Use Of Additivated Lime Mortars For Old Building Rehabilitation Adapted Testing Methods

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Summary: The use of natural pozzolans as additives in lime mortars is a possibility that permits the execution of mortars compatible with old renders and masonry. On the other hand, these mortars provide better mechanical properties and it is believed that they possess an increased durability, in comparison with lime mortars. Recently developed European Standards try to fill the gap of standardization in this field, but some difficulties are experimented in their application. In the present paper European Standard EN 1015-11 is analysed in terms of preparation and conditioning of mortar specimens. Further preparations and conditionings are tested in order to verify their adequacy for use for additivated lime mortars. Results of mechanical, physical and chemical tests are presented and discussed.

Keywords. Mortar, Lime, Pozzolans, Testing Methods, Curing Conditions

1 INTRODUCTION -USE OF NATURAL POZZOLANS IN LIME MORTARS

1.1 Brief historic perspective and present experience

The rehabilitation of old buildings comprises the maintenance and/or repair of old renders, for which mortars presenting compatible characteristics with adjacent masonry and remaining renders should be used. The main component of old renders is usually lime, occasionally enriched by the presence of pozzolanic or other additives. The use of natural pozzolans is well known, having been mentioned by Vitruvio as a material provenient from the region of Pozzuoli and been included in the preparation of mortars and concretes throughout the times (Illston, 1994) as they confer hydraulic properties and therefore enable hardening under water or in wet conditions. It is also believed that the addition of pozzolans confers greater durability to lime mortars, permitting to overcome the need for permanent maintenance.

In Portugal, this natural material of volcanic origin can be found in the Azores islands. In previous studies developed at LNEC (Velosa and Veiga, 2001), Azores pozzolans and Cape Verde pozzolans, the latter of which is commercialised and currently used in Portugal, were used as additives in lime mortars. Comparative physical, mechanical and chemical tests were undertaken in order to determine the effects caused by the addition of these pozzolans; results proved the adequacy of these additivated mortars for use in conservation and the significant improvement in mechanical characteristics induced by the addition of Cape Verde pozzolans. In consequence of these results, further studies on the additivation of lime mortars with natural pozzolanic additives seemed both an interesting and promising theme to proceed with. However, the specificity of mortars both with lime and pozzolans requires a study of hardening reactions and the adaptation of present standards so as to guarantee the most adequate curing conditions that will permit to obtain the most relevant results.

1.2 Chemical reactions during the hardening process

Limestone is the prime material for the manufacture of lime putty or hydrated lime; after burning at a temperature surrounding 900ºC and subsequently adding water, dry hydrated lime or lime putty will be produced, depending on the quantity of water added. In this study commercial dry hydrated lime was used. Reactions leading to the formation of this product are as follows:

$CaCO_3$ (calcium carbonate) + heat (900ºC) $\rightarrow$ CaO (calcium oxide) + CO_2 (carbon dioxide)

CaO (calcium oxide) + H_2O (water) $\rightarrow$ $Ca(OH)_2$ (calcium hydroxide)

In lime mortars hardening will take place through the reaction of calcium hydroxide with carbon dioxide present in the air, forming calcium carbonate as shown in the reaction below.

$Ca(OH)_2$ (calcium hydroxide) + CO_2 (carbon dioxide) → $CaCO_3$ (calcium carbonate) + H_2O (water)

The main components of pozzolanic materials are silica (SiO_2), usually represented as S, and alumina (Al_2O_3), usually represented as A; other compounds that are usually present in significantly lower percentages are iron oxide (Fe_2O_3), magnesium oxide (MgO) and lime (CaO).

The siliceous compounds present in pozzolanic materials react with the calcium hydroxide from lime and produce calcium silicates, mainly in the form of hydrated bicalcic silicaluminate ($2CaO.Al_2O_3.SiO_2.8H_2O$), hydrated calcium silicates and hydrated calcium aluminates (Coutinho, 1997), products which are responsible for the improvement in durability properties in these mortars. The reactions leading to the formation of these compounds occur in the presence of water and depend on the reactivity and fineness of the pozzolanic materials.

2 PREPARATION AND CURING CONDITIONS - STANDARDIZATION

Formerly, European Standards regulated testing methods mainly for cement-based mortars that, since the discovery of Portland cement by Joseph Aspdin in 1824, gradually substituted lime mortars in the execution of renders. Years of experience and studies on the use of cement-based mortars now provide a basis for the belief that they may not be the most adequate for use in renders for old buildings (Torraca, 1996). For conservation purposes, lime mortars and additivated lime mortars fill compatibility requirements in mechanical, physical, chemical and aesthetic terms to a much higher degree (Veiga, 1998).Due to the growing practice, spread throughout Europe, of conserving old buildings rather than building new, the necessity for research and regulations in this area became a reality in recent times. For the specific area of rendering mortars, European Standards EN 1015-1 to EN 1015-4, EN 1015-6 to EN 1015-7, EN 1015-9 to EN 1015-12, EN 1015-17 and EN 1015-19 lay down testing methods, covering various mechanical, chemical and physical testing procedures. For these European Standards, rendering mortars are divided into the following categories:

- Air lime mortars (L)
- Air-lime/cement mortars with cement mass not exceeding 50% of the total binder mass (L/C)
- Cement and air-lime/cement mortars with mass of air-lime not exceeding 50% of the total binder mass (C)
- Mortars with other hydraulic binders (H)
- Retarded mortars (R)

Preparation and curing conditions are described in detail in EN 1015-11, and the procedures are as follows:

Table 1 – Preparation and conditioning of storing specimens (based on EN 1015-11)

Type of mortar	Preparation	Storage time at a temperature of 20 ºC ± 2 ºC in days		
		Relative humidity		
		95 ºC ± 5 ºC or in polyethylene bag		65 ºC ± 5 ºC
		in the mould	with the mould removed	with the mould removed
L; L/C	2	5	2	21
C; H	1	2	5	21
R	1	5	2	21

Preparation 1

- Filling of mould in two equal layers, compacting each layer with 25 strokes of the tamper
- Skimming of excess mortar with a palette knife

Preparation 2

- Placement of mould over glass plate on which two layers of dry white cotton gauze have been placed
- Filling of mould in two equal layers, compacting each layer with 25 strokes of the tamper
- Skimming of excess mortar with a palette knife
- Placement of two layers of white cotton gauze tightly on the mortar surface
- Placement of six layers of absorbent filter paper on top of the gauze

- Coverage with glass plate and turning around of the mould
- Removal of glass plate from the top of the mould and placement of six layers of absorbent filter
- paper on top of the gauze
- Coverage with glass plate and re-inversion of mould
- Placement of 5 kg mass on top

Whilst ‘Preparation 1’ maintains hydraulic mortars in a humid environment, permitting their hardening by hydraulic reaction, ‘Preparation 2’ implies the absorption of excess water by the gauze and absorbent filter paper placed on both sides of the mould. However, in this last case, humidity is still maintained during the first seven days. Comparison of results between these distinct types of mortars proves difficult due to the necessity of different curing conditions to assure a rapid hardening. This difficulty is stressed in mortars that harden both by carbonation and hydraulic reaction, which is the case of lime mortars additivated with natural pozzolans.

However, the application as renders requires knowledge of real conditions, as carbon dioxide is always present and relative humidity varies during the day and seasons.

Under atmospheric conditions, mortar behaviour may vary considerably from that conditioned in the laboratory, both in terms of hardening time and properties; it is therefore necessary to verify the differences induced by changes in conditioning.

2.1 EN 1015-11 in practice

Formerly, at LNEC, ‘Cahier 2669-4’ of CSTB was the standard used as the basis for most testing procedures for lime mortars; however, the approval of European Standards led to the option of experiencing their application, namely the specimen execution according to the recent EN 1015-11. Practice revealed the following difficulties:

- Manoeuvring of moulds for ‘Preparation 2’.
- Difficulty of mortar to harden in the mould in the specified time and conditions.

In fact, the turning around of a mould covered with a glass plate proves difficult, even to experienced hands, as does the re-inversion of the mould with glass plates on each side. On the other hand, it was verified that mortars did not harden sufficiently for removal from moulds in the time and conditions specified in EN 1015-11 – specimens thus conditioned easily broke or disintegrated upon removal from moulds.

Besides, high humidity during setting is a favourable conditioning for hydraulic mortars but a very unfavourable condition for lime mortars, so the results obtained in such condition will not be representative.

3 MATERIALS AND APPLICATION CONDITIONS

3.1 Mortar composition

This work is inserted in a larger study where several other compositions were tested

The mortar used for this set of tests was a lime mortar composed of commercial dry hydrated lime (L), Cape Verde pozzolans (P), grinded and passed through the 0.500 sieve, and river sand (S). The volumetric ratio was 1: 0.5: 2.5 (L:P:S). This composition was chosen as it proved to give best results in comparison with other ratios in previous work (Velosa and Veiga, 2001).

3.2 Preparation and conditioning – a different approach

Taking into account the difficulties found whilst preparing and conditioning mortars following standards and the specific needs of additivated lime mortars, different conditioning was used, taking into account easiness of practice and relation with real atmospheric conditions.

A larger set of tests is still being developed.

For this work, three different conditionings were adopted:

- Control (C 1)- 23ºC ± 2ºC (temperature); 50% ± 5% (relative humidity), in mould for 7 days
- Filter paper (C 2) - 23ºC ± 2ºC (temperature); 50% ± 5% (relative humidity), with a filter paper on both sides of the mould during 7 days
- Water spraying (C 3) - 23ºC ± 2ºC (temperature); 50% ± 5% (relative humidity), with water spraying (20 cc every day), after removing from mould until testing date

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All conditionings implied a preparation with the filling of the mould with mortar in two equal layers, with 25 strokes of the tamper each and skimming of excess mortar with a palette knife.

Preparation and conditioning following C2, implying the filling of the mould over a filter paper and placement of another filter paper on top after complete filling of the mould, was thought of in order to absorb excess water in the mortars, with a solution of easy execution.

The daily spraying with water intended an approximation to real conditions, where high night relative humidity prevails throughout the year. Previous tests (Veiga 1997 and 2000) confirmed the adequacy of this method.

Using these methods, hardening of specimens proved sufficient; the only visible negative effect was the wear of specimens on the side previously not in contact with the mould due to water aspersion method.

Other conditions, including a more approximated condition to that proposed by EN 1015-11 are still in progress and will be presented later.

Figure 1. Specimen submitted to conditioning C3

4 LABORATORY TESTS

A set of laboratory tests was prepared in order to verify the main differences induced by the conditioning situations. Flexural and compression tests were performed so as to conclude upon mechanical properties, water absorption by capillary action informs about the capacity of mortar to resist capillary ascension and is a physical test and, finally, carbonation control (chemical testing) was effectuated in order to assess differences in carbonation speed induced by the different conditionings.

4.1 Flexural and compressive strength

Flexural and compressive tests were performed following EN 1015-11, and the results were obtained at the age of 28 days with values as listed below:

Table 2 – Flexural and compressive strength

	ress (N/mm^2)	ve Stress (N/mm^2)
1	0.53	1.72
2	0.70	1.73
3	0.53	1.98

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Figure 2. Flexural test

There are small improvements of mechanical strength for lime mortars with pozzolanic with changes in conditions techniques; the proportioning of a discontinuous humid environment (water sprinkling) and the use of filter paper over and below the mould during the first days after specimen execution seem both to benefit moderately mechanical strength at 28 days.

4.2 Water absorption by capillary action

This test was executed following *Cahier 2669-4 CSTB* (CSTB, 1993) in order to facilitate comparison of results with previous tests made by this method. Water absorption coefficient was calculated as the gradient of the graph representing √t in the x-axis and absorbed mass over section in the y-axis between √10 min and √90 min. Results at 28 days were as follows:

Table 3 – Water absorption by capillary action

Conditioning	er absorption coefficient ($g/dm^2.min^{1/2}$)
C1	17.0
C2	20.2
C3	14.7

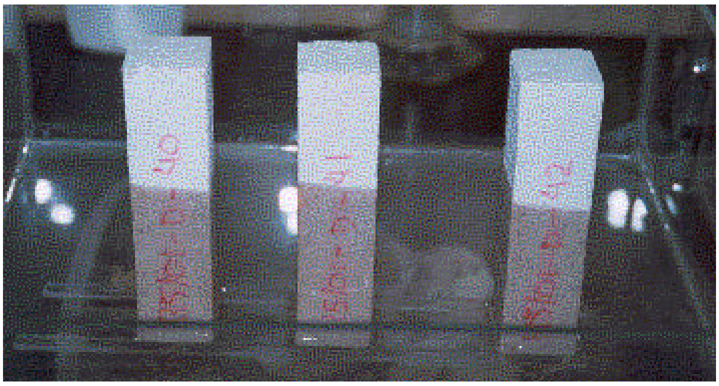

Figure 3. Testing of water absorption by capillary action

This test reveals a higher water absorption coefficient for specimens conditioned with the use of filter paper on both sides of the mould and lower values for specimens sprayed with water, relatively to control specimens.

4.3 Carbonation control

Carbonation depth was measured using testing procedures described in ICCROM's ARC (Teutonico 1998). The results obtained at 28 days are listed below:

Table 4 – Carbonation control

	ıtion depth (mm)
:1	9.1 mm
:2	5.5mm
:3	11.0mm*

*- Medium results obtained from previous testing of lime mortars additivated with pozzolans

From these results it might be concluded that there was a decrease in carbonation speed for conditioning involving the use of filter paper on both sides of the mould and an increase in carbonation speed in the case of water spraying during conditioning.

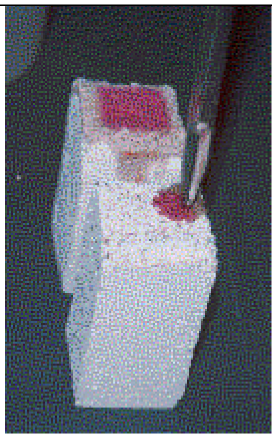

Figure 4. Carbonation test

5 CONCLUSIONS

Conclusions can be formulated on two levels:

- Preparation and conditioning easiness of execution and output
- Relation between laboratory tests and preparation and conditioning

On the first level, execution of specimens proved easier than EN 1015-11 and effective, as specimens could be easily handled after withdrawal from moulds. However, conditioning C3 caused some wear upon specimens due to the water spraying - this method must be improved.

The tested mechanical properties - flexural and compressive strength – seem to be slightly improved by both the experienced preparation and conditioning changes, but these results must be confirmed with tests at 90 days because they are not completely conclusive.

It may be concluded that the use of filter paper led to a decrease in carbonation speed and an increase in the water absorption coefficient. The decrease in carbonation speed could be explained by a better compacity of the mortar, originated by a diminution of the water that evaporates; in fact, better compacity could reduce the diffusion of CO_2; a lower carbonation rate explains a higher water absorption coefficient, because carbonated lime is less water absorbent than non-carbonated.

On the other hand, the spraying of water upon the specimens results in higher carbonation speed and lower water absorption coefficient. In this case, apparently, an increase in the humidity helps to increase the carbonation rate, because that chemical reaction needs some humidity; as a consequence, the mortar becomes less water absorbent.

This small set of tests, included in a larger testing campaign, does not permit great certainties. However, it does indicate that conditioning influences carbonation rate, mechanical resistance and water capillarity and so it is important to continue research so as to conclude about conditions representing reality in a more approximate way.

The development of studies approaching other conditions, similar to EN 1015-11 and a comparison with atmospheric conditions in Summer and in Winter will provide a further and more complete insight into this matter.

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