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Preliminary studies on a lime grout for built heritage conservation

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Abstract

Built heritage often needs conservation operations in order to prevent further degradation and the loss of an important cultural identity. Most of the historical monuments possess walls covered with different kinds of coatings, the most common of which are based on lime mortars. Many of them present severe anomalies such as the loss of adhesion between the layers of plaster and the substrate.
In the area of conservation of façade coverings, this work aims at the development of a grout mortar, in which the rheological characteristics were adjusted to make its appropriate application possible. These grouts must fill the hollow spaces in the wall between the old mortar and the support or the base render. This need imposes compatibility requirements with adjacent mortars and substrates. Apart from fresh state requirements, also some basic hardened state characteristics were analyzed.
Several formulations based on different binders (hydraulic and air lime), on controlled particle size sand and on various types of admixtures were prepared and studied as potential grouts. First, they were studied in terms of rheological behavior and parameters like the amount of admixtures and water content were fixed. Then two of the tested formulations were chosen for application and characterization of mechanical and water behavior. These last tests included flexural and compressive strength, adhesion and capillary tests.

Key words: Conservation, Lime, Grout, Conservation mortars.

1. Introduction

Great part of built patrimonial legacy, that remains until the present, needs conservation actions due to its degradation state. This constructed heritage exhibits the walls covered with different kinds of renders and plasters, the most usual of which are based in lime mortar. Many of them present severe anomalies, such as the loss of adhesion between coats.
In the area of conservation of façade renders and plasters, when loss of adhesion between old mortars layers occur, the application of the grout mortar technique is a possibility of repair without removal. The grout's usual components are aggregate and binder, as a normal mortar. The addition of admixtures is usually performed to improve a particular grout's characteristics either in the fresh or hardened state. Some of the most commonly used admixtures are the water retaining agents, precisely to retain water inside the grout during the dehydration process caused by absorption of the wall, substrate or by evaporation to the atmosphere. Other frequently used admixtures are the plasticizers, which improve the fluidity, and the adhesive agents that improve the adhesion to the substrate. Another grout characteristic is the high amount of kneading water, between 60 to 80% of the total weight of dry grout mortar. This high content of water is related to the high fluidity needed in the application of a grout.
Compatibility between the grout and substrate is essential since grout technique is effectively irreversible and the possibility of re-treatment is not possible [1].
This work aims to develop a grout mortar, in which the rheological characteristics were adjusted to make its appropriate application possible. Since this technique is a grout introduction into a cavity, using a syringe, the fresh state characteristics are very important to enable good flow capacity [2]. However, apart from fresh state requirements, also some basic hardened state characteristics must be compatible with the old materials [2-5].

This research was carried out as a development of the Ph.D thesis *The conservation and restore of external renderings of old buildings – a methodology of study and repair* that Martha Lins Tavares is accomplishing in LNEC and FA/UTL, with the support of FCT (Foundation for Science and Technology) and inserted in Project FCT, POCTI/HEC/57723/2004 – Lime renders conservation: improving repair techniques and materials on architectural heritage. The present study is based in previous work of the Project team [6].

2. Experimental

2.1. Materials

Air lime and hydraulic lime (NHL 5) were used as binders while siliceous sand with a controlled particle size distribution (figure 1) was used as the aggregate. The admixtures used were a water retaining agent (WRA), an adhesive agent based on an acrylic acid co-polymer resin (AA) and a fluidizing agent (FA).
The admixtures were added to the mortars in distinct amounts (0.01 to 2 % of the total weight of dry grout mortar). Table 1 shows the compositions of studied mortars.

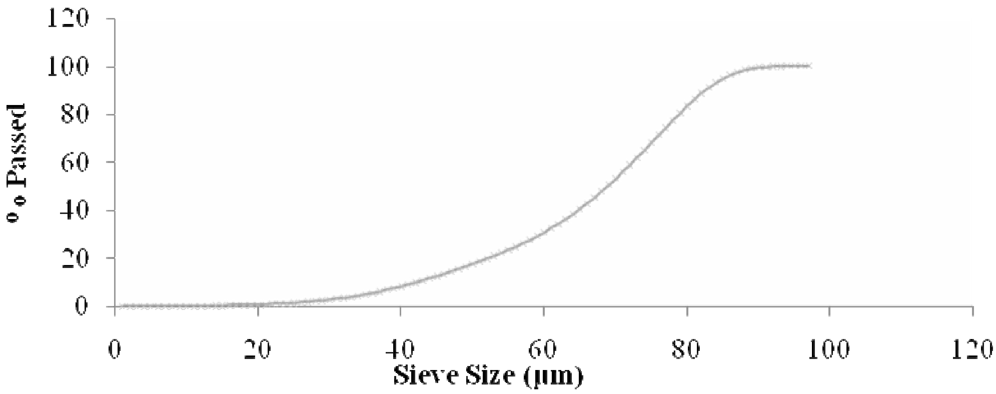


Figure 1: Siliceous sand grain size distribution

Table 1: Compositions of studied lime mortars.

Sample	Formulation (Mass)	Kneading water (%)
CH	33.3% hydraulic lime 66.6% Aggregate P160 WRA+FA	60
CHA	33.3% hydraulic lime 66.6% Aggregate P160 WRA+FA+AA	60
CA	13.6% Air lime 79.5% Aggregate P160 6.9% Metakaolin WRA+FA	60
CAA	13.6% Air lime 79.5% Aggregate P160 6.9% Metakaolin WRA+FA+AA	60

1.1. Analysis

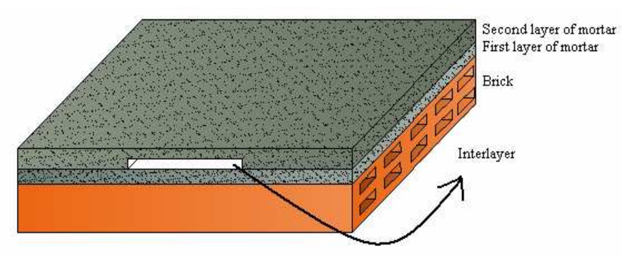
1.1.1. Fresh state characterization

The rheological behavior 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

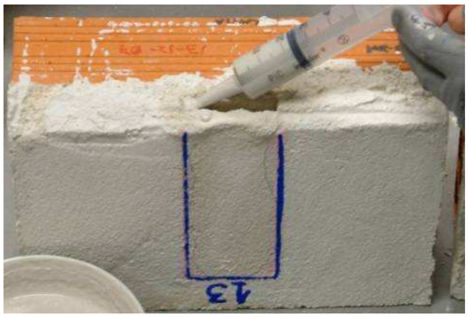
speed (N) can be constructed. This dwell profile is specially designed to evaluate the rheological behavior with time. The relationship between torque and speed (T=g+hN) is characteristic of a Bingham fluid, where g and h are coefficients directly related to yield stress and plastic viscosity, respectively.
The injectability of grout is mostly checked by the grout bulk penetration in a sand coarser column according to the French standard NF P18-891. In the column the sand grain size has strict limits (2.36mm to 4.8mm).
The water segregation test was measured according to NP EN 447 European standard. This technique measures the amount of segregation water in a column [7].

1.1.2. Hardened state characterization

Two types of samples were prepared. The standard prismatic samples, according to NP EN1015-11, and samples prepared by applications on bricks.
The production of brick samples for adhesion and capillarity tests (Figure 2) involved: (i) Application of a first mortar layer on the brick; (ii) place a glass of 10x7x 0.5 cm on the first layer and apply a second layer of mortar; (iii) remove the glass and this way a detachment on a rendering mortar (interlayer, crushed mortar) is produced. The mortar, identified as base mortar, used for the production of brick samples was prepared with a binder:aggregate volume ratio of 1:3, using air lime as binder and a coarser aggregate [6].



a)



b)

Figure 2: a) Brick samples scheme; b) Grout application on a brick sample

The prismatic samples were characterized regarding their mechanical properties and water behavior. The mechanical characterization involves measurements of dynamic elastic modulus (E), flexural and compressive strengths (Fs;Cs), following standard methods (EN 1015-11). Capillary absorption coefficient was measured according to EN 1015-18 European standard. The brick samples characterization involves the measurement of capillary absorption water with Karsten tubes and grout adhesion (pull-off strength) (EN 1015-12). In brick samples, the base mortar was also characterized.

3. Results and Discussion

3.1. Fresh state properties

3.1.1. Rheological characterization

The rheological behavior of two commercial mortars called A and B, which contain hydraulic lime and air lime as binders, respectively, were used as a guide.
The amount of each admixture was studied in order that the rheological parameters, h and g, are situated within the range presented by reference industrial mortars, A and B. During the previous studies, it was observed that the FA admixture improves the flow with a decrease in h and g parameters. The water retaining agent (WRA) showed a thickening effect with an increase in h and g parameters. This last admixture also reduces segregation amongst the grout components. The use of the adhesive agent, AA, as it is possible to observe in Figures 2 and 3, does not seem to affect the rheological characteristics, at least during the first 90 minutes.
Figures 3 and 4 show the rheological parameters behaviour as a function of testing time for the different formulations. It is possible to observe that all the formulations are within the range defined by the two reference mortars.

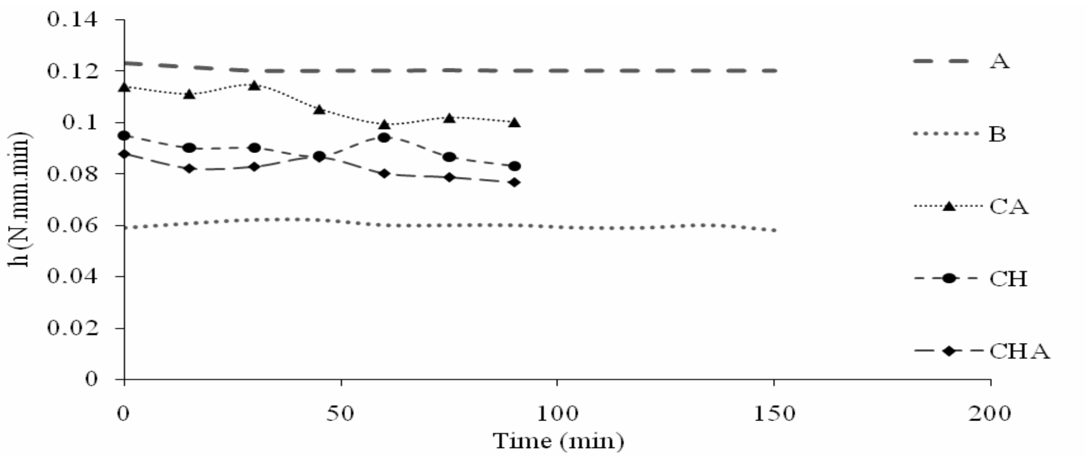


Figure 3: Variation of h parameter as a function of testing time for the different grout composition.

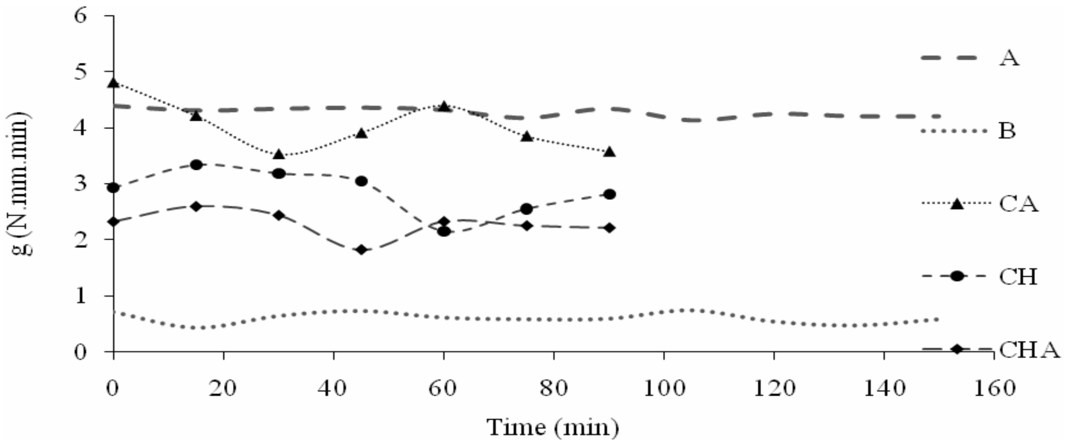


Figure 4: Variation of g parameter as a function of testing time for the different grout composition.

3.1.2. Injectability test

Figure 5 show the injectability test made on the CA formulation. It is possible to observe the aggregate penetration by the CA composition.

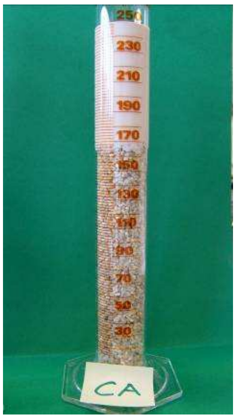


Figure 5: Injectability test made on the CA formulation.

Figure 6 presents the results of penetration volume for the studied formulations in the aggregate. The hydraulic lime based compositions show a higher penetration capacity than the air lime based formulations. The adhesive agent, AA, presence decreases the penetration capacity.

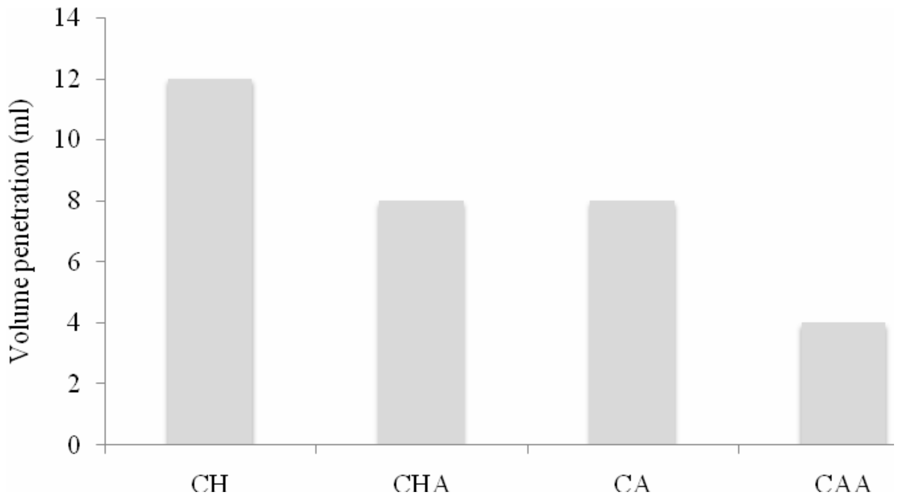


Figure 6: Penetration volume variation for the studied compositions.

3.1.3. Water segregation test

According to the NP EN 447 European standard, after 3 hours of test, a grout mortar must show a water segregation result lower than 2%. The different compositions presented no segregation (0%) in this test, well below the standard required value of 2%. These results were possible because of the WRA presence. Compositions without WRA tested before in a preliminary testing program showed water segregation values much higher than the required maximum of 2%.

3.2. Hardened state properties

3.2.1. Mechanical strength of prismatic samples

Table 2 shows the results of mechanical strength and dynamic elastic modulus for the different compositions at 60 days of curing. The mechanical strength values are low. This is probably related to the high kneading water content used in the grouts preparation as the water effect on porosity is well known. In a real situation, the substrate absorbs part of the kneading water so, in the end, the grout sets with a lower porosity than the prismatic samples. The prismatic samples are useful as a comparative technique between different compositions.
Table 2 also shows that the presence of the adhesive agent (AA) contributes in both cases (hydraulic and air lime binders) to increase the strength value. The hydraulic lime based formulations present higher values of flexural mechanical strength then the air lime based compositions. Because the grout was prepared with a high amount of water and a water retaining agent (WRA) was also used, the hydration reactions are favoured. An air lime based grout hardens due to the portlandite reaction with atmospheric carbon dioxide. As carbon dioxide must diffuse through the pores of the gout mortar, the carbonation process is very slow. Pozzolanic reaction that occurs with the addition of metakaolin also develops at a slow rate. The hydraulic lime based grouts present higher mechanical strength and lower capillary coefficient then the air lime based grouts.
In terms of the dynamic elastic modulus, the hydraulic lime based grouts show similar values to the air lime based grouts (Table 2). The presence of the adhesive agent, AA, increases the dynamic elastic modulus.

3.2.2. Water behaviour

The water absorption tests in prisms, whose results are synthesized in table 2, show that all the grout mortars have relatively high capillary coefficients. Hydraulic lime compositions have slightly lower values. The adhesive agent AA doesn't apparently improve water behaviour.

Table 2 – Mechanical characteristics and water behaviour characteristics measured in prisms

Sample	*Flexural strength (MPa)*	*Compressive strength (MPa)*	*Water uptake coefficient ($kg/m^2h^{0.5}$)*	*Dynamic elastic modulus (MPa)*
CH	0.64	0.50	15.5	3726
CHA	0.66	0.64	16.4	4604
CA	0.36	0.50	17.8	3775
CAA	0.48	0.56	17.8	4215

Figure 7 shows the brick samples water absorption test scheme. In this test the water absorption capacity was evaluated in brick samples, in areas containing only the base mortar and in areas with grout under the base mortar.

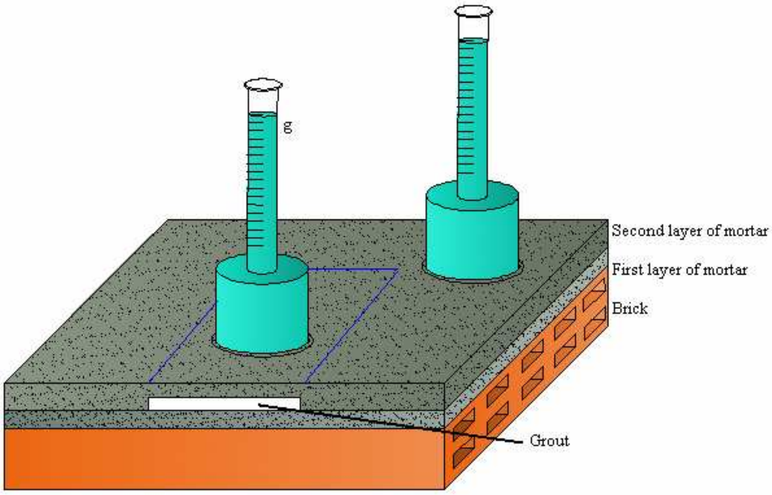


Figure 7: Brick samples water absorption test scheme. Application of Karsten pipes in areas only with base mortar and in areas with grout under base mortar (g).

Figure 8 shows the water absorption for the different studied formulations. It is possible to observe that the water absorption capacity in areas with the grout presence (CHAg, CHg and CAg) is lower then that showed in the areas only with base mortar. This means that the grout open porosity is lower than the base mortar which was expected, because grouts contain hydraulic binders and the base mortar is a recently prepared air lime mortar.

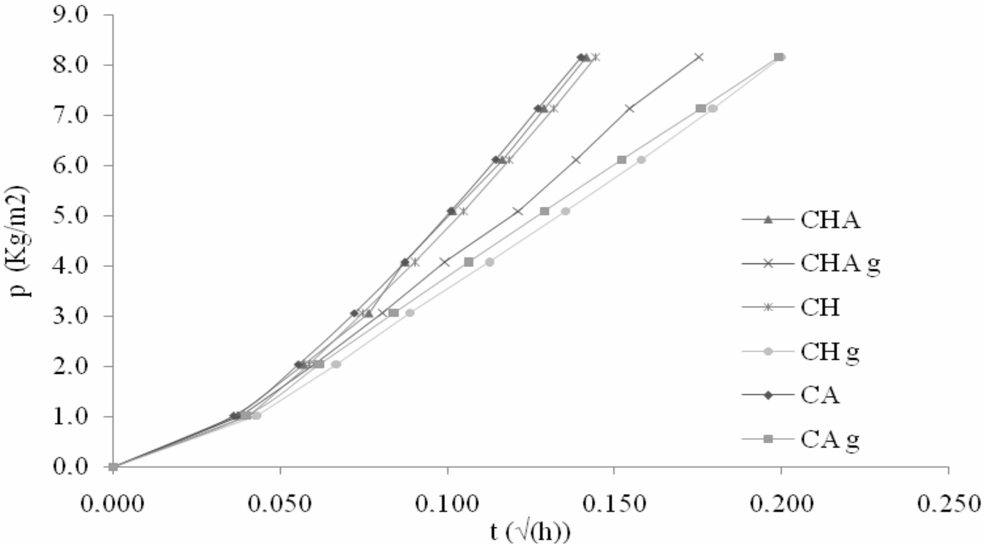


Figure 8 – Water absorption, with time, behavior for the different compositions.

3.2.3. Pull-off strength on brick samples.

The results obtained with the pull-off test (fig. 9) show low adhesion between mortar layers. In all cases the values are lower in zones with grout and the rupture surface is adhesive between the mortar upper layer and the grout. A possible explanation for these results is that the production of brick samples involves the application of the second layer of base mortar on a glass, which, after removal, simulates a detachment on a rendering mortar. Because the glass surface is very smooth, the second layer of base mortar does not have any roughness inside the cavity. Hence, the grout doesn't create a good connection with the mortar on that face and, when the pull off strength test is applied, the mortar base detaches out of the grout in this interface. This problem doesn't happen between the grout and the first roughness layer. So, the preparation of brick samples should be altered to permit the creation of a rough surface in contact with the grout, similar to the real situation.

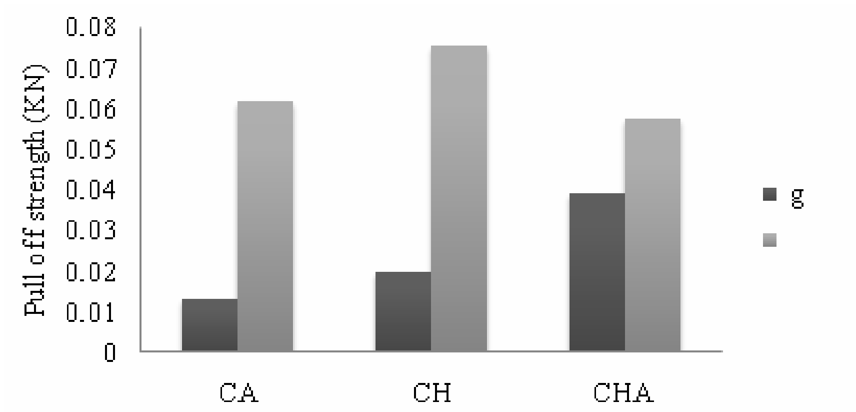


Figure 9: Results from pull off strength tests on brick samples (Darker bars represent values from areas with grout (g) and brighter grey bars represent areas without the grout).

4. Conclusions

In this study, it was possible to develop grouts, based on hydraulic lime or air lime and metakaolin, with good rheological properties in order to act as grouts for conservation of old renders. The presence of the admixtures allowed achieving this good rheological behaviour, assuring no segregation effects.
Mechanical characteristics are low, but they are compatible with weak base mortars. For consolidation of stronger materials the compositions must be adjusted, taking into consideration that their strength must be of the same order of magnitude as the base mortars, preferentially slightly lower.
Water absorption behaviour of the formulations tested is compatible with old mortars. The grouts have rather high coefficients of capillarity but they reduce the water uptake of the base mortar.
The pull-off test showed that the grout formulations evaluated can recover the adhesion between detached layers of mortar, although the final adhesion values measured are low.
The brick sample test revealed to be a very good technique to assess the grout behaviour but it needs to be improved in what concerns the roughness of the space where the grout is inserted, which must be increased to minimize the problem of lack of adhesion in the interface.
This study contributed to improve the knowledge about the development of grout mortars. However, this research must go on with the test of optimized formulations and a larger program of tests, including the evaluation of the porous structure and in situ testing on old lime mortars presenting detachments.

5. References

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