III.21
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; it can cause the separation of different render layers or the separation of the render and substrate; this in turn can produce anomalies such as de-bonding, detachment, cracks and lacuna on the render. The work represented here is part of a study developed at the LNEC – National Laboratory of Civil Engineering of Portugal – to examine how consolidation using grouts for adhesion restitution can be used for the restoration of historical renders. The lime grouts used for consolidation should be mechanically, physically and chemically compatible with the original render, as this is a practically irreversible treatment. The aim of this study is to examine the characteristics of grouts, with consideration to their compatibility and efficacy. This paper details the methodology of the study and a description of the laboratory tests carried out, as well as a critical analysis of the results and a summary of the conclusions. 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 Their technical, aesthetic and historical content contribute to a building’s identity.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 in the maintenance of historical renders. One of the major causes of the decay of render is a loss of adhesion. This anomaly presents itself as a separation between the different layers of a mortar or between mortars and their support, producing defects such as detachments, cracks and lacunae. At present no technique exists to repair this loss of adhesion in situ, hence the current tendency
is to remove the old render and substitute it with a new one, thus resulting in a loss of traditional materials and construction technology.

To re-establish the loss of adherence, a consolidation technique with grout mortars can be used. During the last few years, grouts have become increasingly popular as a material for such repairs. To improve their suitability, their composition has undergone modification throughout time with adjustments being made to the type of binder, and to appropriate fillers and additives. Consolidation by grouting consists of the introduction of a very fluid lime paste into the void area created by the detachment of the render from the substrate.

The aim of this study is to discuss the main characteristics of grouts tested under controlled conditions in a 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]. Table 1 presents the basic requirements for consolidation treatment with grout mortars, as determined from previous studies.

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

<table>
<thead>
<tr>
<th>Consolidation in case of loss of adhesion (grout mortars)</th>
<th>Capillary water absorption coefficient</th>
<th>Capillary water absorption coefficient 50 – 100% of substrate mortar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength</td>
<td>Lower than the substrate’s (&lt; 60%)</td>
<td></td>
</tr>
<tr>
<td>Modulus of elasticity</td>
<td>Lower than of the substrate’s (&lt; 80%)</td>
<td></td>
</tr>
<tr>
<td>Pull-off-strength</td>
<td>≥ 0.1 Nm²</td>
<td></td>
</tr>
<tr>
<td>Shrinkage and dilation</td>
<td>As small as possible (&lt; 4%)</td>
<td></td>
</tr>
<tr>
<td>Consistency</td>
<td>Fluid enough to inject</td>
<td></td>
</tr>
<tr>
<td>Set time</td>
<td>Not over 48 hours</td>
<td></td>
</tr>
</tbody>
</table>

2 Materials and Samples

In this study three different industrial grout mortars were tested to determine which were favourable for use in consolidation. These mortars have the following compositions:

- Mortar A – based on air lime with additives and fillers.
- Mortar B – based on hydraulic lime with additives and fillers.
- Mortar C – based on air lime with calcareous micro-sand and pozzolanic additives.

These grout mortars were prepared according to their producers’ specifications and were mixed with water for approximately 5 minutes. Samples were produced in two forms for laboratory analysis:
Those that were cast within rectangular moulds (40mm x 40mm x 160mm) (Fig. 1).

Those constructed to simulate a loss of adherence where “detachment” between layers was artificially produced in a laboratory [3] (Fig. 2). These specimens were prepared using red perforated bricks rendered on one side with two 10mm thick layers of lime mortar (volumetric proportion lime:sand of 1:3). After the first layer had been applied, a plastic ruler was placed on top, prior to the application of the second layer; the ruler, removed after the render had dried, was used to simulate a void area between the two layers. Three months later the void area was humidified with a water and alcohol solution to facilitate 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 samples were placed in a conditioned room at 23º±2ºC and 50±5% relative humidity.

![Fig. 1 Preparation grout mortars within metal mould.](image)

![Fig. 2 Specimens created to simulate the “detachment” between layers](image)

3 Test methods

The following tests were selected to study the efficiency of the grout mortars:

- **Water absorption by capillarity** – to evaluate the capacity of the grout mortars to absorb water by capillarity (EN 1015 –18:2000).
- **Flexural and compressive strength** – to evaluate the mechanical resistance of the grout mortars (NP EN1015:11).
- **Dynamic modulus of elasticity** – to evaluate the deformation capacity of the grout mortars (method of resonance frequency – LNEC Report 427/05-NRI [5] and NF- B10-511) (Fig. 3)
- **Pull-off test** – to evaluate the adhesion strength between the grout mortars and the render (EN – 1015-12:2000) (Figs. 4, 5 and 6).
- **Shrinkage** – to evaluate the shrinkage of the grout mortars by comparing the variation between the initial (mould dimensions) and final (after curing) dimensions.
• **Rheology** – to evaluate the grout behaviour in fresh state through an analysis of the relationship between the product flux and deformation.

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

4 **Results**

4.1 **Evaluation of behaviour concerning water absorption**

The water absorption behaviour of the moulded grout mortars was evaluated by capillarity and was plotted on a drying curve. The water absorption curve was obtained using the methodology outlined in EN 1015-18, by partial immersion of the specimens and periodical weighing. The drying process was monitored by taking the specimens out of the water and placing them in a conditioned room (23°C and 50% HR) where they were weighed periodically. The results are presented in Fig.7 and Table 2.
4.2 Mechanical resistance evaluation

To evaluate the mechanical resistance, the flexural and compressive strength was determined for the moulded samples, and the pull-off resistance was determined for the simulated samples. The pull-off test was carried out on the samples in a zone with grout (one pull-off determination) and in a zone without grout (two pull-off determinations).

The pull-off test was not possible on all samples due to the detachment of a core during cutting (before pull-off). This happened in all the samples prepared with grout mortar C and in two samples prepared with grout mortar A. The results were obtained for three samples using mortar B and one sample using mortar A and are presented in Table 2.

4.3 Evaluation of grout mortar deformation capacity

The deformation capacity was evaluated through the dynamic modulus of elasticity for the moulded grout mortars, using the frequency of resonance method. This is performed by bombarding the sample with a varied series of high frequency waves; the peak of amplitude is then used to identify the resonance frequency. The resonance frequency is similar to the natural frequency of the specimen and thus it is possible to use it to determine the dynamic modulus of elasticity. The results are presented in Table 2.
4.4 Evaluation of mortars shrinkage

The evaluation of the shrinkage of the grout mortars was determined by measuring each dimension of the moulded samples after drying, and comparing them with the dimensions taken before drying. The shrinkage was perceptible 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) designed for use on mortars. The rotation speed of the vessel can be programmed and in this study, a speed profile was used in which the speed was initially set at a constant value of 160 rpm for 90 min. Each 15 minutes following this, the speed is reduced to 0 rpm and then back to 160 rpm for 155 minutes (fig.8). 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 [6].

![Fig. 8 Torque variation](image-url)
4.6 Overall results

Table 2 Results of grout consolidation - laboratory tests

<table>
<thead>
<tr>
<th>Laboratory test</th>
<th>Grout Mortar A</th>
<th>Grout Mortar B</th>
<th>Grout Mortar C</th>
<th>Render mortar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capillary water absorption coefficient during the first 5 minutes (0 – 5 min) (kg/m²min²)</td>
<td>4.35</td>
<td>3.15</td>
<td>5.45</td>
<td>2.09</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.02</td>
<td>0.11</td>
<td>0.36</td>
<td>0.14</td>
</tr>
<tr>
<td>Flexural strength (N/mm²) (EN1015:11)</td>
<td>0.98</td>
<td>1.69</td>
<td>0.41</td>
<td>0.24</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.07</td>
<td>0.14</td>
<td>0.10</td>
<td>0.04</td>
</tr>
<tr>
<td>Compressive strength (N/mm²) (EN1015:11)</td>
<td>1.64</td>
<td>3.71</td>
<td>0.80</td>
<td>0.62</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.16</td>
<td>0.51</td>
<td>0.16</td>
<td>0.03</td>
</tr>
<tr>
<td>Dynamic elastic modulus (MPa) (NF – B10-511)</td>
<td>3123</td>
<td>4451</td>
<td>2025</td>
<td>2715</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>162</td>
<td>71</td>
<td>60</td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pull-off-strength (N/mm²) (EN-1015-12:2000)</th>
<th>Zone without grout (cohesive rupture)</th>
<th>Zone with grout (rupture within the grout)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.03</td>
<td>0.05</td>
<td>N.D. Rupture during test</td>
</tr>
<tr>
<td>0.04</td>
<td>0.06</td>
<td>N.D. Rupture during test</td>
</tr>
</tbody>
</table>

Shrinkage (%) | 1.3 | 1.3 | 5.6 | - |

5 Discussion

The study of the main characteristics and the performance of grout mortars to re-establish the adherence of old renders is ongoing, however many of the initial details of this experimental research can be discussed here. The characteristics of the three grout mortars that have been studied in this paper include:

- **Injection facility**: all mortars could be easily injected, and presented a good fluidity.
• **Set time:** according to visual observation, mortars A and B began to set after 36 hours, and mortar C began to set after 48 hours; the exact determination of set time will be done later using more accurate test methods.

• **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. This coefficient is an absorption rate and should correspond to the slope of the linear portion of the absorption curve; thus for mortars of high capillarity, as is common with lime mortars in general, it is more accurate to determine the coefficient between 0 and 5 minutes (Fig. 7). As it can be observed in Fig. 7, throughout a 24 hours test, mortar B took more time to become saturated than the other mortars. The highest water absorption value was found in mortar C (which also had the highest drying time) and the lowest in mortar B. These grout mortars show higher water absorption coefficients when compared with the old substrates analysed in previous studies [7]; the older substrates most likely had a lower capillarity than the old grouts. However, through the analysis of Fig. 7 it can be found that grout mortars have lower total water absorption when compared with the lime render mortar (recent lime mortar).

• **Mechanical behaviour:** mortar B presents the highest flexural and compressive strength as well as elastic modulus; however, in general, 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 stiff to be used on newer lime mortars (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 a similar strength to the lime mortar render (zone without grout, Fig. 2). On mortar A rupture occurred through the core (Fig. 6), meaning that the grout’s tensile strength is higher than that of the render, although the test was performed on one specimen meaning that more experiments should be carried out to confirm this result. In mortar B the rupture occurred throughout the grout (Fig. 5), indicating that the grout’s tensile strength was lower than the cohesive strength of the substrate’s mortar and the adhesive strength between the grout and render.

• **Void area filling:** 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. The low yielding stress was prolonged.
throughout the test period. This also seems to be a favourable characteristic for grout mortars: consolidation by grouting is a slow process, and this therefore means that grouts can be used for longer periods of time with a preservation of their initial properties. Through the analysis of torque values, it was verified that all the mortars were stable during the test period.

6 CONCLUSIONS

The results obtained showed that mortars A and B have in general, favourable characteristics. They fulfill the basic requirements for grout mortars, thus they can be used in the conservation of old renders for adherence restitution, as long as the renders are strong and well carbonated. 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 day curing time, probably due to the difficulty of carbonation inside the voids.

The choice of grout mortar depends on the pre-existent renders’ mechanical behaviour and decay (lacunae/detachment deepness, humidity rate in the wall, etc.). Hence, of the tested grout mortars, mortar B should be chosen for more resistant existing renders (compressive strength > 6.1 N/mm², 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 a capillary water absorption coefficient, calculated at 5 minutes, lower than about 5 kg/m².min¹/². Of the grout mortars, only B and C present hydraulic properties. With mortar B, this is due to a hydraulic binder and the possible addition of pozzolanic additives; with mortar C, this is due solely to the pozzolanic additives. However, the powdery texture within mortar C indicates that the pozzolanic additives failed to react fully. The development of a grout with hydraulic characteristics is important; indeed it allows their hardening in spite of a low carbonation rate inside the wall where exposure to the air is minimum [8]. 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 the high increase in mechanical strength which can contribute to the development of anomalies such as detachment or cracking in the old renders.

This investigation framework will eventually lead to the development of new grout mortars which can be customized for their required performance. The formulations can be improved by altering the proportion of hydraulic binder or pozzolanic additions, by choosing aggregates with better grain size distribution and altering admixtures to optimize characteristics such as: fluidity, solidification, penetration and carbonation.
The continuation of this study will allow a more in-depth understanding of the materials used, and will lead to the diffusion of such knowledge through the international and national technical community in order to contribute to the improvement of conservation interventions in historical renders through the use of traditional materials.

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8 References