International Journal for Restoration
Internationale Zeitschrift für Bauinstandsetzen
Vol. 10, No 6, 609–622 (2004)

Current Mortars in Conservation: An Overview

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Abstract

Renders are an important item in historical buildings and the need for their periodical re-application is a basic conservation procedure. In modern times there has been a trend towards the replacement of traditional pure lime mortars by new formulations including Portland cement or hydraulic lime. Apart from those interventions on specific and very important monuments, in which the use of traditional non-hydraulic mortars can be enforced, in most of the projects involving less than first order magnitude heritage the use of some sort of hydraulic components is becoming the rule rather than the exception.

The present paper describes and analyses the results of an experimental study with ten formulations of current mortars - including some that can hardly be considered as adequate conservation procedures - allowing a direct comparison in terms of some of the most relevant characteristics.

Keywords: lime mortars, conservation, replacement mortars, pozzolanic additives

Heute beim Konservieren verwendete Mörtel: Eine Übersicht

Zusammenfassung

Putze sind ein wichtiger Bestandteil historischer Gebäude und die Notwendigkeit für deren regelmäßiges Ersetzen wird als eine grundlegende Restaurierungsmaßnahme angesehen. In der heutigen Zeit ist ein Trend festzustellen, traditionelle reine Kalkmörtel durch Mörtel zu ersetzen, die unter Verwendung von Portland Zement oder hydraulischem Zement hergestellt werden. Einmal abgesehen von Instandsetzungsmaßnahmen an besonderen und sehr bedeutenden Baudenkmalen, bei denen die Verwendung von traditionellen nicht hydraulischen Mörteln verpflichtend vorgeschrieben werden kann, ist die Verwendung von Mörteln mit irgend welchen hydraulischen Komponenten bei weniger wichtig eingestuften Gebäuden heute eher die Regel als die Ausnahme.

In dem vorliegenden Beitrag wird die Auswertung der Ergebnisse einer experimentellen Studie von zehn unterschiedlich zusammengesetzten heute verwendeten Mörteln beschrieben. Darunter befanden sich auch einige, die kaum als für das Konservieren passend eingestuft werden können. Die Ergebnisse erlauben einen direkten Vergleich der wichtigsten Werkstoffeigenschaften.

Stichwörter: *Kalkmörtel, Konservieren, Ersatzmörtel, Puzzolanische Zusätze.*

1 Introduction

The aim of this paper is to present a comparative evaluation of ten formulations of replacement mortars used frequently in old buildings. In spite of their regular use, some of them are clearly not appropriate for that purpose [1], but are included in this study to allow a comparative evaluation.

Most of the formulations are well known and have been previously tested, the results having been published by several research teams. But the results obtained cannot be compared, since the experimental procedures and some of the materials vary considerably. It is known that even in the same laboratory and using the same materials the results of tests conducted with different test specifications will be different [2,3]. Hence the reason for the elaboration of the present paper, in which comparable results are presented, allowing the evaluation of their relative performance.

For this study the lime:sand mortar is used as reference since it is the suitable mortar for conservation of old buildings while the other extreme is provided by the cement:sand mortar. In between, several different mixtures of those two types of binders are considered, along with other types of limes or the addition of brick dust. Several other formulations could be envisaged, but with the ten considered, a sufficiently large frame is offered, allowing some relevant conclusions to be obtained [4].

2 Experimental

2.1 Preparation of the Samples

Ten compositions of mortars were prepared, all of them using the same type of river sand. Five different types of binders were chosen, used either alone or in combination with others. Apart from current hydrated and hydraulic limes and Portland cement available at the Portuguese market, two limes available in the international market were also tested, namely Lafarge and Albaria "Albazzana" limes (both identified as hydraulic, although the latter may be considered as essentially a hydrated lime since its hydraulicity was very slight). Brick dust was also used in some formulations, since it may be considered a traditional component, already mentioned by Vitruvius.

The mortar components of the various formulations were mixed mechanically and always in the same way. The samples were mechanically compacted into the 4x4x16 cm^3 moulds in two layers. The ten compositions studied were all 1:3 (binder:sand) per volume except for the Portland cement one where the ratio was 1:4. They are described in Table 1 and their flow is also included.

For each type of mortar six 4x4x16 cm^3 samples were prepared, cured in a dry environment (20°C and 50% RH) until the tests were conducted. Three of them

Table 1: Sample compositions (by volume) and flows. Where: L = hydrated lime; P = Portland cement; B = brick dust; HL = hydraulic lime; Alb = Albaria lime; Laf = Lafarge lime (brick dust was added as an aggregate).

	Hydrat. lime	Hydraul. Lime	Portland cement	Albaria lime	Lafarge lime	Brick dust	River sand	Flow (%)
L	1						3	74
L+P 50%	1		1				6	67
L+P 33%	2		1				9	67
L+P 25%	3		1				12	71
L+B	1					1	2	68
L+B 0.5	1					0.5	2.5	68
L+HL	1	1					6	73
Alb				1			3	82
Laf					1		3	75
P			1				4	71

were used for mechanical testing as well as for the determination of density, open porosity and release of soluble salts. The other three samples, cut in half, were used for the determination of capillarity water absorption, resistance to chlorides and resistance to sulphates.

2.2 Testing Program

For the purpose of the experimental campaign nine different tests were considered, covering some of the most important characteristics to be evaluated, namely the following:

- bulk density
- open porosity
- compressive resistance
- flexural resistance
- dynamic modulus of elasticity
- capillarity water absorption
- resistance to chlorides

- resistance to sulphates
- release of salts

These tests are briefly described on the following paragraphs. All of them where performed using test specifications developed within the research team - the Fe ## UNL/DEC test specifications [5] - mostly based on current international test procedures collected from different sources. Apart from the evaluation of the resistance to chlorides, a procedure developed by the research team, all the others do not vary significantly from the test methods used for conservation in Europe.

2.2.1 Bulk Density and Open Porosity

These tests were performed following the Fe 01 and Fe 02 UNL/DEC procedures, based on standard procedures by total saturation with water under vacuum.

2.2.2 Mechanical Resistance

Compressive and flexural strength were determined according to Fe 27 UNL/DEC procedure, based on the classic method of performing the compressive test with the half samples obtained from the flexural test. The dynamic moduli of elasticity was determined according to Fe 08 UNL/DEC procedure, based on the determination of the longitudinal resonance frequency with an adequate apparatus.

2.2.3 Capillarity Water Absorption

The tests were conducted according to the Fe 06 UNL/DEC procedure, by placing the half samples in 2 mm of water (over absorbent paper) inside a covered box so as to maintain constant conditions and to limit the amounts of water evaporating from the samples. The tests were conducted until the absorption reached an asymptotic value.

2.2.4 Resistance to Chlorides

The resistance to chlorides was measured following the Fe 12 UNL/DEC procedure. The samples were dried to constant mass and then immersed in a sodium chloride saturated solution for 24 hours, after which they were dried again until constant mass. This enabled the determination of the amount of retained salt. The samples were then placed in a climatic chamber where they were exposed to repeated cycles consisting of 12 hours at 90 % RH and 12 hours at 40 % RH. Every 7 days the samples were weighed to determine mass loss.

2.2.5 Resistance to Sulphates

The determination of the resistance to sulphates was carried out after the Fe 11 UNL/DEC procedure. A saturated solution of sodium sulphate was used for this test, which is based on the evaluation of the mass loss of the samples during a sequence of cycles of 2 hours of immersion in the solution and 22 hours of drying in an oven at 105°C.

2.2.6 Conductivity

The aim of this test (Fe 10 UNL/DEC) is to evaluate the increase of conductivity of the solutions prepared from the samples with distilled water to evaluate the amount of soluble salts that the mortar can release.

3 Results

The samples were tested after 60 days. The results obtained from the various tests, such as density, open porosity, capillarity and mechanical characteristics are presented in Table 2, while those referring to the release of soluble salts and resistance to the action of salts (chlorides and sulphates) are included in Table 3. In the case of chlorides the table also includes the percentage in weight of retained salt and the losses of mass are presented after 30 and 50 cycles (see 2.2.4). As for the sulphates, and since for the purpose of this test only five cycles were considered, the losses of mass suffered by the several formulations after 2, 3, 4 and 5 cycles are enclosed in the table.

Table 2: Data from the physical and mechanical tests of the various mortar formulations

	Density Kg/m^3	Open porosity %	Capillarity coefficient kg/m^2.s$^{1/2}$	Asympt. Absorpt. kg/m^2	Compress. strength MPa	Flexural strength MPa	Moduli elasticity MPa
L	1730	34	0.32	17.9	0.65	0.35	2300
L+P 50%	1840	30	0.26	20.9	4.08	1.23	7340
L+P 33%	1800	31	0.35	21.4	1.58	0.55	4190
L+P 25%	1790	33	0.39	22.2	0.77	0.32	2610
L+B	1630	39	0.26	23.0	1.04	0.36	2600
L+B 0.5	1680	36	0.28	20.5	0.55	0.18	2210
L+HL	1800	31	0.33	20.1	0.40	0.13	1530
Alb	1800	32	0.39	17.5	0.50	0.12	5720
Laf	1910	28	0.22	18.2	5.82	1.63	9050
P	1910	28	0.20	18.6	6.49	1.67	9770

Table 3: Release of soluble salts and salt resistance of the different mortar formulations

	Conduct (μS/cm)	Resistance to chlorides mass changes (%)			Resistance to sulphates mass changes (%)			
		Ret.Cl$^-$ (%)	30 cycles	50 cycles	Cycle 2	Cycle 3	Cycle 4	Cycle 5
L	31	4.3	-8	-30	+5	-20	-89	-100
L+P 50%	41	4.0	+2	-2	-5	-97	-100	-
L+P 33%	47	4.2	-2	-7	-56	-100	-	-
L+P 25%	32	4.3	-10	-16	-81	-100	-	-
L+B	25	5.6	+3	+3	-34	-99	-100	-
L+B 0.5	44	4.8	0	-3	-14	-99	-100	-
L+HL	23	4.3	-26	-44	-20	-71	-100	-
Alb	28	3.6	-5	-11	-9	-57	-91	-100
Laf	57	3.5	+5	+4	+3	-12	-14	-24
P	62	3.6	+5	+4	+3	0	-1	-23

4 Discussion

The ten formulations of mortars considered vary considerably in the type of binders used, ranging from pure lime to pure cement mortars and including some mixed compositions in between. With the exception of the pure cement mortar, in which a relation of 1 to 4 binder:sand was used, all the other formulations follow the standard 1 to 3 ratio. In the case of lime mortars with brick dust, this was considered as part of the aggregate (thus the ratio still is 1:3), although some hydraulic effect appears to have taken place [6], as discussed later.

The analysis of these ten formulations can be attempted variously. The one that will be followed ranges the mortars in four groups according to evident similarities. These groups are:

- group 1: pure hydrated lime mortars (L and Alb)
- group 2: hydraulic lime and pure cement mortars (Laf and P)
- group 3: hydrated lime plus cement/hydraulic lime mortars (L+P 50%; 33%; 25% and L+HL)
- group 4: hydrated lime and brick dust mortars (L+B and L+B 0.5)

The pure hydrated lime mortars (group 1) present similar performance in most of the tests carried out, although the Albaria "Albazzana" lime is sold as hydraulic by the manufacturer. The main difference appears to be related with the internal structure of the mortar, probably induced by the difference in particle size of the powdered limes. The Albaria mortar shows a lower open porosity - hence a higher compactness - which may explain the higher dynamic modulus of elasticity. The better performance of this mortar in the resistance to chlorides may reflect the fact that less chlorides were retained in this mortar. However, this mortar released slightly less soluble salts than the pure lime one (L).

The performance of the group 2 mortars (hydraulic Lafarge lime and pure cement) is remarkably similar, except for the resistance to sulphates, where the cement mortars (P) have a slightly better behaviour in the first cycles. It is important to note that the results obtained with this mortar after the 5^{th} cycle is somewhat deceptive, since it may lead to the conclusion that the performance is good. In general what happens is that the cement mortars present a good behaviour in the first cycles (where most other mortars begin to deteriorate) and suddenly collapse (typically after the 5^{th} or 6^{th} cycle). Also the resistance to chlorides is increased reflecting their higher mechanical resistance. These two mortars released the highest amount of soluble salts as evaluated by conductance measurements.

The hydrated lime plus cement or hydraulic lime mortars (group 3) clearly emphasize the role that cement plays in a mixed binder mortar. The formulations L+P 50% to 25% correspond to a decrease in the amount of cement (and an increase in the amount of hydrated lime, since the binder:aggregate proportion is kept at 1 to 3), from the initial 50% of the total binder, down to 33% and to 25%. Mortar L+HL is also of a mixed binder type, but with hydraulic lime (50% of the total binder volume) rather than cement.

Analysing the three formulations with cement it is clear that the decrease of cement induces a decrease in density and a corresponding increase in open porosity as reflected in the increased asymptotic value of water absorption and the amount of chlorides retained. The respective mechanical resistances are also proportional to the cement content of the mortar and the resistance to chlorides and sulphates follows the same trend.

The physical characteristics of the (L+HL) seem similar to those of (L+P 33%) although as far as the mechanical properties are concerned the values achieved are very low—even lower than for pure hydrated lime mortars (L and Alb). This fact may explain the low resistance to both chlorides and sulphates. However, this formulation was the one that released less soluble salts.

The two mortars of hydrated lime with brick dust (group 4) present lower densities and higher open porosities than the pure lime ones. Furthermore, the changes are proportional to the amount of brick dust added. Since the brick dust was added as part of the aggregate it follows that the densities will be lower. The open porosity, the asymptotic value of water absorption and the retained amount of chlorides is higher for the mortar with more brick dust. This mortar also shows a slightly lower capillary absorption coefficient than that formulated with less brick dust (L+B 0.5).

The mechanical resistance of these mortars clearly reflect the presence of the brick dust, since they decrease in proportion to the amounts used of brick dust added but also in particular when compared with the pure lime mortar L. It is to be noted that although the amount of chlorides retained by the (L+B) mortar is significantly higher than that with less brick dust, the former is more resistant to crystallization of this salt. However, the resistance to sulphates is similar for both these mortars and less than for the pure lime mortar. Finally, it is interesting to note that the mortar with less brick dust released more soluble salts.

The analysis carried out previously, by dividing the ten formulations in four groups according to their similarities, allowed the enhancement of the relative behaviour of those formulations within each group. However, a further step is required, since the final purpose of this analysis is a global comparison of all the mortars considered, within the general framework of their use in conservation of old buildings. For this purpose, the analysis should not be done by the types of tests carried out, but rather taking into account the purpose of the mortars and the characteristics that should be required in a satisfactory appliances.

When dealing with mortars for old buildings, four main issues should be considered:

1) Absorption and evaporation of water (this last issue was not included in this study; it is currently analysed by the determination of either the water vapour permeability or the drying index).
2) Mechanical resistances (including adhesion, that was not considered in this study)
3) Resistance to soluble salts.
4) Amount of released soluble salts.

These four issues should be considered in two different ways:

a) Characteristics needed to protect the walls in which the mortar is applied (i.e., avoiding degradation processes):
   - absorption and evaporation of water
   - mechanical resistances
   - release of soluble salts
b) Characteristics needed to prevent the degradation of the mortar (i.e., increasing durability):
   - resistance to soluble salts
   - evaporation of water
   - mechanical resistance

The relative performance of the ten mortar formulations analysed in this study should be conducted in accordance with the previous general concepts.

a) Characteristics needed to protect the walls

Pure lime mortars have high capillarity coefficients indicating that they have larger pores than the cement mortars. However, they have lower asymptotic values although their open porosity is higher than for the cement mortars, reflecting the presence of fine capillaries. These however, will not tend to absorb moisture as reflected by the lower asymptotic value. Cement mortars appear to have a more homogeneous pore size distribution, similar asymptotic values to those of lime mortars and lower open porosities, as well as a slower capillary absorption rate. Thus, from this point of view it could be considered that pure cement or hydraulic lime mortars could perform better than lime mortars (although it should be noted that in general the cement mortars will have a far lower water vapour permeability, a parameter that was not measured in this study).

The analysis of the mechanical characteristics should be carried out from the point of view of the compatibility with old walls, which are characterized by having low resistances and high levels of deformability. Therefore, from this point of view there is no interest on having very high resistances and, particularly moduli of elasticity. From the results obtained the resistances of the cement and the hydraulic lime mortars seem clearly excessive, with very high moduli of elasticity. This conclusion also applies to some of the mixed cement plus lime mortars (with the exception of types L+P 25% and L+HL). When analysing the release of salts it is clear that those mortars in which cement is used in higher amounts (P, L+P 50%, L+P 33%) and the one with pure hydraulic lime (Laf) show high conductivities, from which a high release of soluble salts may be assumed.

From the previous analysis it can be summarised that pure hydrated lime mortars (L, Alb), some mixed binder mortars (L+P 25% and L+HL) and lime with brick dust mortars (L+B and L+B 0.5) are those complying better with the purpose of protecting the walls on which they may be applied, however taking into account that the latter mortar (L+B 0.5) releases a slightly higher amount of soluble salts.

b) Characteristics needed to prevent the degradation of the mortar

Within this context, the mechanical resistance should be analysed in a different way from the one expressed previously. In fact, if the mortar is to be durable it should have enough mechanical resistance to withstand the aggressions it will inevitably face. This means that the compressive and particularly the flexural strengths should not be too low. Furthermore, they should be achieved in a reasonable amount of time. This is one of the reasons that justify the use of mixed binder mortars, such as type L+P 25%. From this point of view it should be emphasized the good performance of mortars with brick dust, as type (L+B), while most of the mortars that seemed more promising in the previous analysis show low resistance values. The resistance to the action of salts was carried out with respect to sodium chloride and to sodium sulphate crystallization. For the former, the best performance was achieved by cement mortars, such as Laf and P, and for the mortar with brick dust (L+B). The reason for the higher resistance could be attributed in the first two cases to the high mechanical strength, but this is not the case for the latter mortar where this resistances could be attributed to the presence of clays that could bind chlorides by forming the complex Friedel salt. It is important to notice that this trend is also followed by the mortar with less brick dust (L+B 0.5).

As far as the sulphates are concerned, the best performance was also shown for the cement mortars (Laf and P) and again attributed to their high mechanical resistance. However, lime mortars additioned with cement (L+P in all proportions) showed poorer behaviour than the pure lime mortar (L). In this case, although mechanical resistance was increased with respect to the lime mortar, the resistance to sulphate crystallization was poorer. This could be interpreted by the fact that the formation of ettringite in these mortars increased the stress induced by the crystallization test.

From the previous point of view, the best performance was achieved by mortars with high mechanical resistances, namely types Laf and P. It should be noted, however, that in general cement mortars present a good behaviour in the first cycles (where most other mortars begin to deteriorate) and suddenly collapse (typically after the 5^{th} or 6^{th} cycle).

c) Global analysis

After analysing the ten mortars with regards to the two established categories, a global analysis should be done. Considering that the final goal of the use of replacement mortars is the conservation of the walls in which they are applied, the analysis mentioned in a) should overlap with the one in paragraph b). Therefore it seems clear that the best performance was achieved by the pure lime mortars (L and Alb) for walls in which the presence of sulphates can be envisaged and lime plus brick dust (L+B) for those cases with a high concentration of chlorides.

5 Conclusions

The ten mortars tested have been analysed in four groups allowing a better comparison of the relative behaviour of the formulations between groups.

Considering that the final goal of the use of replacement mortars is the conservation of the walls to which they are applied (rather than concerns about the degradation of the mortar), the best performance was achieved by the pure lime mortars for walls in which the presence of sulphates can be envisaged, and by lime mortars with brick dust for those cases where a high concentration of chlorides is present.

Acknowledgements

The authors would like to thank Patrícia Carvalho e Nuno Dias for their collaboration in the experimental work.

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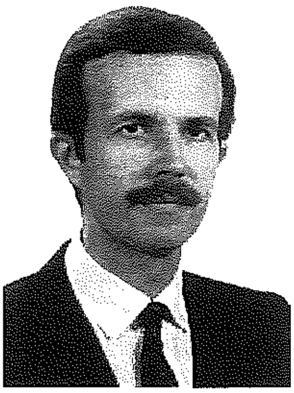

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Received July 24, 2004