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# Grouting mortars for consolidation of historical renders showing loss of adhesion

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**Abstract -** Loss of adhesion is one of the main forms of degradation of old renders, in the form of separation of different render layers or between render and substrate, producing anomalies, such as debonding, detachment, cracks and lacuna on the render. In the present paper a study developed at LNEC – National Laboratory of Civil Engineering of Portugal – is presented, concerning restoration techniques for historical renders by consolidation using grouts for adhesion restitution. Lime grouts for consolidation should be mechanically, physically and chemically compatible with the original render, as this is a practically irreversible treatment. The aim of the study was the discussion of characteristics of grouts, considering both compatibility and efficacy. Several grouting mortars are selected, the methodology of the study and the laboratory tests carried out are described, as well as the critical analysis of the results, and the conclusions are summarized. Some proposals for future research are also presented.

## 1 Introduction

External renders, with their several layers, are important elements of the built structure. Their technical, aesthetical and historical content contribute to the building's identity. The preservation of traditional constructive techniques and the use of compatible repair materials (as similar as possible to the original) are significant issues for the maintenance of historical renders. One of the major causes of renders' decay is loss of adhesion. This anomaly consists of the separation occurring in different layers of a mortar or between mortars and the support, provoking defects such as detachments, cracks and lacunae. The loss of adhesion cannot be repaired with current construction techniques, hence the current tendency is to remove the old renders and substitute them by new ones, thus losing the materials and construction technology.

To re-establish the loss of adherence, the consolidation technique with grout mortars was used. During the last years, grouts have become the most common and favourable agents to re-establish adhesion between layers. Their composition has been modified along time in terms of type of binder, appropriate fillers and additives. This technique consists on the introduction of a very fluid lime paste into the void area of the detachment occurring between the render layers and the substrate.

The aim of this study is discussing the main characteristics of the tested grouts under controlled conditions in laboratory before their application in-situ. As lime grout mortars are irreversible conservation treatments, they should be mechanically, physically and chemically compatible with the original renders [1].

Based on previous studies, table 1 presents the basic requirements for consolidation treatment with grout mortars.

**Table 1** - Basic requirements for consolidation with lime grout mortars [1 and 2]

| | | |
|---|---|---|
| Consolidation in case of loss of adhesion (grout mortars) | Capillary water absorption coefficient | Capillary water absorption coefficient 50 – 100% of substrate mortar |
| | Compressive strength | Lower than the substrate's (< 60%) |
| | Modulus of elasticity | Lower than of the substrate's (< 80%) |
| | Pull-off-strength | ≥ 0,1 Nm² |
| | Shrinkage and dilation | As small as possible (< 4%) |
| | Consistency | Fluid enough to inject |
| | Set time | Not over 48 hours |

## 2 Materials and specimens

In this study three different industrial grout mortars were tested in order to re-establish the adherence between the render layers. These mortars have the following compositions:

Mortars A – based on air lime with additives and fillers.

Mortars B – based on hydraulic lime with additions and fillers.

Mortars C – based on air lime with calcareous micro-sand and pozzolanic additive.

These grout mortars were prepared according to their producers' specifications. The products were mixed with water during approximately 5 minutes. Two types of specimens were prepared for laboratorial tests:

- Prismatic specimens of grout mortars (40mm x 40mm x 160mm) (Fig. 1).
- Specimens constructed to simulate the loss of adherence with a "detachment" between layers in laboratory [3] (Fig. 2). These specimens were prepared with red perforated bricks rendered on one side with two layers of lime mortar (volumetric proportion lime:sand of 1:3), with total thickness of 20 mm. One

layer with 10 mm was applied and then a plastic ruler was placed on it before the application of a second layer. This ruler was used to simulate a void area between the two layers and was then removed after the render dries. Three months later the void area was humidified with a water and alcohol solution, to facilitate the grout penetration. The grout was then injected, at first with a very fluid consistency, in order to facilitate the complete filling of the hole. After the treatment, the specimens were placed in a conditioned room at 23º±2ºC temperature and 50±5% RH.

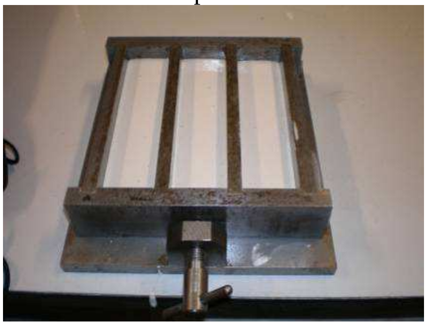

**Fig.1** Preparation of prismatic specimens of grout mortars.

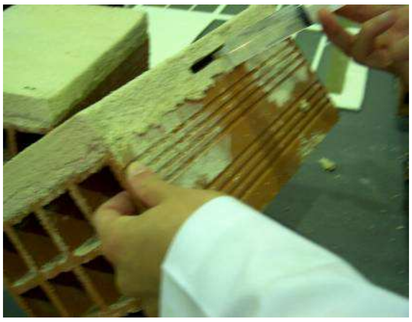

**Fig.2** Specimens simulating the "detachment" between layers

## 3 Test methods

The following tests were selected to study the products efficiency:

Water absorption by capillarity – evaluates the capacity of grout mortars to absorb water by capillarity (EN 1015 –18:2000).

- Flexural and compressive strength – evaluate the mechanical resistance of grout mortars (NP EN1015:11).
- Dynamic modulus of elasticity – evaluates the deformation capacity of grout mortars (method of the resonance frequency – LNEC Report 427/05-NRI [5] and NF- B10-511) (Fig. 3)
- Pull-off test – evaluates the adhesion strength of grout mortars to the render (EN – 1015-12:2000). (Figs. 4, 5 and 6)
- Shrinkage – evaluates the shrinkage of grout mortars, by comparing the variation between the initial (mould dimensions) and final (after curing) dimensions.
- Rheology – evaluates the grout behaviour in fresh state, through a relation between the product flux and deformation.

The tests (except for the rheology) were carried out after 90 days of curing.

**Fig. 3** Determination of dynamic modulus of elasticity.

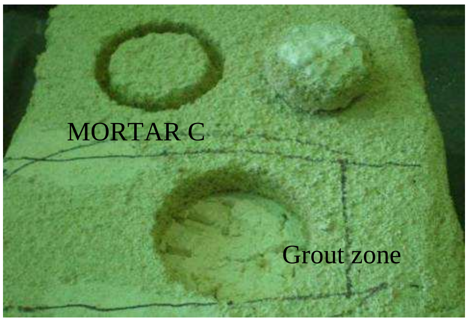


**Fig. 4** Cut in the specimen showing cracks in the grout mortar C


**Fig.5** Specimens after pull-off test – mortars B.


**Fig.6** Specimens after pull-off test – mortars A.

# 4 Results

## *4.1 Evaluation of behaviour concerning water absorption*

The water absorption behaviour of grout prismatic mortars was evaluated by determining the water absorption by capillarity and drying curve. The water absorption curve was obtained using a technique based on EN 1015-18, by partial immersion of the specimens and periodical weighing. The drying process was then also monitorized, by taking the specimens out from water and keeping them in a conditioned room (23ºC and 50% HR) and periodical weighing. The results are presented in table 2 and figure 7.

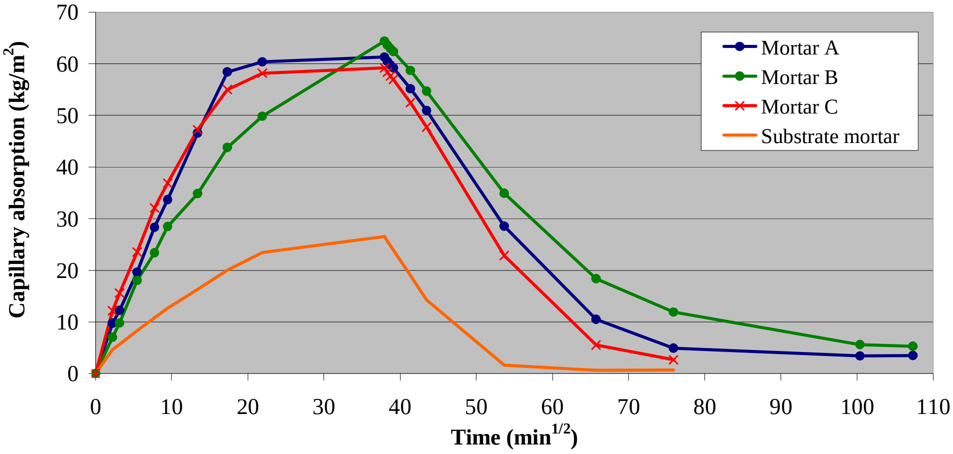


**Fig. 7** – Water absorption and drying of grout specimens

## *4.2 Mechanical resistance evaluation*

To evaluate the mechanical resistance, first the flexural and compressive strength were determined on prismatic grout specimens, and then the pull-off resistance was determined on specimens with simulation of loss of adherence between layers. The pull-off test was carried out on the specimens in a zone with grout (one pull-off determinations) and in a zone without grout (two pull-off determinations).

The pull-off test was not possible on all specimens due to detachment during cutting (before pull-off). This happened in all specimens with mortar C and in two specimens with mortar A. The results of the three specimens with mortar B and one specimen with mortar A are presented in table 2.

## *4.3 Evaluation of grout mortar deformation capacity*

The deformation capacity was evaluated through the dynamic modulus of elasticity of prismatic grout mortars, determined by the frequency of resonance method. The method consists on submitting the specimen to high frequency waves, varying the frequency and identifying the resonance frequency through the peak of amplitude. The resonance frequency is similar to the natural frequency of the specimen and thus it is possible to use it to determine the dynamic elastic modulus. The results are presented in table 2.

### *4.4 Evaluation of mortars shrinkage*

The evaluation of grout mortars shrinkage was determined by measuring each dimension of prismatic specimens after drying, and comparing it with the initial dimensions. The shrinkage could be perceptible visually in all dimensions (length, width and thickness).

### *4.5 Mortar evaluation in fresh state*

The rheological behaviour was studied with a specific rheometer (Viskomat PC) for mortars. The rotation speed of the vessel can be programmed and, in this study, a speed profile was used in which the speed is set at a constant value (0 rpm) for a long period of time (90 min). Each 15 minutes the speed is brought to 160 rpm and then back to 0 rpm. In these variable speed zones, flow curves of torque (T) vs. rotation speed (N) can be constructed. The relationship between torque and speed (T=g+hN) is characteristic of a Bingham fluid, where g and h are coefficients directly related to yield stress and plastic viscosity, respectively [6].

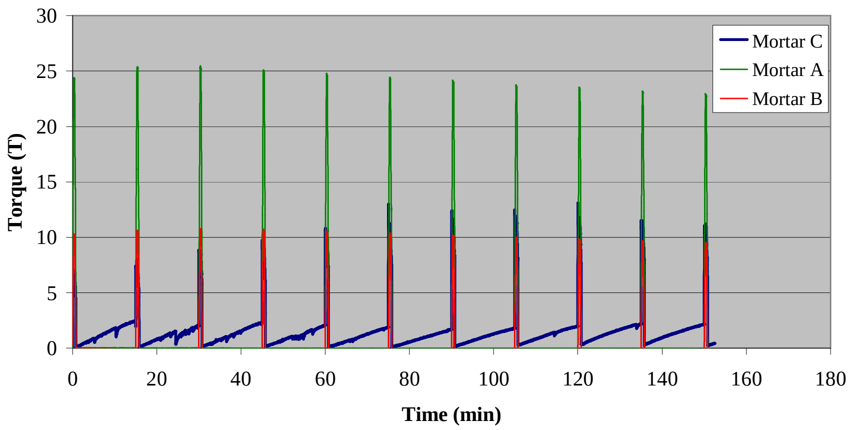


**Fig 8** Torque variation

### *4.6 Global results*

The global laboratorial test results, after 90 days of curing, are presented in table 2 and illustrated in figs. 7 and 8.

**Table 2** - Results of grout consolidation - laboratorial tests

| Laboratorial test | Mortar A | Mortar B | Mortar C | Render mortar |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Capillary water absorption coefficient during the first 5 minutes (0 – 5 min) ($kg/m^2min^{1/2}$) | 4,35 | 3,15 | 5,45 | 2,09 |
| Standard deviation | 0,02 | 0,11 | 0,36 | 0,14 |
| Flexural strength (N/mm²) (EN1015:11) | 0,98 | 1,69 | 0,41 | 0,24 |
| Standard deviation | 0,07 | 0,14 | 0,10 | 0,04 |
| Compressive strength (N/mm²) EN1015:11) | 1,64 | 3,71 | 0,80 | 0,62 |
| Standard deviation | 0,16 | 0,51 | 0,16 | 0,03 |
| Dynamic elastic modulus (MPa) (NF – B10-511) | 3123 | 4451 | 2025 | 2715 |
| Standard deviation | 162 | 71 | 60 | 8 |
| Pull-off-strength (N/mm2) (EN-1015-12:2000) | Zone without grout (cohesive rupture) | | | |
| | 0.03 | 0.05 | N.D. Rupture during test | - |
| | Zone with grout (rupture within the grout) | | | |
| | 0.04 | 0.06 | N.D. Rupture during test | - |
| Shrinkage (%) | 1.3 | 1.3 | 5.6 | - |

## 5 DISCUSSION

The study of grout mortars main characteristics and performance to re-establish the adherence of old renders is still running, although there are several relevant characteristics that can be pointed out with this experimental research:

- Injection facility: all mortars could be easily injected, and presented a good fluidity.
- Set time: according to visual observation, 36 hours correspond to the beginning of set time for mortars A and B, and 48 hours for mortar C, although the exact determination of set time should be done later with adequate tests.
- Water capillarity absorption and drying: the capillary water absorption coefficient during the first 5 minutes was lower for mortar B compared with the other mortars. The physical meaning of this coefficient is an absorption rate and it should correspond to the slope of the linear portion of the curve, thus for mortars of high capillarity, as lime mortars in general, it is more accurate to determine it between 0 and 5 minutes (fig. 7). As it can be observed in fig. 7, throughout 24 hours test, mortar B took more time to get water saturated than the other mortars. The highest water absorption value was found in mortar C and the lowest in mortar B. These grout mortars show higher water absorption coefficients when compared with old substrates analysed in previous studies [7], probably due to old

substrates low capillarity. However, through the analysis of fig. 7 it can be found that grout mortars have lower total water absorption compared with the lime render mortar (recent lime mortar). The drying of mortar C was also quicker than mortars A and B's.

- Mechanical behaviour: mortar B presents the highest flexural and compressive strength as well as elastic modulus, however the results are moderate. Although it could be possible to use the studied grout mortars on old and well carbonated substrates, they are too strong and too stiff to be used on the new lime mortars used as substrate in the specimens (table 2). Mortar C presented the lowest resistance and elastic modulus, lower than the lime render mortar; mortar B presented the highest resistance and elastic modulus (table 2). Mortars A and C can be used to consolidate old and weak lime renders, in most situations.
- Adherence: the pull-off test showed that grout mortars have similar strength as lime render mortar (zone without grout, fig. 2). On mortar A the rupture occurred through the support (fig.6), meaning that the grout´s tensile stress strength is higher than the render's strength, although the test could be performed on one specimen only and more experiments should be carried out to confirm this result. In mortar B the rupture occurred through the grout (fig 5) meaning in this case that grout's tensile strength is lower than the cohesive strength of substrate´s mortar and than the adhesion strength between grout and render.
- Void area filling: The observation of the rupture surface of the pull-off test on grout mortars A and B, showed that the hole in the specimens was uniformly filled (figs 4 and 5). On mortar C voids and some cracks were found (fig. 4) with a powdered appearance, possibly due to incomplete carbonation.
- Shrinkage: the highest shrinkage (5.6 %) was found in mortar C and the lowest shrinkage, around 1%, was found in mortars A and B (table 2).
- Rheological behaviour: the highest and lowest plastic viscosity were respectively found in mortars B and C. Mortar B presented a low yielding stress, which could be a positive factor for grout mortars, meaning it is adaptable to voids to be filled. On the other side the low yielding stress is prolonged along all the test period and this seems to be also a favourable characteristic for grout mortars: indeed this treatment is a slow process and the grouts can be used for longer periods of time, preserving their initial properties. Analysing torque values, it was verified that all the mortars are stable during the test period.

## 6 CONCLUSIONS

The results obtained showed that mortars A and B have general favourable characteristics. They fulfil the basic requirements for grout mortars, thus they can be used in old renders conservation for adherence restitution, as long as these are strong and well carbonated renders. Grout mortar C was found to be weaker and more deformable than the other tested grout mortars. With the low characteristics obtained, grout mortar C could be used to consolidate weak renders; however, it was observed that it didn't harden during the 90 days of curing time, probably due to difficulty of carbonation inside the voids.

The grout mortar choice depends on the pre-existent renders mechanical behaviour and decay (lacunae/detachment deepness, humidity rate in the wall, etc.). Hence, considering the tested grout mortars, mortar B should be chosen for more resistant existing renders (compressive strength > 6,1 N/mm$^2$, according to the requirements defined in table 1, which is a rather high value for old lime renders).

Concerning water absorption, all the tested grout mortars should be used only on old renders with capillary water absorption coefficients, calculated at 5 minutes, lower than about 5 kg/m$^2$.min$^{1/2.}$

Mortar B has an hydraulic binder, mortar C has a pozzolanic additive to get hydraulic characteristics and it is possible that mortar B has also pozzolans as additives. However, in the case of mortar C, apparently the pozzolanic additive didn't react, because a powdery texture was observed.

The development of grouts with hydraulic characteristics is important; indeed it allows their hardening in spite of low carbonation rate inside the wall, not exposed to the air [8]. As a result, mortar B presented lower water absorption, higher mechanical strength, higher shrinkage and lower deformability. However, the addition of hydraulic binders should not be excessive in order to prevent a high increase of mechanical strength which contributes to the development of anomalies in the old renders, as detachments or cracks.

This research must go on by developing new grout renders formulated in this investigation framework, with optimized behaviour. The formulations should be improved, by altering the proportion of hydraulic binder or pozzolanic additions, by choosing aggregates with better grain size distribution and adequate admixtures, in order to optimize several characteristics such as: fluidity, solidification, penetration and carbonation.

The continuation of this study will allow us to go deeper in this area and diffuse the knowledge through the international and national technical environment in order to contribute to the improvement of the conservation interventions in historical renders using traditional materials.

## 7 ACKNOWLEDGEMENTS

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