) that sprinkling daily with water could approximate the real conditions, where humidity is rather high at night, even in summer.

Table 3 : Mortar composition (Volume dosage)

Mortar	Lime	Azores pozzolans	Cape Verde pozzolans	River sand
ML	1	-	-	3
MPA	1	1	-	4
MPC1	1	-	1	4
MPC2	1	-	1	4
MPC3	1	-	0,5	2,5

4. MECHANICAL PROPERTIES

Mortars must possess mechanical strength; however, for use in old buildings, high mechanical strength may be harmful, as it may infer damage on old and fragile masonry. In a similar way, a high modulus of elasticity implies a high rigidity and, therefore, an incapacity for mortars to accompany masonry deformations without fracturing. Flexural and compressive test were executed following EN 1015-11, and the results obtained were as listed below.

Table 4 : Flexural and compressive strength

Mortar	Max. Flexural Stress (N/mm^2)		Max. Compr. Stress (N/mm^2)	
	28 d	90 d	28 d	90 d
ML	0.3	0.3	0.5	0.8
MPA	0.2	0.1	0.6	0.5
MPC1	0.3	0.3	1.3	1.1
MPC2	0.3	-	1.4	-
MPC3	0.5	-	2.0	-

The dynamic Modulus of Elasticity was determined following Cahier 2669-4 CSTB, and the obtained results are listed in Table 5.

Table 5 : Modulus of Elasticity

Mortar	Modulus of Elasticity (N/mm^2)	
	28 d	90 d
ML	1804.6	2032.8
MPA	3733.1	5561.7
MPC1	-	-

These results show that Azores pozzolans did not contribute towards an increase of mechanical properties of lime mortars. On the other hand the addition of Cape Verde pozzolans significantly increased compressive strength.

The change in curing conditions did not express itself in these results, but MPC3 gave higher values when subject to flexural and compressive testing.

5. PHYSICAL PROPERTIES

Old buildings have no protection against humidity deriving from capillary ascension of water and, as all other buildings, are affected by climatic conditions, namely rainwater and wind. As the penetration of water through masonry and renders is usually inevitable, the main desirable characteristic is a rapid drying capacity. Tests were executed in order to assess the combined wetting-drying effect through water absorption by capillary action, effectuated following Cahier 2669-4 and another test, developed at LNEC (Fe Pa 38) (Teresa Gonçalves et al 1995; JoãoPalma 1992) which permits to measure the wetting and drying time of mortars.

Table 6 : Water absorption by capillary action (28 days)

Mortar	Water absorption coefficient ($g/dm^2.min^{1/2}$)
ML	11.7
MPA	21.5
MPC1	17.7
MPC2	17.5
MPC3	14.7

Mortar ML, containing only lime seems to have the best behaviour concerning capillary absorption of water, while mortar MPA additivated with Azores pozzolans has the highest water absorption coefficient and, therefore, a faster water absorption than the others. The change in curing conditions did not affect mortars MPC in test results, but a change in volumetric ratio, from MPC1 to MPC3 implied a better performance in this issue.

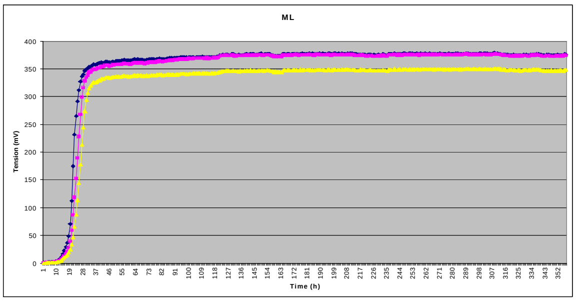

Figure 3 : Drying capacity – ML

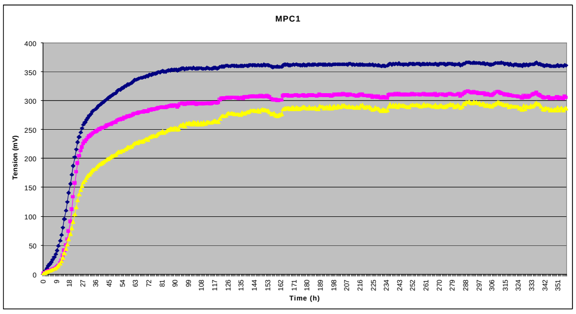

Figure 4 : Drying capacity – MPC1

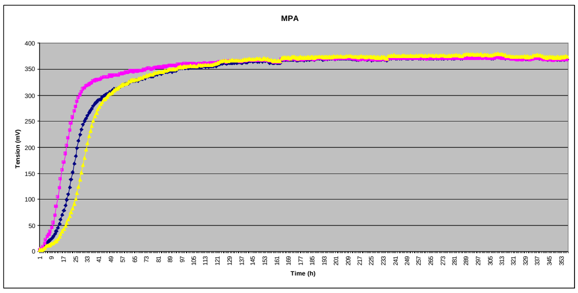

Figure 5 : Drying capacity – MPA

The graphs above indicate that the addition of pozzolans to lime mortars does not interfere with their natural drying ability, as drying intervals are similar for all specimens. However, other experimental campaigns held at LNEC (Rosário Veiga 2000) concluded that the behaviour of lime mortars in this issue is more adequate for old buildings than that obtained with cement-based mortars, as these present higher drying times. As these test results were satisfactory for mortars ML, MPA and MPC1, they were not repeated for the other mortar compositions.

Another physical property of great relevance in mortars destined to act as renders is shrinkage. To verify its importance in the various mortars, dimensional variations were measured following Cahier 2669-4 CSTB. The results were initially taken on a daily basis in the first 3 days of the test and were then taken at a 5-day and later, 10-day intervals until the age of 90 days; it was verified that around the age of 40 to 50 days, values stabilized, implying no significant increase in dimensional variations.

Table 7 : Dimensional variations

Mortar	Dimensional variations (mm/m)			
	8 days	14 days	28 days	50 days
ML	0.081	0.104	0.114	0.156
MPA	0.308	0.362	0.378	0.470
MPC1	-	-	-	-
MPC2	0.398*	0.552	0.757	0.729
MPC3	0.369*	0.442	0.806	0.819

* - Measurement taken at 10 days

Considerable initial dimensional variations and continuously significant variations in time were encountered for all additivated mortars, in comparison with lower variations produced by ML.

6. CARBONATION CONTROL

Figure 6 : Carbonation test

Carbonation speed was measured with a phenolphthalein solution and based on ICCROM's ARC test description. (Jeanne Marie Teutonico 1998).

Specimens were kept at a 23ºC temperature and 50% relative humidity. Results were as follows:

Table 8 : Carbonation control

Mortar	Medium carbonation depth(mm)	
	28 d	90 d
ML	9.4mm	20mm
MPA	11.3mm	20mm
MPC1	11.0mm	20mm
MPC2	5.3mm*	-

* - results at 14 days

Carbonation speed nearly always increased when lime mortars were mixed with pozzolanic materials, a similar behaviour being expected for MPC2, which was sprinkled with water on a daily basis and whose carbonation depth was measured at the age of 14 days. In all cases monitored at 90 days, complete carbonation had taken place.

7. DURABILITY

Laboratorial testing in order to verify the durability of mortars ML, MPA and MPC1 towards different climatic conditions was performed in a climatic chamber upon bricks with a layer of mortar with 1 cm and followed the following cycles:

- Rain/heat (70ºC for 3 hrs; 1l/min rain for 5hrs; 16 hrs drying interval)
- Rain/cold (60ºC for 8 hrs; -15ºC for 15 hrs)
- Freeze/thaw (rain for 8 hrs; -15ºC for 15 hrs; 1 hr interval)

This test was based on a method described on Cahier 2669-4 CSTB adapted by Veiga, R. (Rosário Veiga1998), and each cycle lasted for 10 days. No significant variations were noticed after the first two cycles but the freeze/thaw test caused severe damage to all mortars, the most resistant being MPA.

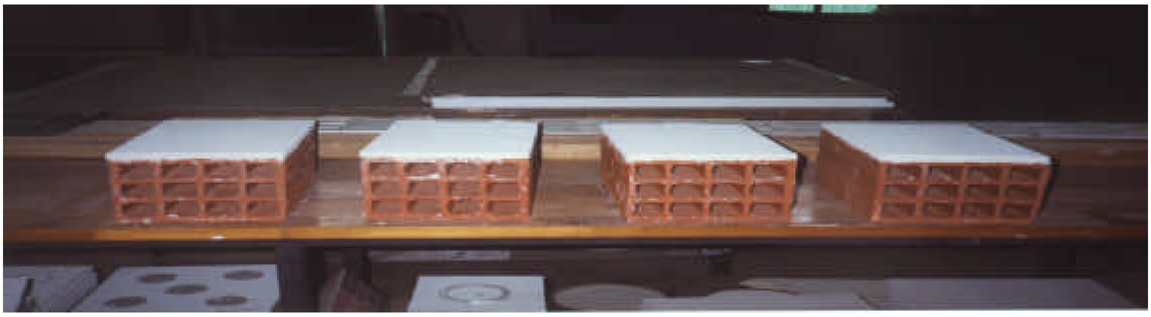

Figure 7 : Bricks with 1cm of mortar

As a complement to laboratorial testing, two walls from LNEC's Natural Weathering Station (LNEC – LERevPa) were rendered with MPA and MPC1. Continuous control revealed signs of degradation due to initial damage on renders that took place during execution, but a generally good durability of both mortars, although weather conditions were extremely rainy during the past winter.

Figure 8 : Renders with MPA and MPC1

8. CONCLUSIONS

From the initial tests made upon Azores and Cape Verde pozzolans, it may be concluded that, although Azores pozzolans present higher values for Blaine's specific surface and a higher percentage of fine material, as shown by the analysis of particle size distribution, they are not the most reactive. In fact, reaction with lime, effectuated by pozzolanic reactivity test, indicated a faster speed of reaction between lime and Cape Verde pozzolans. This difference in reactivity may account for stronger mechanical characteristics of mortars composed by lime and Cape Verde pozzolans (MPC1, MPC2, MPC3) and for no significant impact in this field with the addition of Azores pozzolans (MPA) comparatively with non-additivated lime mortars (ML). In fact, the great variation in mortar characteristics due to the addition of pozzolans (Cape Verde) is the significant increase in compressive strength, permitting to overcome one of the main problems of lime mortars. MPC1, MPC2 and MPC3 attained values in the order of 1 N/mm^2 to 2 N/mm^2 for compressive strength at only 28 days, while ML reached only 0.5 N/mm^2.

Although water absorption through capillary action was rapid in all additivated mortars, even more so than in ML, drying intervals proved to be similar for all mortars in study. Even though a high intake of water by renders is no doubt negative, the capacity to expel this water is an extremely important factor; renders act as sacrificial coatings and adjacent masonries must be spared damage caused by water that is unable to exit through the renders.

Carbonation testing suggested a possible increase in carbonation speed in the presence of pozzolans. This is a positive indicator, as renders are frequently, although wrongly, executed with high thickness, raising difficulties towards complete carbonation. However, from the results obtained from artificial ageing and natural exposure, no visible impact was encountered, related to durability increase, by the addition of these materials. The only throw-back in this testing campaign were the high dimensional variation values expressed by mortars with pozzolans, in comparison with low dimensional variations in lime mortars.

Different curing conditions proved of almost no significance in the obtained results and other curing conditions must be tested as these mortars harden by hydraulic reaction and carbonation, combined. The difference in results due to the change in volumetric ratio of materials, using less pozzolanic material, may be accounted for by the slow reaction of pozzolans with lime and the possibility that they act as inert material at first.

The use of pozzolanic materials in lime mortars, for conservation purposes, seems plausible as they adjust themselves to most requirements and greatly improve mechanical characteristics of lime mortars; however, further studies must be developed in order to attain the most adequate manner in which these materials may be used.

REFERENCES

Gonçalves, Teresa et al., 1995. Evaluation of the capacity for impermeabilization of wall renders. In *International Symposium on Moisture Problems in Building walls, Proceedings.* Porto.

Palma, João 1992. Aparelho detector de humidade com base na variação da condutibilidade, Relatório 56/92-GEEt. Lisbon: LNEC.

República Portuguesa 1960. Caderno de Encargos para o fornecimento e recepção de pozolanas, Decreto n.º 42999 de 4 de Junho de 1960. Lisboa: Imprensa Nacional de Lisboa.

Teutonico, Jeanne Marie 1988. A Laboratory Manual for Architectural Conservators. Rome: ICCROM.

Veiga, M. Rosário, 1997. Comportamento de argamassas de revestimento de paredes. Contribuição para o estudoda sua resistência à fendilhação. Dissertação para obtenção do grau de Doutor em Engenharia Civil pela Faculdade de Engenharia da Universidade do Porto. Lisbon: LNEC.

Veiga, M. Rosário; Carvalho, F., 1998. Some Performance characteristics of lime mortars for use on rendering and repointing of ancient buildings. *Proc. 5th International Masonry Congress*, London, 1998.

Veiga, M. Rosário, 2000. Protecção contra a água de paredes de edifícios antigos. avaliação experimental da capacidade de protecção de argamassas de reboco com base em cal. *Proc. Encontro Nacional sobr Conservação e Reabilitação de Estruturas - REPAR 2000.* Lisbon: LNEC.