Specification and time required for the application of a lime-based render inside historic buildings

Especificação e tempo de aplicação de um reboco tradicional à base de cal no interior de edifícios históricos

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Abstract
Intervention in ancient buildings with historical and architectural value requires traditional techniques, such as the use of lime mortars for internal and external wall renderings. In order to ensure the desired performance, these rendering mortars must be rigorously specified and quality controls have to be performed during application. The choice of mortar composition should take account of factors such as compatibility with the substrate, mechanical requirements and water behaviour. The construction schedule, which used to be considered a second order variable, nowadays plays a decisive role in the selection of the rendering technique, given its effects upon costs. How should lime-based mortars be specified? How much time is required for the application and curing of a lime-based render? This paper reflects upon the feasibility of using traditional lime mortars in three-layer renders inside churches and monasteries under adverse hygrothermal conditions and when time is critical. A case study is presented in which internal lime mortar renderings were applied in a church in Northern Portugal, where the very high relative humidity meant that several months were necessary before the drying process was complete.

Keywords
Lime mortars; historic buildings; performance assessment; construction schedule.

Resumo
A intervenção em edifícios com valor histórico e arquitectónico exige a utilização de técnicas tradicionais, tal como a aplicação de argamassas à base de cal para o revestimento exterior e interior de paredes.
De modo a assegurar-se um desempenho adequado destas argamassas de reboco é fundamental a sua especificação exigencial e o controlo de qualidade durante a execução. A selecção da composição das argamassas deverá ter em atenção, nomeadamente: a compatibilidade com o suporte, as exigências mecânicas e o comportamento face à água. Por outro lado, o tempo de execução, que no passado era uma variável de segunda ordem, é hoje um factor de decisão importante para a selecção da solução de reboco a adoptar, dado o seu impacto no custo dos trabalhos. Duas grandes questões se colocam. Como se especifica um reboco à base de cal? Qual o tempo necessário para a sua aplicação e secagem? Neste artigo pretende-se reflectir sobre a viabilidade de utilização das argamassas tradicionais à base de cal para a realização de rebocos em três camadas, no interior de igrejas e mosteiros, em condições higrotérmicas adversas, quando o tempo de execução é um factor de decisão. É apresentado um estudo de caso referente à aplicação de rebocos interiores à base de cal numa igreja do Norte de Portugal em que, devido à elevada humidade relativa interior, foram necessários vários meses para a sua secagem.

Palavras-chave
Argamassas de cal; edifícios históricos; avaliação de desempenho; calendarização.

Introduction

In historic buildings with thick stone walls, such as churches and monasteries, the use of lime mortars is recommended for inner wall renderings. This enables the materials and technologies used in the past to be preserved, while, at the same time, allowing water vapour to diffuse through the walls.

The rehabilitation project should clearly specify the characteristics of the internal rendering and desired performance. For this reason, specifications should be formulated as requirements rather than prescriptions. Quality control during the works process is also crucial, and the assessment procedures and tests to be carried out should be stipulated.

It is also important for planning and cost control to calculate how long each job will take, particularly those that affect other tasks, such as renderings. Hygrothermal conditions inside churches and monasteries are often far from ideal and may therefore have a considerable influence upon the time required for the curing and drying of lime mortars.

Hence, answers are required for the following questions, with regard to the application of traditional lime-based rendering mortars inside historical buildings:

1. How should lime-based mortars be specified?
2. How much time is required for the application and curing of a lime-based render?
3. To what extent is this influenced by interior hygrothermal conditions?

This paper reflects upon the feasibility of using traditional lime mortars, in three-layer renders, inside historic buildings.

Requirements for traditional mortars

The choice of mortar composition has to take account of factors such as compatibility with the substrate and surrounding surfaces, mechanical requirements, and water behaviour, and may include air lime, hydraulic lime, pozzolans or other additives, and different types of aggregates. Commercial pre-dosed lime mortars may also be considered.

Table 1 Characteristics of various mortars for wall protection.

Mortar	Capillarity kg/(m².s^{½})	*Sd* m	*E* MPa	*Rt* MPa	*Rc* MPa	Conductivity µS/cm	Ca^{++} mg/l
ca:3	0.37	0.089	2300	0.33	0.65	30	9
cA:3	0.35	-	1490	0.12	0.50	26	12
ch:4	0.34	-	1350	0.14	0.44	23	9
cL:3fl	0.22	-	7260	1.45	4.45	30	12
cL:3	0.21	-	9040	1.63	5.82	55	17
ci:4	0.19	-	9770	1.67	6.49	60	14
ch:ca	0.33	-	1530	0.13	0.39	21	10
ci:ca1	0.25	-	7340	1.23	4.08	45	9
ci:ca2	0.35	-	4180	0.55	1.58	39	10
ci:ca3	0.38	-	2600	0.32	0.77	30	10
ca:esc	0.27	-	2490	0.41	2.55	21	9
ca:pt1	0.28	-	2600	0.36	1.04	23	9
ca:pt0.5	0.29	0.098	2210	0.18	0.55	41	8
cocciop	0.34	0.095	2730	0.71	1.20	91	20
cocciopA	0.35	0.071	1020	0.20	0.43	41	22
intonA	0.24	0.091	1790	0.36	0.89	58	16
medol	0.56	0.094	1450	0.33	0.59	90	21

In the project phase, the materials specification should be formulated as a requirement, rather than a prescription. For this reason, it is essential to define the performance of the mortars, such as:

- Tensile strength – *Rt* (MPa);
- Dynamic elasticity modulus – *E* (MPa);
- Water vapour diffusion - *Sd* (m);
- Water absorption coefficient / capillarity (kg/(m².h^{½}));
- Salt resistance (%);
- Etc.

Table 1 shows the characteristics of various types of mortars for wall protection in accordance with studies carried out by Paulina Rodrigues [1].

For planning purposes, it is of the utmost importance that the specifications stipulate the requirements to be fulfilled, based upon a predefined quality profile, as is illustrated in Figure 1.

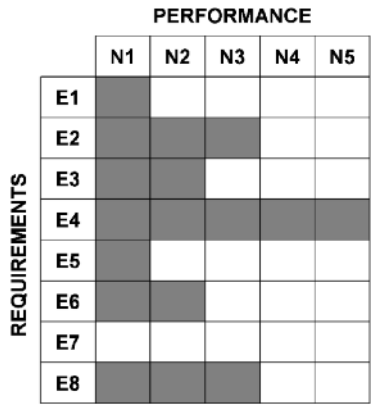

Fig. 1 Structure of a hypothetical requirements manual specifying mortars to be used in interior wall renderings.

Unfortunately, there is no simple methodology for selecting traditional mortars, nor is there the precise knowledge of the characteristics of this type of product. Hence, it is important to perform tests and experiments before or during the works process.

The disadvantages of this are:

1. The planning and cost of tests and experiments;
2. The problem of liability and the need for guarantees and insurance in case pathologies occur.

Given the specific nature of traditional three-layer lime-based renders, it is advisable to carry out a series of tests, both in the laboratory and "in situ", in order to ensure quality control. The values obtained should then be compared with the reference values given in the specifications. For example, Figure 2 shows the determination of adhesive strength of lime-based renders to stone masonry wall, and Table 2, the results obtained in these types of tests.

It is important to preserve the traditional materials and technologies in historic buildings, which means that studies have to be performed on a case-by-case basis. However, this is not always justified, or easy, as regards the rehabilitation of the current constructed heritage.

In short, those involved in the construction process need to be aware that rigorous selection of traditional mortars is not possible, and that all measures should therefore be taken to control the materials applied and ensure their durability.

Table 2 Example of results from adhesive strength tests.

Location	Sample	Force N	Area mm²	Adhesive strength MPa
A	2-S	320	≅ 3417	0.09
	4	400	≅ 1759	0.20
B	3	120	≅ 1564	0.08
	4	170	≅ 1610	0.11
	5	170	≅ 1500	0.11
C	1	120	≅ 1612	0.07
	3	180	≅ 1475	0.12
	4	190	≅ 1685	0.11
D	1	730	≅ 1771	0.41
	2	570	≅ 1656	0.34
	3	390	≅ 1759	0.22

How much time is required for the application of a lime render inside a historic building?

Time used to be considered a second order variable. However, nowadays, the construction schedule plays an important role in the selection of the rendering technique.

In Northern Portugal, adverse hygrothermal conditions can sometimes make it difficult to use traditional lime mortars in three-layer renders inside churches and monasteries. Measurements taken by the Laboratory of Buildings Physics at the Faculty of Engineering, University of Porto, show that relative interior humidity is normally

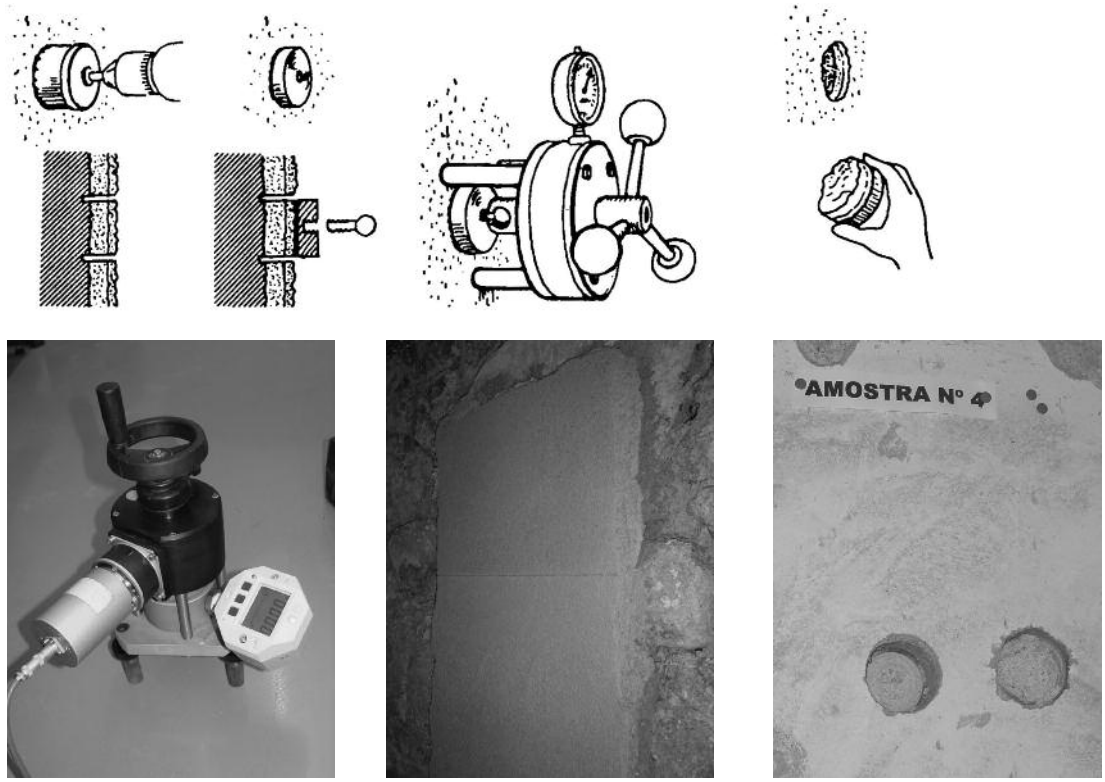

Fig. 2 Adhesive strength test apparatus and samples.

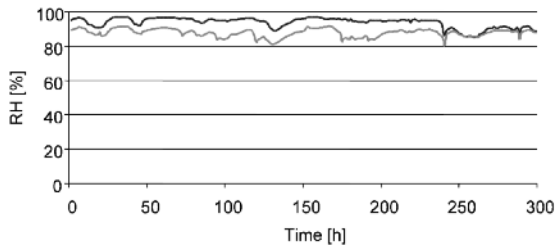

Fig. 3 Relative humidity inside a church in Northern Portugal.

very high for most of the year (Figure 3). On the other hand, the indoor temperature tends to be stable, at around 8 to 15° C [2].

In order to objectively assess the time necessary to apply a lime-based mortar inside a church, four samples were prepared in the northern wall of the transept, with the compositions indicated in Table 3, after removing the previous cement based render and cleaning of the substrate.

Table 3 Traces, in apparent volume, of the compositions of the mortar samples.

Sample	Layer	Air lime	Hydraulic lime	Sand
1	First	5	2	12.5
	Second	5	-	12.5
	Third	4	-	12.5
2	First	5	2	12.5
	Second	3	2	12.5
	Third	3	1	12.5
3	First	-	5	12.5
	Second	3	2	12.5
	Third	4	-	12.5
4	First	4	1	12
	Second	4	1	14
	Third	4	1	16
	Fourth	4	1	12

Fig. 4 Drying of a lime-base rendering inside a church in Northern Portugal (September 2004 and January 2005).

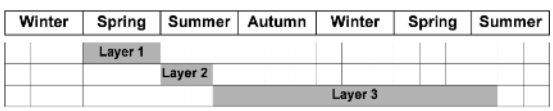

Fig. 5 Diagram showing the minimum time needed for the application of a lime mortar rendering inside a church in Northern Portugal.

The samples were prepared in such a way as to enable the different layers of the mortar rendering to be analysed. They were concluded at the end of March 2004.

It was only possible to undertake adhesive strength tests on the samples seven weeks after the last rendering layer had been applied, as curing had not yet taken place. Moreover, adhesive strength scores could only be obtained for Samples 2 and 4, which showed greater hardening [3].

Hygrothermal and drying conditions affect rendering performance

The drying time depends upon the vapour pressure gradient between the rendering surface and the air, and on the air-surface vapour transfer coefficient (β), which is currently considered to have a value of 2×10^{-8} s/m [4]. The drying flow (F) may be calculated using the following formula:

$F = \beta (C_s - C_{ar})$

in which

F – Drying flow (kg/m².s)

β – Air-surface vapour transfer coefficient (s/m)

C – Vapour concentration (kg/m³)

As the relative humidity is very high inside churches and monasteries (near 100 %) and the wall temperature is near the inner temperature, the vapour concentration gradient and the drying flow tend to zero. In these circumstances, it may take a long time for the lime mortar to dry (Figure 4), with consequences for the curing process and planning of the works.

In addition, surface condensation often occurs, given the strong thermal inertia in this type of building, which also affects the application of these lime-based renders.

The diagram in Figure 5 shows the minimum time necessary for the application of a lime mortar rendering inside a church in Northern Portugal.

Conclusions

The main conclusions that we can draw from this study are as follows:

1. In historic buildings, the traditional materials and technologies must be preserved;

2. Lime renderings facilitate vapour diffusion in walls;

3. The specifications, as regards materials, should be presented in the form of requirements, rather than prescriptions;

4. As we do not fully understand how traditional lime mortars perform, it is advisable to carry out a series of tests and experiments during the course of the work;

5. The quality control procedures should be made explicit in the specifications;

6. The hygrothermal conditions inside churches and

monasteries are not conducive to the curing and drying of renderings;

7. Many months are required to plan the application of lime renderings.

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