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Consolidation of renderings simulating stone in the façade of LNEC's building

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SUMMARY: The main façade of the building of Laboratório Nacional de Engenharia Civil (LNEC), is covered by a rendering simulating stone, composed by air lime and calcareous aggregate, using a special technique, assigned in Portugal, as marmorite. *This rendering was applied in the fifties of the XXth century and in the beginning of 2006 presented some degradation, at material and aesthetic level, demanding a conservation intervention. This paper reports the study carried through for the consolidation of these renderings; it gives information about the rendering technique, presents a set of tests to evaluate the effectiveness of the consolidation products, analyzes the results obtained and describes in-situ application, including the techniques used.*

KEY-WORDS: simulation of stone, lime mortars, consolidation

INTRODUCTION

The main building of LNEC, of late modernist style, was designed by the portuguese architect Porfírio Pardal Monteiro and constructed in 1950-52. The main façade of the building is covered by a rendering simulating stone, assigned as marmorite, composed by air lime and calcareous aggregate (fig. 1, table 1 and 2). This kind of render was used in the region of Lisbon and South of Portugal on the fifth to seventh decades of XXth century. It was obtained by water spraying of the rendering surface during the hardening process, to remove the superficial binder and let the aggregates on sight.

This rendering is an important element of the built structure; therefore besides possessing a protective function, it possesses a decorative function of great relevance for the image of the building. Its maintenance implies the conservation of traditional constructive techniques and the use of compatible repair materials, as similar as possible to the original [1].

The render presented some degradation, at material and aesthetic level, demanding a conservation intervention. The peculiarity of the rendering technique and of the materials used, as well as the general good state of conservation presented, advised the accomplishment of a careful intervention based on conservation principles, with maximum preservation of the original. The conservation of the façade's rendering was considered very important, not only for the aesthetic reason, but also for its meaning for the history of materials and of construction technology.

Previous studies of the constituent materials, of the execution technique, and of the main anomalies were carried out by a team of researchers of LNEC. The repair products to be used were also tested in laboratory and detailed restoration specifications were prepared [2].

The anomalies observed on this rendering were: i) loss of cohesion, consisting in loss of mechanic resistance of mortar's layers due to loss or alteration of the binder among particles, provoking several defects, such as peeling, desegregation, and powdering; ii) loss of adhesion, consisting on the separation or detachment that can occur in different layers of a mortar or between mortars and the support, provoking defects such as detachments, cracks and lacunae (fig. 2). These problems were observed only on a few zones of the rendering, and were not considered very serious, however they should be treated. The treatment required the use of several products and distinct techniques of consolidation [3].

The consolidation of wall paintings and of stone surfaces has been the subject of some studies and several papers can be found about those matters [4, 5, 6 and 7]. However, the consolidation of lime based external renders is not yet well studied, and only a few scientific documents concerning the subject are known. These studies can be based on the larger experience collected on consolidation of stone and mural paintings.

In table 1 a stratigraphic description of the built structure is synthetically presented.

Table 1 - Description of the built structure [2]

Stratigraphy	**Composition**
Masonry	Brick, concrete structure
Protective Rendering	Cement Portland mortars with approximate thickness of 20 mm
Decorative Rendering	Air Lime mortars, with calcareous aggregate with approximate thickness of 8 mm.

The characteristics of old marmorite presented on table 2 show a rather compact material, with low rate of water absorption.

Table 2 - Composition and characterization of old *marmorite* [2]

Composition	Air lime and calcareous aggregate
Capillary coefficient by contact (0 to 5minutes) ($kg/m^2min^{1/2}$)	Cc5 = 0,48
Porous structure	Bimodal structure, with predominance of pores of radius about 0,5 µm,
Open porosity	12%

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Fig. 1 – General view of the main façade of LNEC.

Fig. 2 – Detail of a zone with detachment.

PRODUCTS AND TESTS

Products

Several consolidants have been used to restore cohesion and adhesion to old mortars. Nevertheless, some of them change renders' properties significantly originating new anomalies and functional problems for the buildings. Based on previous studies, the basic requirements of a consolidant for lime mortars are synthesized in table 3.

To restore the loss of cohesion, *limewater* was used as a consolidant, and to re-establish the adhesion between layers an *industrial grout* was used, based on hydraulic lime. The choice of hydraulic lime instead of air lime was due to the verified difficulty of carbonation of air lime between layers. Results obtained in previous studies justified this option [7, 8, 9 and 10].

LIMEWATER - This is the oldest consolidation treatment known; Vitruvio described this technique: *...executed with lime and a large quantity of clean water* [11]. Its effectiveness is contested by some authors, but it is used by several technicians and there are scientific studies evidencing good results [7]. The material is compatible with lime mortars, besides being an economic treatment. The technique consists of successive applications of a calcium hydroxide solution on the damaged rendering. The calcium hydroxide reacts with the carbon dioxide becoming calcium carbonate, which precipitates in the material's pores thus reducing the voids' volume [12].

GROUT – For 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 an adhesive of a very fluid lime paste into the void area of the detachment occurring between the render layers and the substrate [13]. The grout used was an industrial mortar, based on hydraulic lime with additions and fillers.

Table 3 - Basic requirements for consolidant lime mortars [3, 10 and 13].

Type of consolidant	Property	Requirements
Consolidant for lost cohesion	Penetration	Good penetration from surface to the interior
	Porosity	Not to modify the porosity of the mortars to be treated
	Behaviour to the water	Good capacity of moisture transference from the interior to the exterior
	Chemical and physical compatibility	Good chemical and physical compatibility with mortars to be treated
	Aesthetic aspect	Not to change the rendering colour to be treated
Consolidant for lost adhesion (grout mortars)	Capillary coefficient	Capillary 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	$\geq$ 0,1 Nm^2
	Shrinkage and dilatation	As small as possible (< 4%)
	Consistency	Fluid enough to inject
	Set time	Not over 48 hours

The products were previously studied in laboratory (tables 6). The results are in tables 5 and 6 [9, 10].

In situ and laboratorial tests

A test campaign for evaluation of the efficacy of the consolidation treatment was carried out through the tests presented in table 4.

Table 4 - Description of the consolidation tests

<table>
<tr><th>Type of consolidant</th><th>Laboratorial tests</th><th>In situ tests</th></tr>
<tr><td>Limewater</td><td>color measurement, water vapour permeability, water absorption by capillarity, penetration of consolidant and mechanical resistance.</td><td>color measurement, permeability to water under low pressure (Karsten tubes), control of salts and mechanical resistance.</td></tr>
<tr><td rowspan="2">Grout with hydraulic lime</td><td colspan="2">Laboratorial tests</td></tr>
<tr><td colspan="2">water absorption by capillarity, shrinkage and dilation, flexural and compressive resistance, modulus of elasticity, pull-off-strength.</td></tr>
</table>

Synthesis of the test results

The main test results, both laboratorial and in situ, are presented in tables 5 and 6 and illustrated in figs. 3 and 4.

Table 5 - Results of consolidation with limewater - in situ and laboratorial tests

In situ tests		**Results**			
		Ancient lime mortars (XVIII century)		**Wallet with lost cohesion**	
Color identification NCS, index 2	After consolidation	**S 1005 Y 50 R**		**S1000N**	
	Before consolidation	S 1005 Y 50 R		S1000N	
Half-quantitative determination of salts (Strip test)	After consolidation	**Negative for nitrate chloride and sulphate salts**			
	Before consolidation	Negative for nitrate chloride and sulphate salts			
Karsten tubes – water absorption under low pressure (cm^3) (RILEM – *Water absorption under low pressure. Pipe method*. Test Nº II.4)	After consolidation	0 min	0	0 min	0
		5 min	**3,63**	5 min	**3,10**
		10 min	**4,0**	10 min	**4,0**
	Before consolidation	0 min	0	0 min	0
		5 min	3,86	5 min	3,37
		10 min	4,0	10 min	4,0
Compression strength using Smitdt impact hammer (VH)	After consolidation	**33,6**		**43, 9**	
	Before consolidation	22,2		36,9	
Durometer hardness (Shore A)	After consolidation	**59,0**		**63.0**	
	Before consolidation	37,1		50,2	

Laboratorial tests	**Results**	
	New air lime based mortars with volumetric dosage 1:3	
	After consolidation	Before consolidation
Evaluation of consolidation deepness with phenolphthalein agent	**Penetration 4mm**	-
Colour identification NCS, index 2	**S 0500N**	S 0500N
Half-quantitative determination of salts (Strip test)	**Negative for nitrate chloride and sulphate salts**	
Capillary coefficient-0-10 min (Kg/m².min^{½}) (EN 1015 –18:2000). Cylindrical specimens	**1,13**	1,15
Permeability vapour diffusion (m) (Sd means) (EN 1015 –19:1998)	**0,07**	0,07
Flexural strength (N/mm²) (EN1015:11)	**0,34**	0,07
Compressive strength (N/mm²) (EN1015:11)	**0,84**	0,16

Table 6 - Results of consolidation with hydraulic lime based grout - laboratorial tests

Laboratorial tests	**Results**	
	Air lime mortars (volumetric dosage 1:3)	**Grout mortars**
Capillary coefficient (0 - 5min) (kg/m^{2}min$^{1/2}$) (EN 1015 –18:2000)	2,09	**3,15**
Flexural strength (N/mm²) (EN1015:11)	0,24	**1,69**
Compressive strength (N/mm²) (EN1015:11)	0,62	**3,71**
Elastic modulus (MPa) (NF – B10-511)	2715	**4451**
Pull-off-strength (N/mm2) (EN-1015-12:2000)	0,03 (cohesive rupture) Zone without grout	**0, 04** (rupture within the *grout)*. Zone with grout
Set time	Not determinated	36 hour
Shrinkage	Not determinated	1,3%

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Fig. 3 – Test with Shmitdt impact hammer on ancient lime mortar

Fig. 4 – Pull-off test in laboratory

In figure 5 capillarity coefficients are presented; in figure 6 water absorption of the studied specimens and of pre-existent render of "marmorite" is presented.

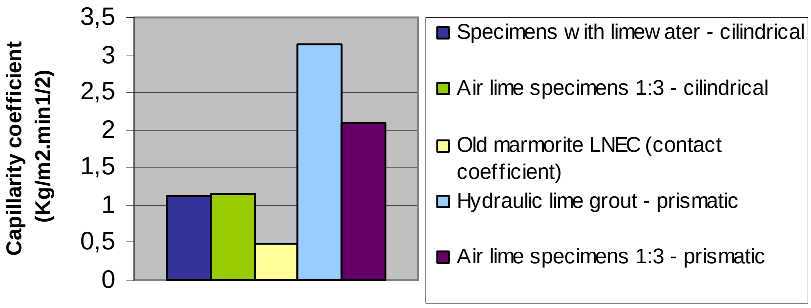

Fig. 5 – Capillarity coefficient

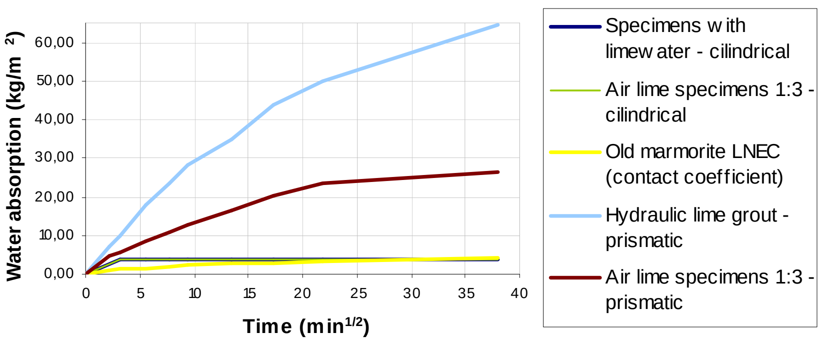

Fig. 6 – Water absorption

APPLICATION IN THE BUILDING

Application of limewater - The product was applied on the rendering, using the spray technique with a manual spray, from a distance of 50 cm, in the end of the day, at 25ºC T and 55% HR. The application was interrupted when it was verified that the rendering was completely damp. This saturation effects happened approximately after 15 applications (fig.7).

Application of the hydraulic lime grout – Previously the zone of detachment was humidified with a mixture of water and alcohol, to favour the grout penetration. The product was then applied, with a manual syringe, being the first layers slightly more fluid than the following layers, to allow a better penetration, until filling the emptiness (fig.8).

Fig. 7 – Lime water application in building

Fig. 8 - Grout application in building.

DISCUSSION AND ANALYSIS OF THE TEST RESULTS

For consolidation of loss of cohesion – using limewater

Evaluation of the aesthetic aspect and half-quantitative determination of salts: the colour of the render consolidated with lime water did not change. As verified with *Strip tests,* the treated render does not contain soluble salts (table 5).

Evaluation of the mechanical resistence *in situ* and in laboratory: the results obtained at *in situ* tests with Shmitdt impact hammer, and durometer, and at laboratory test (flexural and compressive strength) demonstrated an increase of resistance on the mortars superficial layers after treatment (table 5).

Evaluation of the behaviour to water: the tests on ancient mortars (XVIII century) with the Karsten tubes showed that they are extremely permeable to water. The obtained results in terms of laboratorial capillarity tests, show that de capillarity coefficient is similar in specimens without consolidant and with limewater as a consolidant and higher than “marmorite” sample. Concerning water vapour permeability the specimens with consolidant do not present a barrier to water vapour diffusion (table 5).

Evaluation of the consolidant penetration: the evaluation of the depth of the consolidant demonstrated that limewater penetrates only in the mortar superficial layers, so its use is recommended only for mortars with superficial loss of cohesion (table 5).

For consolidation of loss of adhesion – using hydraulic lime grout

Evaluation of the consistency and set-time: the grout tested showed to be easily injectable, with good fluidity. The set time initiated at 36 hours, which is according to the established parameters (tables 3 and 6).

Evaluation of the shrinkage: the grout demonstrates low shrinkage which is according to the established parameters (tables 3 and 6).

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Evaluation of the behaviour to water: the grout presents good water behaviour, showing a higher coefficient of capillarity than the substrate used in tests (air lime mortar 1:3) and than marmorite sample, however within the acceptable parameters (tables 3 and 6).

Evaluation of the mechanical resistence: the Flexural and Compressive tests proved that the grout presents an increase of strength and a higher modulus of elasticity than the lime mortar used as a substrate; however the values are moderate (table 3 and table 6). The pull-off test showed that the grout has resistance similar to the substrate (zone without grout, table 6). The rupture occurred in the grout mortar (fig 3), meaning that the grout's tensile stress is lower than the adhesive strength between mortar and substrate. The observation of the rupture surface of the pull-off test showed that the grout filled uniformly the hole provoked in the Specimen developed for the effect (fig 4).

FINAL CONSIDERATIONS

The study verified the viability and effectiveness of limewater, as a consolidant of lime mortars with loss of cohesion in LNEC's façade. This consolidant increases, in superficial layers, the mechanical resistance. It was important to verify that consolidant did not introduce any changes in water permeability, as well as any salts that did not exist previously, in the rendering

Due to the extreme chemical compatibility of the limewater with the treated rendering, and to the fact that rendering of the main façade of LNEC did not present very serious problems (peeling, desegregation, pulverulence) of cohesion, this consolidant was chosen, to restore the lost cohesion.

With the set of tests carried out it was verified that the hydraulic lime based grout fulfil the basic requirements for a grout, being possible its use for the restitution of adherence in old lime renderings well carbonated and resistant, as was the case of LNEC's marmorite.

Consolidation technique is a rather complex method of restoration, because of the different materials that can be used with this purpose and the theoretical questions concerning the use of reversible materials. In fact, the consolidation method is always irreversible. The success of a good consolidation treatment depends not only on the chosen product, but also on the application, and the intrinsic characteristics of the conservation state of the material to treat, as well as on the ability and good sense of the restorer.

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