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Editorial

Este número da revista, tal como o anterior, é dedicado à publicação de artigos que resultaram de comunicações apresentadas na conferência internacional intitulada *HMC08 – Historical Mortars Conference*, que decorreu em Lisboa, no Laboratório Nacional de Engenharia Civil (LNEC), entre 24 e 26 de Setembro de 2008.

Esta conferência foi uma iniciativa que resultou da conjugação das actividades desenvolvidas no âmbito de quatro projectos de investigação financiados pela Fundação para a Ciência e Tecnologia, nomeadamente os seguintes: *Cathedral – Caracterização e conservação de argamassas tradicionais históricas de edifícios religiosos do Alentejo*; *Desenvolvimento de metodologias para a avaliação dos efeitos da humidade em paredes antigas*; *Conservarcal – Conservação de rebocos de cal: melhoria das técnicas e materiais de restauro arquitectónico*; e *Estudo de argamassas compatíveis para a preservação do património edificado*.

Mais de uma centena de comunicações foram apresentadas na conferência por investigadores de um grande número de países. Distribuíram-se por quatro temas: *I – Caracterização de argamassas históricas*; *II – Degradação e diagnóstico de alvenarias históricas*; *III – História, salvaguarda e conservação de revestimentos históricos*; e *IV – Soluções compatíveis de argamassas para conservação*.

O número anterior da *Conservar Património* publicou sete comunicações dos temas I e II. O presente número apresenta oito comunicações dedicadas aos temas III e IV. Quer num caso, quer no outro, os artigos foram escolhidos através do trabalho conjunto da comissão organizadora da conferência e da direcção da revista. Essa selecção teve em conta os interesses e as características da revista *Conservar Património* e a qualidade e o interesse das comunicações. Com base em semelhantes critérios, outras comunicações apresentadas na conferência foram encaminhadas para a revista *International Journal of Architectural Heritage*.

A ARP e a *Conservar Património* novamente agradecem à comissão organizadora da conferência, muito especialmente à eng.ª Rosário Veiga, esta oportunidade de, através da publicação destes dois números temáticos da revista, ficarem envolvidas nesta conferência internacional sobre as argamassas com interesse histórico. Agradecem igualmente o apoio recebido para a sua publicação.

A ARP e a *Conservar Património* agradecem também aos autores das comunicações seleccionadas o seu interesse e a sua disponibilidade para submeterem à *Conservar Património*, de acordo com os procedimentos habituais, os respectivos artigos.

Editorial

This issue of *Conservar Património*, like the previous one, is dedicated to the publication of articles resulting from communications presented at the HMC08 – Historical Mortars Conference, which took place in Lisbon at the National Laboratory of Civil Engineering (LNEC) in September 24-26, 2008.

The conference was a direct result of the joint activities of four research projects, funded by the Fundação para a Ciência e Tecnologia, including: *Cathedral – Characterization and conservation of traditional and historical mortars from Alentejo's religious buildings*; *Development of methodologies for the evaluation of the effects of humidity in old walls*; *Conservarcal – Lime mortar conservation - improving repair techniques and materials on architectural heritage*; and *Study of compatible mortars for the preservation of built heritage*.

More than one hundred presentations were given by researchers from several countries, organized under four themes: *I – Characterization of historical mortars*; *II – Decay and diagnosis of historic masonry structures*; *III – History, protection and conservation of historical renders and plasters*; and *IV – Design of compatible repair mortars*.

The previous issue of *Conservar Património* published a total of seven communications from themes I and II; the current issue features eight communications dedicated to themes III and IV. In both cases, the papers were jointly selected by the conference organizing committee and the journal's board of directors. This selection took into account both the interests and characteristics of *Conservar Património* and the quality and interest of the communications. Based on analogous criteria, other communications given at the conference were forwarded to the *International Journal of Architectural Heritage*.

ARP and *Conservar Património* wish to thank once again the conference organizing committee, and particularly Engineer Rosário Veiga, both for the opportunity of being involved in this international conference on historical mortars through the publishing of these two special issues, and for the granted support.

ARP and *Conservar Património* would also like to express their thanks to the authors of the selected papers for their interest and compliance with the journal's regular procedures in submitting their papers to *Conservar Património*.

Earth mortars use on neolithic domestic structures. Some case studies in Alentejo, Portugal

Argamassas de terra em estruturas domésticas do Neolítico. Alguns casos de estudo no Alentejo, Portugal

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Abstract

Earth mortars were constructively used since Ancient Neolithic in Southwest Iberia pre-historic habitat settlements. According to archaeological information, these materials were applied on Neolithic Period to render pits; latter, on Copper and Bronze Age, earth mortars were also used binding stone masonry, covering and filling vegetable structures, in mudbrick masonry and probably in massive walls. This paper aims to show some specific information about earth constructive traces obtained in interior Alentejo neolithic settlements of Defesa de Cima 2, Lajinha 8, Horta do Albardão 3, Valada do Mato (Évora district) and Toca da Raposa (Portalegre district). The analysed materials were composed by samples of burned clayish mortars coming from renderings or small thickness walls of probable storage bins and combustion structures. The samples descriptions include the drawing, measurement and photographic record of the chosen traces and also structural and granulometric analysis. The authors believe these analyses can contribute to deepen the knowledge of pre-historic domestic structures and constructive techniques, making possible technological reproduction of habitat settlements.

Keywords

Archaeological traces; characterisation; earth mortar; Neolithic habitat.

Resumo

O uso construtivo de argamassas à base de argila verificou-se no Sudoeste Peninsular desde o Neolítico Antigo. De acordo com os dados da arqueologia, estes materiais foram aplicados no Período Neolítico para revestimento de fossas; posteriormente, já na Idade do Cobre e do Bronze, as argamassas à base de argila foram utilizadas no assentamento de alvenarias de pedra, no revestimento de paredes compostas por engradados de materiais vegetais, na execução de adobes e, possivelmente, na construção de paredes maciças de terra. Esta comunicação tem por objectivo apresentar alguns dados mais específicos sobre os vestígios construtivos de terra detectados nos sítios de *habitat* neolíticos de Defesa de Cima 2, Lajinha 8, Horta do Albardão 3, Valada do Mato (distrito de Évora) e Toca da Raposa (distrito de Portalegre), essencialmente compostos por fragmentos de argamassas à base de argila, cozidos por fogo, provenientes do revestimento de fossas utilizadas como estruturas de combustão (lareiras e fornos) e de armazenagem (silos). A descrição das amostras incluiu a medição e o registo gráfico e fotográfico dos vestígios seleccionados. Foram também realizadas análises granulométricas e microestruturais. Julga-se que este tipo de estudos poderá contribuir para aprofundar o conhecimento das estruturas domésticas pré-históricas e das suas técnicas construtivas, possibilitando a reprodução tecnológica desses sítios de *habitat*.

Palavras-chave

Vestígios arqueológicos; caracterização; argamassa de terra; *habitat* neolítico.

Introduction

Archaeological materials exhumed in south Portugal settlements show that earth mortars were largely used on pre-historic domestic structures.

In a first stage of sedentariness – Neolithic –, clayish mortars were used to render ditches apparently used as storage bins or combustion structures. This technique seems to have been applied in Atafonas [1], Defesa de Cima 2 (Torre de Coelheiros, Évora) [2], Lajinha 8 [3], Horta do Albardão 3 (São Manços, Évora) [4], Xarez 12, Carraça 1 (Reguengos de Monsaraz, Évora) [5-7] and Salema (Santiago do Cacém, Setúbal), where renderings with 2.0 cm to 5.0 cm thicknesses were found *in situ*, covering pits with several shapes and dimensions [8].

In Xarez 12 some of the earth structures, interpreted as culinary ovens, seem to have moulded walls, with thickness until 30.0 cm, prolonged above the pits [7].

Later, on Copper Age, the presence of earth vestiges showing negative prints of ramifications is dominant. These materials, probably coming from covering and filling hut's vegetable structures, were found in São Pedro (Redondo, Évora) [9], Monte da Ponte (Nossa Senhora da Tourega, Évora) [10], Monte Novo dos Albardeiros [11], Torre do Esporão 3 (Reguengos de Monsaraz, Évora) [12], Porto das Carretas [13], Moinho de Valadares 1 [14], Mercador (Mourão, Évora) [15], Porto Torrão (Ferreira do Alentejo, Beja) [16], Cerro do Castelo de Santa Justa, Cerro do Corte João Marques (Alcoutim, Faro) [17] and Alcalar (Portimão, Faro) (figures 1 and 2) [18]. In some of these settlements, earth mortars were also used binding stone blocks of defensive walls and hut bases.

As to mudbrick masonry, traces were found in Monte da Tumba (Torrão, Alcácer do Sal, Setúbal) [19] and Alto do Outeiro (Baleizão, Beja) (figure 3) [20].

Earth was probably used on the construction of massive walls, as it seems to be the case in Alcalar's hut from "Corte 5", still in excavation.

Clayish renderings covering underground structures (bins and a water tank) were also found in calcolithic settlements, like Alto do Outeiro [20] and Alcalar [21].

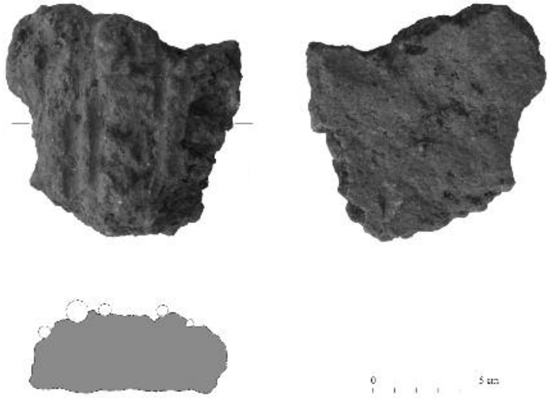

Fig. 1 Fragment of earth mortar with ramification traces from Alcalar calcolithic settlement.

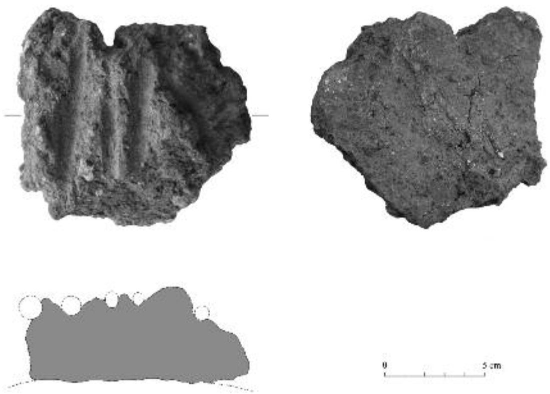

Fig. 2 Fragment of earth mortar with ramification traces from Alcalar calcolithic settlement.

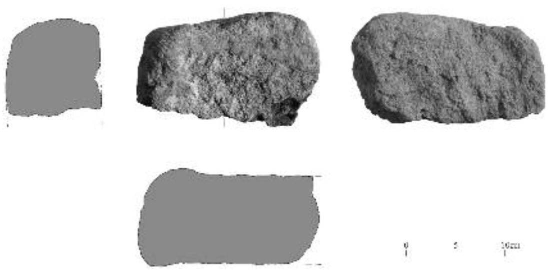

Fig. 3 Mudbrick fragment from Alto do Outeiro calcolithic settlement.

On Bronze Age, in spite of the lack of domestic structures vestiges, earth mortars seem to have been largely used, mostly covering and filling hut's vegetable structures; traces were found in Rocha do Vigio 2 (Reguengos de Monsaraz, Évora) (figure 4) [22, 23] and Castro dos Ratinhos (Moura, Beja) [24]. In Castro dos Ratinhos, archaeologists also found traces of earth renderings from a hut stone base.

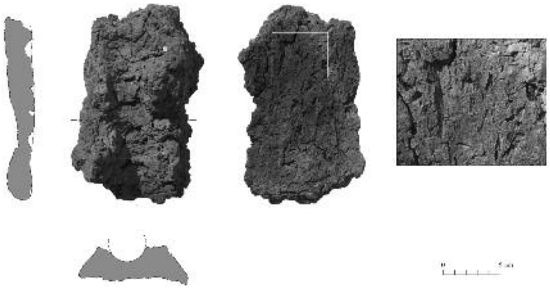

Fig. 4 Fragment of earth mortar with ramification traces from Rocha do Vigio 2 (Bronze Age settlement).

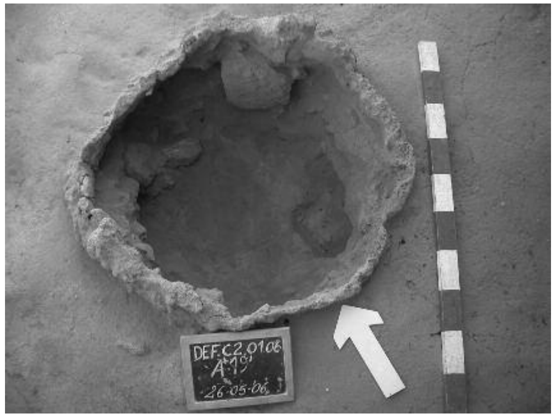

Fig. 5 Defesa de Cima 2: pit 5 after excavation (photo: Filipe Santos/ Arqueohoje).

Fig. 6 Defesa de Cima 2: detail of pit 5 interior renderings (photo: Filipe Santos/ Arqueohoje).

Neolithic earth vestiges

Methodology

The analysed materials were composed by fragments of burned clayish mortars coming from renderings of underground structures (Defesa de Cima 2, Lajinha 8 and Horta do Albardão 3) and a probable *combustion base* (Toca da Raposa). Materials from Valada do Mato came from a thrown down belonging to a probable domestic stone structure.

On a first stage, samples were measured, drawned and photographed; the second stage, still running, consists on laboratorial analyses (micro structural morphology by binocular glass observation, granulometry and mineralogical interpretation).

Defesa de Cima 2 (Torre de Coelheiros, Évora)

Chosen samples belonged to the renderings of two Ancient Neolithic pits, probably used as storage bins, both excavated in the granitic substrate.

These renderings, with about 2.0 cm to 3.0 cm thickness, were exposed to combustion by fire, after application in the pits walls (and, in some ditches, in the bases). According to archaeologists of Defesa de Cima 2, this procedure could be intentional, with the objective of waterproofing the bins interior [2].

Pit 5 (figure 5) had a circular plan, with a 90 cm diameter and a maximum preserved depth of 83 cm; inside, close to the basis, it contained imbricate stones with combustion vestiges. Clayish renderings were continuous, surfacing the lateral walls of the ditch (figure 6).

Pit 16 was too destroyed. It had a circular plan, with a 80 cm diameter and a maximum preserved depth from 40 cm to 50 cm. Only part of lateral renders was preserved.

Vestiges (figure 7) were composed by small nodules and plaques of various dimensions, with 3 cm maximum thickness. Concave faces of the plaques were smoothed and some of them had finger prints.

Pastes had brown-reddish colours and homogeneous compositions. As to the proportion between aggregates, fine elements (ilithic clays and sands) were dominant. Under binocular glass (figure 8), the presence of quartz and feldspar was observable.

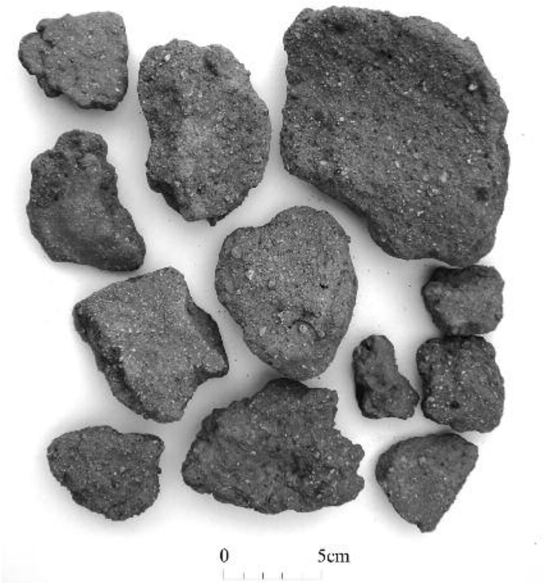

Fig. 7 Defesa de Cima 2: samples from pit 5.

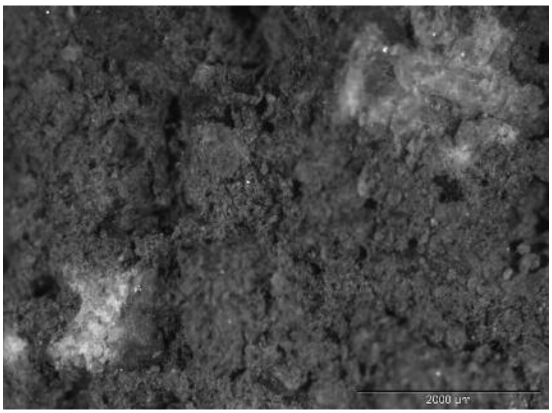

Fig. 8 Defesa de Cima 2: binocular glass photo of a sample from pit 5, 20x amplified.

Different layers on the renderings, negative traces of organic materials, animal or vegetable fibbers were not detected.

Pastes presented little pores, with diameters until 1.0 mm; micro fissures were also rare, with apertures until 0.2 mm.

Results from granulometry tests are presented on Table 1.

Table 1 Granulometry of pastes from Defesa de Cima 2.

Fraction	Ø (mm)	% - pit 5	% - pit 16
Large pebbles	60-20	0	0
Medium pebbles	20-6	0	0.2
Small pebbles	6-2	7.2	1.5
Coarse sand	2-0.6	21.7	25.7
Medium sand	0.6-0.2	50.6	41.0
Fine Sand	0.2-0.06	12.2	19.0
Silt + clay	<0.06	8.2	12.5

Lajinha 8 (São Manços, Évora)

Samples from Lajinha 8 Ancient Neolithic settlement came from combustion structure L8.1, apparently a kind of oven [3].

Structure L8.1 (figures 9 and 10) was made upon a pit with 90 cm of diameter and 20 cm of depth. Clayish renderings surfaced the walls and the base of the ditch; inside archaeologists found thermoclasts.

The structure was probably arched covered by clayish materials, thrown down above the pit's fill (figure 9).

Samples were collected from the walls and the base renderings. Vestiges were composed by small plaques of various dimensions, with 1.5 cm to 3.0 cm maximum thickness. Concave interior faces of the plaques were smoothed. Pastes had brown-reddish colours and homogeneous compositions. Fine elements were dominant.

Fig. 9 Combustion structure L8.1 of Lajinha 8 before dismounting, with vestiges from the probable covering.

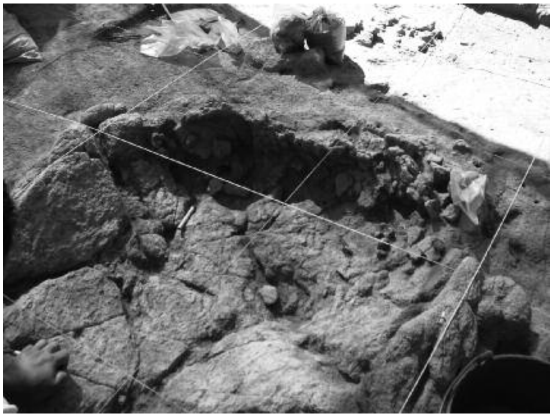

Fig. 10 Combustion structure L8.1 of Lajinha 8 after excavation, with renderings vestiges in situ.

Some sands (mostly quartzes) were found, with diameters until 1.0 mm.

Negative traces of organic materials, animal or vegetable fibbers were not detected. Pastes presented some pores, with diameters until 1.0 mm; micro fissures were also rare, with apertures until 0.5 mm.

Horta do Albardão 3 (São Manços, Évora)

Earth vestiges from Early Neolithic settlement of Horta do Albardão 3 probably belonged to a combustion structure made upon a pit, excavated in the granitic substrate. This artificial concavity had an oval plan, measuring 76 cm x 89 cm and was 39 cm to 44 cm deep.

Materials were collected from the interior of the ditch, above a stone layer with traces of combustion; archaeologists think that they probably belonged to the structural walls or an arched covering [4].

Vestiges (figure 11) were composed by plaques of burnt clayish pastes, with 5.0 cm to 6.5 cm thickness, smoothed in one of the faces. Only one sample presented ramification traces (in the opposite face of the one that seem to have been smoothed).

Pastes had brown-reddish colours and homogeneous compositions. Fine elements quantities were superior to larger aggregates; sands were mostly composed by quartz, with diameters until 0.5 mm (figure 12).

Negative traces of organic materials, animal or vegetable fibbers were not detected. Pastes had some porosity, with circular and oval pore, no larger than 0.5 mm diameter; fissures had apertures until 0.2 mm.

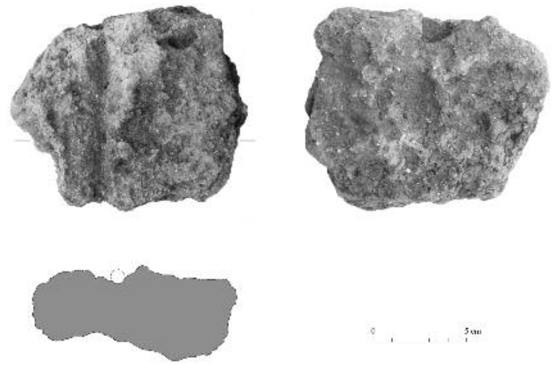

Fig. 11 Horta do Albardão 3: sample H.ALB.3.01.06 (3).

Fig. 12 Horta do Albardão 3: binocular glass photo of sample H.ALB.3.01.06 (3), 20x amplified.

Valada do Mato (São Matias, Évora)

Materials from the Ancient Neolithic settlement of Valada do Mato were collected from a thrown down, mixed with many stone blocks, that probably belonged to an oval plan domestic structure [25].

Vestiges (figure 13) were composed by small plaques of burnt clayish pastes, with 1.0 cm to 2.5 cm thickness, smoothed in one face and irregular on the other.

Pastes had brown-reddish colours and revealed some homogeneity on composition. As to the proportion between aggregates, it was possible to observe the dominance of fine elements and the presence of quartz sands, with diameters until 0.5 mm (figure 14).

Fig. 13 Valada do Mato materials, from unit 9/19.

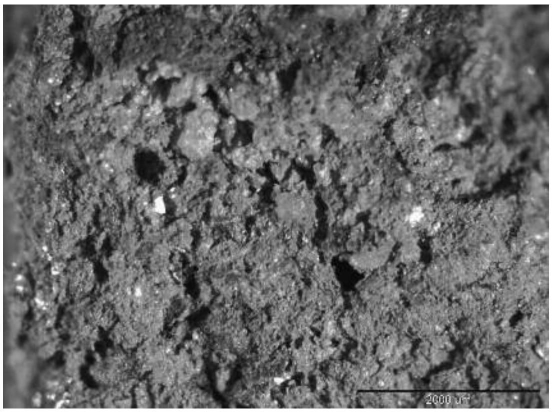

Fig. 14 Valada do Mato: binocular glass photo of a sample from unit 9/10, 20x amplified.

Negative traces of organic materials, animal or vegetable fibbers were not detected. Pastes had some porosity, with elongated pores (like pore-fissures), with diameters until 1.0 mm; rare fissures were detected, with apertures until 0.1 mm.

Toca da Raposa (Alter do Chão, Portalegre)

A sample from the Ancient Neolitic settlement of Toca da Raposa was collected from a probable combustion base made of clayish paste, with an elongated form (like a plaque), with about 2.0 cm thickness (figure 15) [26].

The paste had ochreous colour and revealed some homogeneity in its composition. As to proportion between aggregates, fine elements were in larger quantity. Some larger aggregates (small pebbles) were detected,

Fig. 15 Toca da Raposa possible combustion base (photo: Jorge Oliveira).

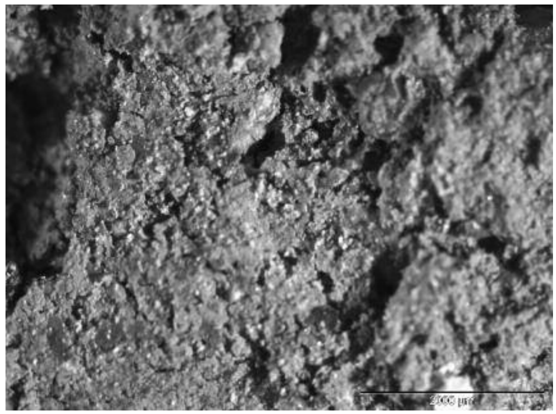

Fig. 16 Toca da Raposa: binocular glass photo of a sample from the probable combustion base, 20x amplified.

with diameters about 2.0 mm. There were not detected any negative traces of organic materials, animal or vegetable fibbers (figure 16).

Pastes had some porosity – with elongated pores (like pore-fissures), with diameters until 1.0 mm – and also some fissures, with apertures until 0.5 mm.

Discussion

All pastes presented homogeneous mixtures, under binocular glass observation, due to good kneading. Fine elements were dominant, with large quantities of sands. Pastes had some porosity and micro fissures with apertures only until 1mm.

Except for the materials from Horta do Albardão 3 (plaques with 5.0 cm to 6.5 cm of thickness), all samples seem to have come from renderings, with 1.0 cm to 3.0 cm thicknesses and smoothing in one of the faces. In two cases – Defesa de Cima 2 and Lajinha 8 (figures 6 and 10) – pastes were still above buttress (walls and bottoms of the pits).

After materials extraction (clay, sand), mixing and kneading, pastes would be hand laid above buttress, in only one layer. Subsequently, renderings would be manually smoothed.

All materials were burnt by fire, and the case of vestiges interpreted as combustion structures enforces those interpretations. However, in Defesa de Cima 2, where pits were interpreted as storage bins, two suppositions stand:

- Renderings combustion was made only to waterproof the bins' interior;

- Renderings combustion was made to toast cereals, to better conserve them and, in this case, structures would have two functions – storage and combustion.

Due to maximum conserved depths of many structures of Defesa de Cima 2 – until 83 cm – it seems highly probable that those pits function was related with storage, as archaeologists support.

Conclusions and future developments

From a data base which includes all the main excavated habitat places in South Portugal, it will be possible to identify some of the techniques and typologies used on the construction of domestic structures, since Ancient Neolithic to the Bronze Age.

The authors also believe that the development and analysis of case studies will help to understand the technologies of extraction, manufacture and application processes of earth building materials on Pre-history, making technological reproduction of habitat settlements possible, outside the original site.

References

1 Albergaria, J., 'O sítio neolítico das Atafonas (Torre de Coelheiros, Évora)', *Revista Portuguesa de Arqueologia*, **10**(1) (2007) 5-35.

2 Santos, F.; Carvalho, P., 'O sítio neolítico da Defesa de Cima 2 (Torre de Coelheiros, Évora). Primeiros resultados', communication presented on the *III Coloquio de Arqueologia do Sudoeste Peninsular – Aljustrel* (2006).

3 Gaspar, R., 'Intervenção arqueológica na Lajinha 8 (São Manços, Évora). Relatório Final', report, Lisboa, Archeo'Estudos (2008).

4 Santos, F., 'Minimização de impactes sobre o património cultural decorrentes da construção do canal da conduta C1_3 do Bloco 3 do Bloco de Rega do Monte Novo. Sítio do Neolítico Final/Calcolítico da Horta do Albardão 3 (S. Manços, Évora). Trabalhos arqueológicos. Relatório Final', report, Arqueohoje, Lisboa (2006).

5 Gonçalves, V. S., 'Intervenções na área da barragem do Alqueva (2000). Bloco 3. Habitats Sítio: Carraça 1', report, IPA, Lisboa (2000).

6 Gonçalves, V. S., 'Intervenções na área da barragem do Alqueva (2001). Bloco 3. Povoados. Sítio: Carraça 1', report, IPA, Lisboa (2001).

7 Gonçalves, V. S., 'Comer em Reguengos, no Neolítico. As estruturas de combustão da Área 3 de Xarez 12', in *Muita gente, poucas antas? Origens, espaços e contextos do Megalitismo. Actas do II Colóquio Internacional sobre Megalitismo,* IPA, Lisboa (2003) 81-91.

8 Silva, C. T.; Soares, J., *Pré-História da Área de Sines*, Gabinete da Área de Sines, Lisboa (1981).

9 Mataloto, R.; Estrela, S.; Alves, C., 'As fortificações calcolíticas de São Pedro (Redondo, Alentejo Central, Portugal)', in *Los primeros campesinos de La Raya. Aportaciones recientes al conocimiento del Neolítico y Calcolítico en Extremadura y Alentejo. Actas de las Jornadas de Arqueología del Museo de Cáceres*, Museo de Cáceres, Cáceres (2007) 113-141.

10 Hock, M.; Kalb, P., 'O povoado fortificado calcolítico do Monte da Ponte, Évora', in *Actas do 2º Congresso de Arqueologia Peninsular, Zamora, 1996*, Fundación Rei Afonso Henriques, Zamora (1997) 417-423.

11 Gonçalves, V. S., 'A ocupação pré-histórica do Monte Novo dos Albardeiros (Reguengos de Monsaraz)', *Portugália* **9-10** (1989) 49-61.

12 Gonçalves, V. S., 'TESP3: o povoado pré-histórico da Torre do Esporão (Reguengos de Monsaraz)', *Portugália* **11-12** (1991) 53-72.

13 Silva, C. T.; Soares, J., 'Porto das Carretas - um povoado calcolítico fortificado do vale do Guadiana', *Al-madam* **2** (2002) 176-180.

14 Valera, A. C., 'Moinho de Valadares e transição Neolítico final/ Calcolítico na margem esquerda do Guadiana: uma análise preliminar', *Era Arqueologia* **1** (2000) 24-37.

15 Valera, A. C., 'A ocupação pré-histórica do sítio do Mercador (Mourão): a campanha de 2000', *Era Arqueologia* **3** (2002) 42-57.

16 Valera, A. C.; Filipe, I., 'O povoado do Porto Torrão (Ferreira do Alentejo)', *Era Arqueologia* **6** (2004) 28-61.

17 Gonçalves, V. S., *Megalitismo e metalurgia no alto Algarve oriental, uma aproximação integrada*, INIC/ UNIARQ, Lisboa (1989).

18 Morán, E., 'Conjunto Megalítico de Alcalar (Portimão). Povoado de Alcalar. Parcela 15L. Campanha 3(2001). Relatório preliminar dos trabalhos de terreno efectuados no corte 04', report, IPA, Lisboa (2001).

19 Silva, C. T.; Soares, J., 'O povoado fortificado calcolítico do Monte da Tumba - Escavações arqueológicas de 1982-86 (resultados preliminares)', *Setúbal Arqueológica* **8** (1987) 29-79.

20 Grilo, C., 'O povoado pré-histórico do Alto do Outeiro, Baleizão, Beja', communication presented on the *III Coloquio de Arqueologia do Sudoeste Peninsular – Aljustrel* (2006).

21 Morán, E., 'Relatório dos trabalhos arqueológicos efectuados em Março-Abril de 1999 no povoado calcolítico de Alcalar. Parcela nº 16-L propriedade de Uta Tackenber', report, IPA, Lisboa (1999).

22 Bruno, P., 'O uso da terra na construção de uma cabana do Bronze final. Estudo dos materiais provenientes do sítio proto-histórico Rocha do Vigio 2 (Campinho, Reguengos de Monsaraz)', *Terra: forma de construir. Arquitectura-Antropologia-Arqueologia*, Argumentum, Lisboa (2006) 67-73.

23 Calado, M.; Mataloto, R.; Rocha, A., 'Povoamento proto-histórico na margem direita do Regolfo de Alqueva (Alentejo – Portugal)', in *Arqueologia de la tierra. Paisajes rurales de la Protohistoria Peninsular*, Universidad de Extremadura, Cáceres (2007) 129-179.

24 Silva, A. C.; Berrocal-Rangel, L., 'Castro dos Ratinhos. Relatório. 4ª Campanha – 2007', report, Edia/ Projecto Arqueológico dos Ratinhos, Beja (2007).

25 Diniz, M., *O Sítio de Valada do Mato (Évora): aspectos da neolitização no Interior/ Sul de Portugal*, IPA, Lisboa (2007).

26 Oliveira, J., *Património Arqueológico da Coudelaria de Alter*, Colibri/ Universidade de Évora, Lisboa (2006).

Conservation of old renderings – the consolidation of renderings with loss of cohesion

Conservação de revestimentos antigos – a consolidação de revestimentos com perda de coesão

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Abstract

The study of external renderings in the scope of conservation and restoration has acquired in the last years great methodological, scientific and technical advances. These renderings are important elements of the built structure, for besides possessing a protection function, they possess often a decorative function of great relevance for the image of the monument. The maintenance of these renderings implies the conservation of traditional constructive techniques and the use of compatible materials, as similar to the originals as possible.

The main objective of this study is to define a methodology of conservative restoration using strategies of maintenance of renderings and traditional constructive techniques. The minimum intervention principle is maintained as well as the use of materials compatible with the original ones. This paper describes the technique and products used for the consolidation of the loss of cohesion.

The testing campaign was developed under controlled conditions, in laboratory, and in situ in order to evaluate their efficacy for the consolidation of old renders. A set of tests is presented to evaluate the effectiveness of the process.

The results are analysed and a reflection is added referring to the applicability of these techniques. Finally the paper presents a proposal for further research.

Keywords

Lime mortars; techniques of restoration; consolidation; lime water.

Resumo

O estudo dos revestimentos exteriores tem vindo a adquirir, nos últimos anos, avanços metodológicos, científicos e técnicos. Estes revestimentos são elementos importantes da estrutura edificada, pois para além de terem uma função protectora apresentam também muitas vezes uma função decorativa relevante para a imagem do edifício. A manutenção destes revestimentos implica a conservação das técnicas construtivas tradicionais e o uso de materiais de restauro compatíveis e o mais similar possível ao original.

Uma das principais formas de degradação é a perda de coesão, que consiste na perda da resistência mecânica das camadas de reboco devido à perda ou à alteração da ligação entre partículas, provocando diversas anomalias, tais como: desagregação e pulverulência. Estas anomalias não podem ser reparadas com as técnicas actuais da construção, que prevêem a sua substituição por novos revestimentos, perdendo-se a história dos materiais e da tecnologia da construção.

O principal objectivo deste estudo é definir uma metodologia de restauro conservativa, usando estratégias de manutenção dos revestimentos e das técnicas construtivas tradicionais, onde haja uma intervenção mínima, utilizando materiais compatíveis com os originais. Escolheu-se a técnica de consolidação como método para a preservação destes revestimentos.

Neste artigo descreve-se a técnica e os produtos utilizados para a consolidação da falta de coesão, apresenta-se um conjunto de ensaios para avaliar a respectiva eficácia, analisam-se os resultados obtidos e em conclusão faz-se uma reflexão sobre a aplicabilidade destas técnicas. Mediante os resultados obtidos apresenta-se ainda um conjunto de propostas para ensaios futuros.

Palavras-chave

Argamassas de cal; técnicas de restauro; consolidação; água de cal.

Introduction

The external renders of old buildings are important elements of the built structure. Besides their protective function, they also have a decorative function of great relevance for the image of the building. Their maintenance implies the conservation of traditional constructive techniques and the use of compatible repair materials, as similar as possible to the original.

One of their main degradation symptoms is the loss of cohesion, which consists 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, disintegration, and powdering. These anomalies can not be repaired with current construction techniques, which are usually destructive and have as a consequence the substitution by new renders, losing the materials history and construction technology.

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 [1-4]. 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.

Products and tests

Products

Several consolidants have been used lately to restore cohesion to old mortars. Nevertheless, some of them change significantly the properties of the render and for this reason they generate new anomalies and functional problems for the building. Conscious of the importance of the use of a sustainable technology and of traditional materials for the restoration of old lime mortars, it was decided to study three different consolidants – lime water, additivated limewater and ethyl silicate – applied to mortars. Based on previous studies, the basic requirements of a consolidant are synthesized in table 1.

Limewater - This is the oldest consolidation treatment known; Vitruvius described this technique: ...executed with lime and a large quantity of clean water [5]. Its effectiveness is contested by some authors, but it is used by several technicians and there are scientific studies evidencing good results [4]. 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 [6].

Additivated limewater - Metakaolin was used as an additive to improve the adhesion of limewater to the substrate and consequently to improve the lime mortar's mechanical resistance. Metakaolin is a mineral obtained through kaolin's heat treatment and grinding, resulting in a material of raised pozzolanicity, capable of quickly consuming calcium hydroxide, and whose pozzolanic activation by calcium hydroxide supplies products of strong structure and similar composition as those produced with portland cement [7].

Ethyl silicate – Ethyl silicate belongs to the alcoxisilane family, used since XIXth century. The chemical composition of ethyl silicate has been modified throughout the years, and different formulations are commercialized, based on main components. After hydrolysis and con-

Table 1 Basic requirements for lime mortars consolidant [2-4, 9].

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 colour of the rendering to be treated

densation, ethyl silicates originate colloidal silica that is deposited inside the porous structure [1-2].

In this study the ethyl silicate used was Tegovakon® V (BIU International), which is a tetraethoxysilane (TEOS). Ethyl silicate has been used as stone consolidant and more recently as wall paintings consolidant [8].

The preparation of the products

The limewater used was kept in laboratory in a closed bucket for some years. The metakaolin used was MetaStar 501of Imerys. It was decided to use a concentration of metakaolin in limewater similar to the concentration of lime in simple limewater. For this, it was necessary to know the amount of lime in 1 L of simple limewater by drying the liquid in a stove. The measured amount of lime in simple limewater was 2 g. To prepare the additivated limewater the same amount of metakaolin was added to limewater.

The drying of limewater additivated with metakaolin was also carried out and it was easily observed that the two dry products presented differentiated structures. The residue of the simple limewater was presented as a powder (calcium carbonate) with formation of small crystals, while the residue of the additivated limewater presented a greater amount of plate shaped crystals (figs. 1 and 2).

The pH of the two types of consolidants was measured, and the values were compared. The simple limewater pH was 10.3, that of the additivated limewater was 7.3 and the pH of Tegovakon was 3.0.

Fig. 1 Residue after drying of the simple limewater.

Fig. 2 Residue after drying of limewater additivated with metakaolin.

Application of the consolidants on lime mortar specimens and old mortars

Three different kinds of experimental applications were accomplished with the consolidants.

Several specimens were prepared with air lime and sand mortar with volumetric ratio 1:3. Different shapes and dimensions were adopted according to the tests to perform:

Cylindrical bases with 200 mm diameter and 20 mm thickness for water vapour permeability and water absorption by capillarity.

Prismatic bases with 40 mm x 40 mm x 160 mm for flexural resistance tests.

The procedure for the laboratorial specimens consisted on applications of the chosen consolidants on the described mortar bases, for subsequent analyses in laboratory. The product was first applied on the laboratory specimens in a room conditioned at 23 °C and 50 % HR, using the spraying technique with a manual spray, from a distance of 50 cm; after each application the specimens and spray were weighed for the verification of the consolidant consumption. The application was interrupted when it was verified that either the specimen was completely damp or the back of the specimen was wet; this saturation effects happened approximately after 25 applications. The tested specimens had two different shapes and sizes: cylindrical specimens with a treated area of 0.0314 m^2; prismatic specimens with a treated area of 0.0064 m^2.

In situ applications consisted on applications of the chosen consolidants on old plasters of a XVIII century building with problems of loss of cohesion.

In situ and laboratory tests

A test campaign for evaluation of the efficacy of the consolidation treatment was carried out comprising the tests presented in table 2 and illustrated in figs. 3-5.

Synthesis of the test results

The main tests results, both in laboratory and in situ, are presented in tables 3 and 4 and illustrated in figs. 6-8.

Discussion and analysis of the test results

Evaluation of the aesthetic aspect and half-quantitative determination of salts: the colour of render consolidated with lime water and lime water with metakaolin did not change; but render consolidated with ethyl silicate becomes a little darker. Using Strip colorimetric tests, it was verified that the treated render did not contain soluble salts (tables 3 and 4).

Evaluation of the consolidant penetration: the evaluation of the penetration depth of the consolidant demonstrated that limewater and limewater with metakaolin penetrate only in the mortar superficial layers, so their use is recommended only for mortars with superficial loss of cohesion (table 4).

Evaluation of the mechanical resistance in situ and in laboratory: the results obtained at in situ tests with the Schmidt impact hammer and the durometer, and at laboratory test (flexural and compressive strength) demonstrated an increase of resistance on the mortars superficial layers after treatment. The highest strength increase was obtained with ethyl silicate followed by limewater with metakaolin and simple limewater (tables 3-4 and figs. 7-8).

Evaluation of the behaviour to water: the tests on ancient mortars (XVIII century) with Karsten tubes showed that these ancient mortars consolidated with limewater and ethyl silicate are extremely permeable to water; using limewater with metakaolin as consolidant they become less permeable (fig. 6). The obtained results

Table 2 Description of the consolidation tests.

Type of consolidant	Laboratory tests	In situ tests
- Limewater - Lime water with metakaolin - Ethyl silicate	colour measurement, water vapour permeability, w ater absorption by capillarity, penetration of consolidant and mechanical resistance.	colour measurement, permeability to water under low pressure (Karsten tubes), control of salts and mechanical resistance (Schmidt impact hammer and Durometer tests).

Table 3 Results of consolidation - in situ tests on ancient lime mortars (XVIII century).

In situ tests		Lime water	Lime water with metakaolin	Ethyl silicate
Colour identification NCS, index 2	Before consolidation	S 0500 – N	S 0500 – N	S 0500 – N
	After consolidation	S 0500 – N	S 0500 – N	S 0502 Y
Half-quantitative determination of salts (Strip test)	Before consolidation	Negative for nitrate chloride and sulphate salts		
	After consolidation	Negative for nitrate chloride and sulphate salts		
Compression strength using Schmidt impact hammer (VH) ISO 7619:1997 and ASTM C 805	Before consolidation	22.2	22.2	22.2
	After consolidation	33.8	33.4	33.4
Durometer hardness (Shore A). ISO 7619:1997 and ASTM D 2240	Before consolidation	37.1	37.1	37.1
	After consolidation	59	65.2	67.6

Fig. 3 Test with Schmidt impact hammer on ancient lime mortar.

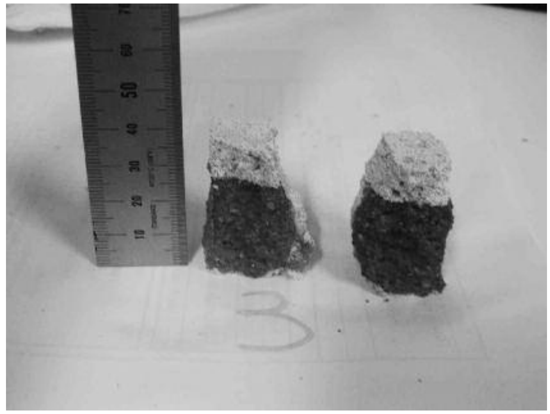

Fig. 4 Test for evaluation of consolidation deepness with phenolphthalein agent.

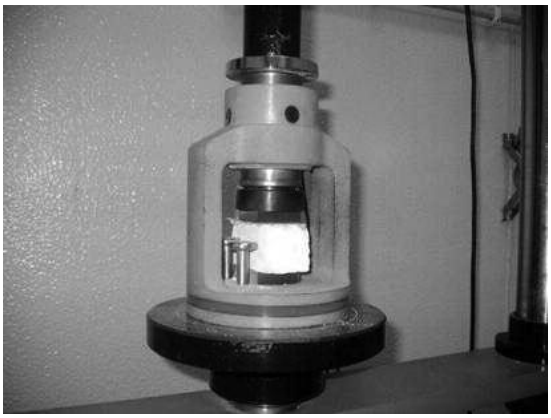

Fig. 5 Flexural strength test.

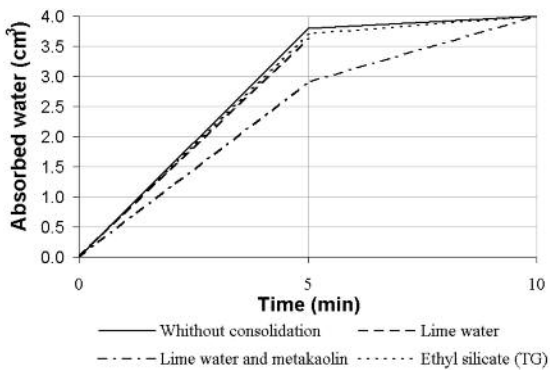

Fig. 6 Evaluation of permeability to water under low pressure, in ancient lime mortars (karsten tubes).

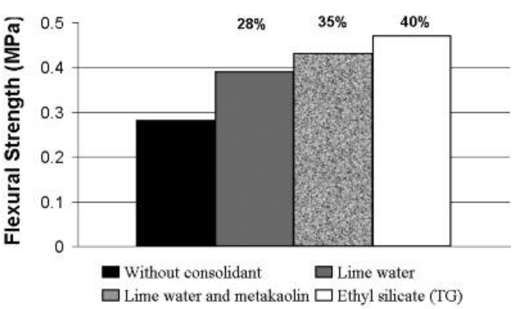

Fig. 7 Evaluation of resistance increase (laboratory test).

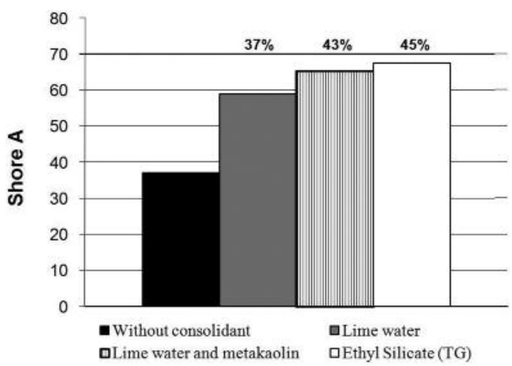

Fig. 8 Evaluation of resistance increase of ancient mortar (in situ test using a durometer).

Table 4 Results of consolidation - Laboratory tests. New air lime based mortars with volumetric dosage 1:3.

Laboratory tests		Lime water	Lime water with metakaolin	Ethyl silicate
Evaluation of consolidation deepness with phenolphthalein agent	Before consolidation	Penetration 4mm	Penetration 4mm	Not determined
Colour identification NCS, index 2	Before consolidation	S 0500 – N	S 0500 – N	S 0500 – N
	After consolidation	S 0500 – N	S 0500 – N	S 0502 Y
Half-quantitative determination of salts (Strip test)	Before consolidation	Negative for nitrate chloride and sulphate salts		
	After consolidation			
Capillary coefficient-0 -10 min ($kg/m^2.min^{1/2}$) (EN 1015 –18:2000). Cylindrical specimens	Before consolidation	1.16	1.16	1.16
	After consolidation	1.13	1.08	0.11
Permeability vapour diffusion (m) (Sd means) (EN 1015 –19:1998)	Before consolidation	0.07	0.07	0.07
	After consolidation	0.07	0.06	0.07
Flexural strength (N/mm^2) (EN1015:11)	Before consolidation	0.28	0.28	0.28
	After consolidation	0.39	0.43	0.47

in terms of water absorption by capillarity in laboratory show that the capillarity coefficient is similar for specimens without consolidant and consolidated with limewater or limewater with metakaolin but it is lower for specimens consolidated with ethyl silicate. Concerning water vapour permeability, none of the consolidation treatments produces a barrier to water vapour diffusion (table 4).

Final considerations

The study verified the viability and effectiveness of consolidants for lime mortars.

The use of metakaolin as an additive in limewater decreased the alkalinity of the product and increased the mechanical resistance of the treated mortars, when compared with the mortars consolidated with simple limewater. It was also observed that the additivated limewater dries with formation of plate shaped crystals; this must be followed to assess its influence on the improvement of the mechanical resistance of the mortar after treatment.

Due to the extreme chemical compatibility of limewater with old (lime) renderings and considering the results of the set of tests carried out, it is possible to recommend the use of limewater and limewater with metakaolin for consolidating old renderings with low cohesion. These consolidants increase the mechanical resistance of the superficial layers. It was important to verify that the selected consolidants did not introduce in the rendering any changes in water vapour permeability, nor any salts previously inexistent.

For old mortars with severe cohesion problems it is possible to recommend the use of ethyl silicate as consolidant, as it was the consolidant that mostly increased the mortars resistance.

The study of these consolidants – limewater and additivated limewater – can contribute to the creation of ecological and economically viable materials, through the promotion and use of traditional technologies.

This study must be developed with other products that can be added to limewater in order to improve its effectiveness, which is due to the increasing of calcium carbonate introduced in the mortar, promoting cohesion and mechanical resistance of lime renders.

Consolidation is a rather complex method of restoration, because different materials can be used with this purpose and there are 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 on the intrinsic characteristics and the conservation state of the material to treat, as well as on the ability and good sense of the restorer.

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References

1 Delgado Rodrigues, J., "Consolidation of decayed stones. A delicate problem with few practical solutions", in *SACH'2001: 3rd International Seminar on Structural Analysis of Historical Constructions*, Guimarães (2001).

2 Pinto, A. P. F., 'Conservação de pedras carbonatadas: Estudo e selecção de tratamentos', PhD dissertation, Instituto Superior Técnico, Lisboa (2002).

3 Mora, P.; Mora, L., *La Conservazione delle pitture murali, Compositrice*, Bologna (2001).

4 Brajes, I.; Kalsbeek, N., 'Limewater absorption and calcite crystal formation on a limewater-impregnated secco wall painting', *Studies and Conservation*, 44(3) (1999) 145-156.

5 Gárate, I., *Artes de la cal*, Didot, Madrid (1994).

6 Tavares, M.; Veiga, M. R., 'A conservação de rebocos antigos - restituir a coesão perdida através da consolidação com materiais tradicionais e sustentáveis', in *VII SBTA: Seminário Brasileiro de Tecnologia de Argamassas*, Recife (2007).

7 Velosa, A. L., 'Argamassas de cal com pozolanas para revestimento de paredes antigas', PhD dissertation, Universidade de Aveiro (2006).

8 Leitner, H., 'L'uso dei silicate nella conservazione della pittura murale dal ponto di vista del restauratore', in *I Silicati nella Conservazione: Indagini, Esperienze e Valutazioni per il Consolidamento dei Manufatti Storici, Fondazione per le biotecnologie*, Torino (2002) 157-174.

9 Villegas, R., 'Metodologia para la evaluacion y estudio previo de tratamientos', in *Metodología de diagnóstico y evaluación de tratamiento para la conservación de los edificios históricos*, ed. R. Villegas Sánchez, E. Sebastián Pardo, Instituto Andaluz del Património Histórico, Sevilla (2003) 194-205.

Earth mortars and earth-lime renders
Argamassas em terra e rebocos em cal e terra

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Abstract
Earth surface coatings play a decorative architectural role, apart from their function as wall protection. In Portuguese vernacular architecture, earth mortars were usually applied on stone masonry, while earth renders and plasters were used on indoors surface coatings. Limestone exists only in certain areas of the country and consequently lime was not easily available everywhere, especially on granite and schist regions where stone masonry was a current building technique.
In the central west coast of Portugal, the lime slaking procedure entailed slaking the quicklime mixed with earth (sandy soil), in a pit; the resulting mixture would then be combined in a mortar or plaster. This was also the procedure for manufactured adobes stabilized with lime. Adobe buildings with earth-lime renderings and plasters were also traditional in the same region, using lime putty and lime wash for final coat and decoration. Classic decoration on earth architecture from the 18th-19th century was in many countries a consequence of the François Cointeraux (1740-1830) manuals – *Les Cahiers d'Architecture Rurale" (1793)* – a French guide for earth architecture and building construction. This manual arrived to Portugal in the beginning of XIX century, but was never translated to Portuguese. References about decoration for earth houses were explained on this manual, as well as procedures about earth-lime renders and ornamentation of earth walls; in fact, these procedures are exactly the same as the ones used in adobe buildings in this Portuguese region.
The specific purpose of the present paper is to show some cases of earth mortars, renders and plasters on stone buildings in Portugal and to explain the methods of producing earth-lime renders, and also to show some examples of rendering and coating with earth-lime in Portuguese adobe vernacular architecture.

Keywords
Earth architecture; earth-lime renders; plasters.

Resumo
As superfícies arquitectónicas em terra desempenham um papel decorativo, para além da função meramente protectora dos paramentos. Na arquitectura vernácula portuguesa, as argamassas em terra eram tradicionalmente usadas na elevação de paredes em alvenaria de pedra, enquanto os rebocos em terra eram aplicados nas paredes interiores. A pedra calcária existe apenas em algumas zonas do país e consequentemente a cal não estava disponível, especialmente nas regiões de xisto e granito onde a alvenaria em pedra era uma técnica corrente.
Na região centro litoral de Portugal, o procedimento para extinguir a cal consistia na mistura de terra arenosa com cal aérea viva, posteriormente regada e usada como argamassa e reboco. Este era também o procedimento para estabilizar as terras usadas na produção de adobes. Os edifícios construídos em adobe eram posteriormente rebocados com argamassas em cal e terra e decorados com argamassas de cal em pasta e areia muitas vezes com acabamento colorido em barramento de cal.
A ornamentação do tipo clássico na arquitectura em terra dos séculos XVIII e XIX foi em muitos países influenciada pelo manual de François Cointeraux (1740-1830) – *Les Cahiers d'Architecture Rurale" (1793),* um guião francês para a construção e arquitectura em terra.
Este manual chegou a Portugal no início do século XIX, mas nunca foi traduzido para a língua portuguesa. Referências à decoração para as casas construídas em terra são devidamente explicadas neste manual, assim como os procedimentos para a aplicação de argamassas em terra e cal na ornamentação das paredes em terra. De facto essas indicações são coincidentes com as que encontramos na arquitectura de adobe em Portugal na região do centro.
O objectivo deste artigo é mostrar alguns casos de argamassas e rebocos em terra existentes na arquitectura vernácula elevada em alvenaria de pedra e explicar os métodos usados na produção de argamassas em terra e cal, assim como exemplos de rebocos existentes na arquitectura vernácula de adobe em Portugal.

Palavras-chave
Arquitectura em terra; rebocos em terra; cal.

Earth mortars and renders

Earth can be used for construction purposes, if it has inherently good cohesion, provided by the presence of clay which acts as a natural binder. Soil or earth is the result of the transformation of the underlying parent rock under the influence of a range of chemical, biological and physical processes related to climatic conditions and to animal and plant life. Essentially the origin of a soil or earth is determined by the nature of the parent rock, the climate, the vegetation and the topography.

Earth is available everywhere and has undoubtedly been one of the most widely-used construction materials in the world. In Portuguese vernacular architecture, earth mortars were usually applied on stone masonry, while earth renders and plasters were used on indoors surface coatings. Lime was not easily available in certain areas of the country, especially on granite and schist regions where stone masonry was a current building technique (figures 1 and 2). Traditionally, earth renders or plasters were used for coating indoors on vernacular stone architecture in Portugal and earth mortar was applied in the construction of stone walls. Different grain size distribution or textures were used for mortars, renders or plasters. The texture reflects the particle sizes contained in the soil and influences the properties of the earth for construction. Each particle fractions - gravel, sand, silt and clay - with a specific set of characteristics can define those of the soil if the fraction is present in adequate quantities[1]. For example: ten per cent clay is enough to give soil cohesive and plastic properties but for mortars a sandy soil is required (with sand predominance of size between 2 mm and 0.08 mm), and for renders and plasters a sandy-clay soil is preferable (with sand predominance of size between 1 mm and 0.06 mm). Coarse sand is required for earth mortars and fine sand for earth renders and plasters.

Fig. 1 Mozinhos – Penedono (Guarda). Example of vernacular stone architecture.

Fig. 2 Mozinhos – Penedono, indoors earth render.

Local knowledge and traditional know-how was enough to select earth material, gathered from the natural environment, to be applied on building stone masonry. General procedure was to mix earth with water in order to obtain a semi-soft paste. With this homogeneous material it is easy to shape an earth ball which is neither sticky nor soiling and that flattens without disintegrating when dropped from a height of 1 m. Sometimes earth is previously passed through a sieve (10 mm for a mortar or render and 4 mm for a plaster) and mixed with 50 % of sand (coarse and fine sand for mortar and fine sand for render). The quantity of water depends on the clay properties but it is more or less between 16 and 20 % of the mixture.

On Portuguese vernacular architecture built on stone masonry, particularly in the Beiras region, earth renders and plasters were used on indoors surface coatings. The procedure was called "barrar" the house, and it

[1] The classification of grain sizes adopted is ASTM-AFNOR, standards are as follow: pebbles (200-20 mm), gravel (20-2 mm), coarse sand (2-0.2 mm), fine sand (0.2-0.06 mm), silts (0.06-0.02 mm), fine silts (0.02-0.002 mm) and clays (>0.002 mm).

means to apply a single thick or thin layer of sandy-clay plaster on a stone wall [1]. Its thickness varies between 2 to 4 mm.

Earth renders and plasters were applied to dry stable walls which were prepared. The preparatory phase in applying rendering was carried out with particular care. The support was rid of all loose and crumbling material, dust, and it was brushed with a metallic brush. In order not to reduce the adhesion of the rendering, the wall was moistened to avoid capillary suction, but not too much. Indoors surfaces used earth plaster in a single-coat applied with the hands, sometimes smoothed with the laying-on trowel and the float. In general, interior finishes are often smooth, to diminish the adhesion of dust produced by activities inside. A mixture of earth, cow dung and water was also used as a mortar to cover the floor.

Only a few examples of these renders and plasters still remain on some decayed Portuguese houses of the Beiras region. This technique of rendering and plaster with earth in Portugal has disappeared a long time ago, since these houses were abandoned by their inhabitants on the mid-20th century.

Earth-lime renders and plasters

Apart from their wall protection function, surface coatings play a decorative architectural role. The main functions of a protective coating are:

- Protection of the wall against bad weather and impact;
- Improvement of appearance by hiding the imperfections of the wall;
- improving thermal comfort, specially indoors;
- giving an attractive decoration, ornamentation and colour to the surface [2].

Adobe buildings in Portugal appear in valleys near the rivers, like Tejo, Sado, Mondego and Guadiana, and central coastal area, Beira Litoral and Estremadura Setentrional.

Most of the Portuguese adobe architecture is rendered, surfaces varying from a simple smooth finishing to exuberant and colourful decorations. This architecture is difficult to identify, as layers of renderings cover the construction. But it can be recognised in the Beira Litoral region because rendering is limited to the public façade, the rest having no rendering at all [3].

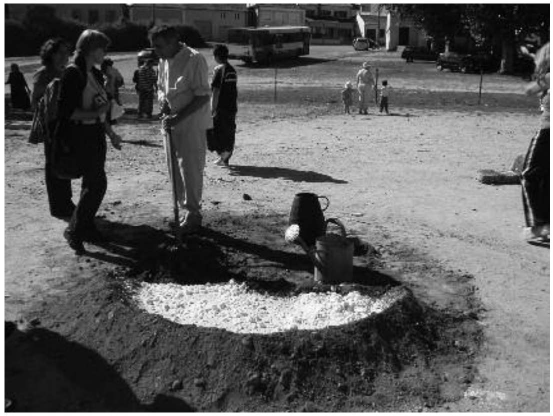

Fig. 3 Oliveirinha (Aveiro), workshop V ATP. Slake the quicklime, already mixed with earth.

Fig. 4 Oliveirinha, workshop V ATP, the adobe production. Earth stabilized with lime.

In the central west coast of Portugal the lime slaking procedure entailed slaking the quicklime mixed with earth (sandy soil), in a pit; the resulting mixture would then be combined in a mortar or plaster (figures 3 and 4). The lime needs to be in small lumps so it can be accurately batched by volume against the earth. The process requires time and space. The technique has, however, a distinct advantage over more familiar mixing procedures, consisting of an early marriage between binder material and aggregate, which encourages the covering of all the aggregate particles with a lime paste in a way and to a degree which can never be matched by conventional modern mixing [4]. Adobe buildings with earth-lime

Fig. 5 Oliveirinha, workshop V ATP. Earth-lime mortar.

Fig. 6 Oliveirinha, workshop V ATP. Rendering adobe wall with earth-lime render.

renderings and plasters were also traditional in the same region. Lime was used for stabilizing earth material because of its action on the clay particles of the soil (figures 5 and 6). The effect of lime on earth material is to reduce the voids of the earth material and to modify the links between the particles. The clay acquires a flocculated structure, whith the calcium ions provided by the lime forming contacts between grains. The clay-lime reaction results in the appearance of new crystalline structures which glue the earth particles together. This phenomenon occurs after a fairly long time [2].

Fig. 7 Vilamar 1, architectonic surface detail.

Fig. 8 Vilamar 2, decoration detail.

Fig. 9 Martingança (Leiria), adobe wall detail.

Case studies: Vilamar and Martingança

The three samples of earth-lime renders from adobe buildings in Portugal (the case studies from Vilamar and Martingança) are good examples of the above described phenomenon (figures 7, 8 and 9). On both case studies, mortar procedure was to slake the quicklime mixed with the earth which was combined with plaster for rendering. The difference between those houses was the adobe material and the joints mortar of the masonry. On Vilamar houses adobe was stabilized with lime and masonry joints were built with earth-lime mortar; on the contrary, the Martingança house was built with adobe without stabilization and the masonry joints were built with earth mortar. The houses from Vilamar (Cantanhede-Coimbra), built on 1931 and 1932, are from the architectural type Gandaresa house, a courtyard house with a decorated public façade and no rendering on the other façades. The house of Martingança (Leiria), built perhaps on 1920 or 1930, is from the architectural type house with an integrated porch, completely rendered, without decoration and without differences among façades.

The decorated façades from Vilamar houses, Vilamar 1 and Vilamar 2, present a rendering in two coats. The anchor coat, the first one, is an earth-lime render which thickness ranges from 2 to 4 mm and its surface has a rough appearance; the second coat is a lime-putty layer with a 1 mm thickness. Some coloured lime-wash layers are also visible as wall finishing over the second coat. The ornamentation or decoration in relief applied over the first coat, exclusively on the top, base and angles of the façade, is a plaster rendering built with lime-putty and fine sand which thickness ranges from 3 (column) to 4 mm (cornice). Some iron pleats act as anchor points between the wall and the reliefs.

The Martingança house walls have renderings in two coats with a wall finishing on multiple layers of white lime-wash. The first and second coats of renders are very similar in what concerns grain size distribution, their thickness ranging from 1 to 2 mm. It is visible, on the Martingança case, the poor adhesion of the render to the support. The main reason for this defect is the structural tension between the earth wall and the earth-lime render (figure 9). Maybe if the masonry joints were built with the same material as the render this deficiency would not have taken place. That is what has happened in the Vilamar houses, where there is a complete adhesion between the support and render.

In what concerns rendering decay there are some differences between Vilamar houses. Vilamar 1 has numerous symptoms of render decay and their causes are multiple. For example: it is visible the render crumbling on the wall base caused by rising damp, the small craters pitted on the surface of the rendering, the presence of cracks and the surface maintenance with unsuitable materials like cement (figure 7). In Vilamar 2 there are also symptoms of rising damp and render crumbling on the wall base; cracks are caused by structural defects in foundations and by the presence of efflorescences on the wall (figure 8).

The difference on grain size distribution on the first coat of render can explain some of these differences between Vilamar 1 and Vilamar 2. The crumbling on the Vilamar 1 render and the presence of small craters on the surface are directly caused by the unbalanced grain size distribution of the render with a high percentage of coarse sand and silts. On the Vilamar 2 render the grain size distribution is much more balanced.

These three houses were abandoned a long time ago. Unfortunately this is the most common situation for adobe architecture in both regions. The emigration, the new uncharacteristic architecture, and the prejudice against adobe architecture are the main reasons for the abandonment and in consequence for the destruction of this vernacular architecture.

François Cointeraux (1740-1830) and the earth-lime renders on earth architecture

François Cointeraux was a French builder from Lyon, France. He was the author of 72 fascicles or edition pamphlets about earth architecture and the responsible for the renovation of these traditional building techniques in France and, later, in many other countries[2]. The purpose of this movement in the 18th-19th centuries was to provide cheap, healthy, incombustible and durable

[2] The original documents are available on the French National Library. Photocopies and micro-films of all this documentation are also available in CRATerre (International Centre for Earth Architecture) in Villefontaine, France.

housing. François Cointeraux's writings were translated into various languages and published in United Kingdom, Germany, Denmark, Italy, even Australia, and played a important role in spreading the earth techniques in these countries [5].

References about earth-lime renders and plasters on earth architecture can be read on the 1st, 2nd and 4th "Cahiers d'architecture rurale" and on the specific fascicle "L'Art de peintre a fresque sur le pisé", whose author is François Cointeraux. Renders based on mineral binders like lime should be applied in several coats, at least two, but preferably three: a first anchor coat, an uncraked second coat and a finishing thin coat, with the thickness of each coat diminishing towards the surface. François Cointeraux knew exactly the problems between an earth support and an earth-lime protect coat. On the "L'art de peintre sur le pisé" he researched the theme and concluded that anchor points are always necessary between earth support and mineral coat. On adobe walls, the fragments: flakes of stone or broken pottery could be inserted in the fresh joints mortar. This solution is very common on adobe walls in Portugal, when the adobe is not stabilized with lime. For rammed earth, anchoring points of the same composition as the rendering can be also provided. Layers of lime mortar or lime included in outer thickness of rammed earth could act like anchor points [6]. François Cointeraux discovered this solution for rammed earth when he compared the behaviour between an earth-lime render over an adobe wall and over a rammed earth wall. On the second case the rendering could be easily scratched; on the contrary, the render over an adobe wall had a good adhesion to the support. The other discovery made by François Cointeraux concerns the composition of the earth-lime render. If the composition of the joint mortar is the same as the rendering's, the adhesion between wall and render is better.

Another function of the wall protection surface coatings is the decoration and the ornamentation. This aspect of rendering in finishing and decorating adobe buildings is apparent in many countries and has been exploited for one or two hundred years in Portugal. The variations on geometric decoration, painted, sculpted or moulded in the thickness of the render, are numerous. On the other hand, some decorations are simple, like the coloured layers in lime-wash over the adobe walls or over earth-lime render coats. François Cointeraux refers this aspect on the "4th Cahier d'école d'architecture rurale", with drawings of two situations: "maison de terre ou pisé décorée" and "la même maison de terre sortant de la main de l'ouvrier" [5] and also with a funny dialogue between the wall and the decoration coat, where the social differences among habitants were mentioned on the decoration motifs of their rammed earth houses [6].

The motifs of the decoration on a bourgeois house described by François Cointeraux are exactly the same as the farmer adobe houses in the Beira Litoral region in Portugal. Cornice on the top, pilasters, columns, and reliefs on the surface and a base course in a different texture and thickness are the motifs of the earth-lime renders and plasters. Different iron nails act as anchor points between the render coat and the decoration. Vilamar adobe houses are examples of this decoration and we can also find geometric and Art Deco ornamentation on the Gandaresa houses.

There is no clear explanation for this coincidence, only some hypotheses. The François Cointeraux "Cahiers" arrived to Portugal in the beginning of the 19th century, but were never translated to Portuguese. The know-how of these techniques from the builders on the region, the influences from France and from the emigration, especially from Brazil and North America, could explain this decoration and the solutions for rendering adobe buildings in Portugal.

Conclusion

The Gandaresa house is an adobe architectural house type, with a great quality of space, construction and architectural characteristics. Unfortunately the majority of these houses are abandoned and only a few examples were restored and still habitable. On the other hand, the house with an integrated porch is a poor adobe house, without architectural quality and unsuitable to nowadays use. The majority of these houses are also abandoned. It is essential to stimulate the discussion of the importance of value-based criteria. Perhaps the house with an integrated porch has no place in the present landscape of Portugal.

The use of earth mortars and renders in Portugal never surpassed a vernacular and regional craft, abandoned many years ago and replaced for lime mortars and renders recently. The technology of this technique was not developed, and it is disappearing, like the vernacular dwellings built on stone masonry and earth. Measures to be implemented should considerer practical intervention to conserve the vernacular buildings, and a combination of traditional and modernity in the restoration of this architecture. Earth mortars and renders can be of use in the future, but not in a traditional way like it was in the past.

In what concerns earth-lime renders, the procedures for rendering adobe walls in Portugal have not been enough researched. The study and research associated to this subject of conservation investigation have been sporadic and characterized by the use of inadequate criteria and measures to guide their effort. Recent research on the Aveiro University is a successful example in Portugal. They designed and implemented a complete programme which analyses different aspects such as: existing pathologies of adobe buildings before conservation, laboratory analysis of the composition of earth and its stabilisation with lime, study and documentation of the adobe buildings on the Aveiro region, the compatibility of conservation materials for the application on adobe buildings, and finally a social involvement of the community with the Aveiro city council on the conservation and preservation of the adobe cultural heritage [7-8].

Still, it would be an illusion to treat such matter as indicative of success. In conclusion, a coherent and methodological programme of action to prevent decay and improve living conditions in the adobe Portuguese architecture should be undertaken.

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References

1 Barros, H., *Inquérito à habitação rural. Vol. 2, A habitação rural nas províncias da Beira*, Universidade Técnica de Lisboa, Lisboa (1947) 190-195.

2 Houben, H.; Guillaud, H., *Earth construction. A comprensive guide*, Intermediate Technology Publications, London (1994) 88-91, 333.

3 Galhano, F.; Oliveira, E. V., *Arquitectura tradicional portuguesa*, 2^{nd} ed., Publicações D. Quixote, Lisboa (1994) 178-226.

4 Ashurst, J.; Ashurst, N., *Mortars, plasters and renders. Pratical Buiding Conservation. English Heritage Technical Handbook. Volume 3*. Gower Technical Press, Ltd., Hampshire (1989) 3.

5 Guillaud, H., *Une grande figure du patrimoine régional Rhône-Alpes. François Cointeraux (1740-1830) pionnier de la construction moderne en pisé*, CRATerre-EAG, Villefontaine (1997) 12, 18.

6 Cointeraux, F., *L'art de peintre a fresque sur le pisé avec la découverte de l'auteur pour rendre durable cette peinture, ensemble les enduits, les tapisseries et l'épreuve du canon dans le pisé*, École d'Architecture Rurale (1805) 37-41, 55-57.

7 Veiga, R.; Velosa, A., 'Argamassas de conservação para edifícios em adobe' in *TERRA 2007. Proceedings*, Aveiro (2007), 142-4.

8 Santiago, L., 'A casa Gandaresa do distrito de Aveiro. Contributo para a sua reabilitação como património cultural', MA dissertation, Universidade de Évora (2007) 2083.

From Vitruvius' ceramic powder additives to modern restoration

Dos aditivos de pó cerâmico de Vitrúvio à restauração moderna

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Abstract
The text aims at giving a general view of the use of lime mortars additivated with ceramic powder taking advantage of its pozzolanic reactions. It emphasizes the main explicit references of this technique in the ancient writers, starting from Vitruvius and going through important theoreticians of the Renaissance, until it reaches the military engineers of the 17th and 18th centuries, particularly the Portuguese engineers who had a strong influence in the overseas constructions techniques. Some mistakes in the interpretation of these texts regarding the properties attributed to the addition of ceramic powder in lime mortars are also mentioned.
The continuation of the work refers to the description and commentaries of the tests and laboratory observations carried out on the additivated mortars in question. Among these are highlighted the hardening time, the mechanical resistance (axial compression and traction by diametral compression), water absorption by capillary uptake, total water porosity, accelerated aging in saturated solution of Na_2SO_4, loss on ignition x-rays fluorescence, permeability to water vapor and other procedures that contribute to the evaluation of the behavior of lime mortars additivated with the "cocciopesto" and of the pozzolanic reactions occurring in the material. As the theory would have no sense if it is not necessarily put in practice, the work ends with the description of the application of the mortar additivated with ceramic powder in a concrete case of restoration, with the description of the obtained results.

Keywords
Ceramic powder pozzolanas; additivated mortars; mortars for restoration.

Resumo
O texto pretende dar uma visão geral do uso das argamassas de cal aditivadas com pó cerâmico e as vantagens conseguidas através das reações pozolânicas obtidas. Destacam-se as principais referências explícitas desta técnica nos antigos autores, principiando por Vitrúvio, passando através dos mais importantes teóricos do Renascimento até chegar aos engenheiros militares dos séculos XVII e XVIII, particularmente os engenheiros portugueses que tiveram forte influência nas técnicas construtivas do Além-mar. Alguns equívocos na interpretação dos textos antigos, em relação às propriedades do aditivo de pó cerâmico são também, apontados.
O trabalho, em seguida, trata da descrição e comentário dos ensaios e observações de laboratório, levados a efeito nas argamassas aditivadas em questão. Entre estes destacam-se o tempo de endurecimento, a resistência mecânica (compressão axial e tração por compressão diametral), capilaridade ascendente, porosidade total acessível à água, envelhecimento acelerado em solução de Na_2SO_4, perda ao fogo, fluorescência de raios-x, permeabilidade ao vapor d'água e outros procedimentos que contribuem para a avaliação do comportamento das argamassas de cal aditivadas com "cocciopesto" e as reações pozolânicas acorridas no material.
Como a teoria não teria sentido se não tivesse que ser necessariamente materializada na prática, o texto termina com a descrição da aplicação da argamassa aditivada com pó cerâmico, em um caso concreto de restauração, com a descrição dos resultados obtidos.

Palavras-chave
Pozolanas de pó cerâmico; argamassas aditivadas; argamassas para restauração.

Introduction and history

The ceramic powder additivated mortars are not novelty in the study of historic mortars. In the Italian language they became known by the word *cocciopesto*, familiar to every specialist in this matter. What still remains to be studied further are some of the properties of this additive, especially the pozzolanic reactions that the mortar goes through with this mixture, trying to understand the empiric observations done by the ancient authors, from Vitruvius to military engineers of the 18th century. In the case of Brazil, its employment in the constructions is studied very little, even if its application was abundant, as it has been observed in the sampling and material analyses of old buildings, especially fortresses.

What will be mentioned now is in great part known by the history of architecture and archeology professionals, but it is worth mentioning because these are important pieces of information that lead to varied directions. It is not as much a systematic investigation of every source that refers to pulverized ceramic additivated mortars, as it is a collection of some examples throughout different times and construction professionals about the various qualities that were attributed to the additive. To close this text some observations will be presented regarding laboratory tests of old mortar samples containing brick powder and also of new ones, trying to understand their properties.

As usual, the oldest reference to this matter comes from the master Vitruvius in at least two segments of his text: *Also in the case of river or sea sand, if anyone adds crushed and sifted potsherds, in the proportion of one to three, he will produce a blending of material which is better for use* (Book II) [1, v. 1, p. 97]. Later on he said: *I have described how plastering is to be done in dry places: I will now explain how stucco is executed in damp places so as to avoid blemishes. First of all, in the chambers situated at ground level, to the height of about three feet* [Roman foot = 0,29 cm] *from the pavement, rough-cast made of powdered earthenware is applied and then the surface is smoothened, instead of a lime and sand mortar with powdered ceramic so that this part of the plaster may not suffer from damp* (Book VII) [1, v. 2, p. 97]. It is clear in the teachings that this is not, as many people say it is, a mortar to avoid the passage of water, but a mortar that avoids damages on the plaster because of its resistance and porosity. What is more, it was with this additivated mortar that the *opus signinum*[1] was fabricated, which was used as finishing without the need for paint and consequently letting the wall breathe freely. Its behavior would be comparable to one of a "sanitation" mortar, as it is known in the present, and not to an impermeable mortar that would not work well. Plinio, likewise, makes references to the ceramic powder mortar when he says: *Constructions exposed to humidity or built up in places where it may be affected by the vicinity of the sea, could, with advantages, be covered with a coat of plaster made with crushed ceramic* [2, p. 139]. Both teachings suggest the property of making mortars endure better the effects of moisture, regarding the durability towards the tensions of crystallizations of soluble salts. In practice it is easy to notice, especially in the archeological remains of Roman baths, the presence of lime plasters additivated with ceramic powder (Fig. 1). It is important to emphasize that, in spite of Vitruvius being the first author whose written references on this subject made it to our times, the use of crushed ceramics as additive was employed before his time by other more ancient civilizations, as the Greeks [3, p. 422].

In medieval times, when Villard de Honnecourt, in his well known sketches and notes book, gives us a recipe for an impermeable recipient, he specifies the use of oil besides the brick powder. The oil produces hydrorepe-

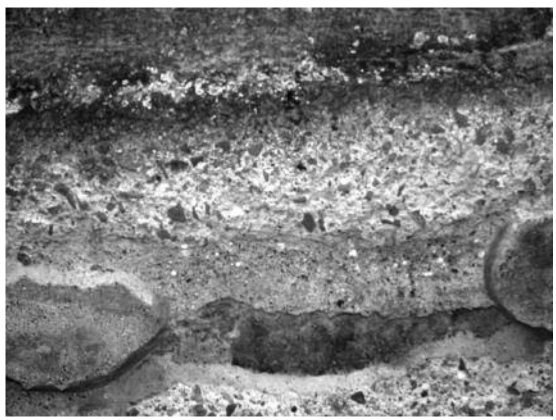

Fig. 1 Ceramic additivated mortars in Stabian baths in Pompey, Italy.

[1] Done as in Signia or from this town.

lence when added to the lime mortar[2]: *You take lime and crushed "pagan" tiles in the same proportion then you add a little more "pagan" tiles until its color surpasses the original color. Add to this cement some linseed oil so you can make a recipient to contain water*[3] [4, p. 100].

In the same manner, in the beginning of the Renaissance, the qualified teachings of Leon Battista Alberti came, in his *De re ædificatoria (L'Architettura)*, affirming: *If then you add one third of crushed bricks, it is the general opinion that this mixture will become much more tenacious*. It is important to observe that, once again, the objective was to bring more resistance and not impermeability. In fact, the original text reads *multo tenaciorem* [5, p. 188]. Later on, the experienced Pietro Cataneo, describing a special pavement, which must have been the one named "Venetian", recommends adding to the lime an identical amount of crushed tiles and also iron scoria. It is possible to conclude that these additives must harden the mixture because they bring hydraulic properties, making the pavement more resistant [6, p. 35]. Good references to the ceramic powder mortar were also made by Scamozzi, in some parts of his text, exemplifying their use in the old Roman theater of Vicenza [7, p. 297]. The hydrorepelence was obtained with a treatment of animal fat or vegetable oils, such as linseed oil.

The European military engineers of the 17th and 18th century, that many times had to deal in the fortresses with the fury of the cannons, with walls leaning against embankments or in the vicinity of water, made frequent use of this additivated mortar, as reported by Knight de Ville: *In Palmanova there is a mixture with a cement that, when dry, creates a body that resists well to bad weather and when it is hit by the cannon discharge it is not ruined*[4]*: This mortar could be made of crushed bricks, of lime and of crushed marble* [8, p. 89]. The teachings of the French, Italian and Dutch military engineers were source of knowledge for the Portuguese engineers; among them was Azevedo Fortes, the most well known Portuguese writer in the art of Fortification of the 18th century, who taught us: (…) *however, if it is near a river or for a water ditch it is necessary to protect the facing with good regular masonry in its beds and joints, and settled with lime and sieved tile powder, and also with bitumen if necessary* [9, p. 285]. So, his disciples and followers who worked in Brazil or taught in our military classes certainly applied these techniques of production of mortars, as observed in some of the documents and in several examples found in monuments through the investigation of their mortars (Fig. 2).

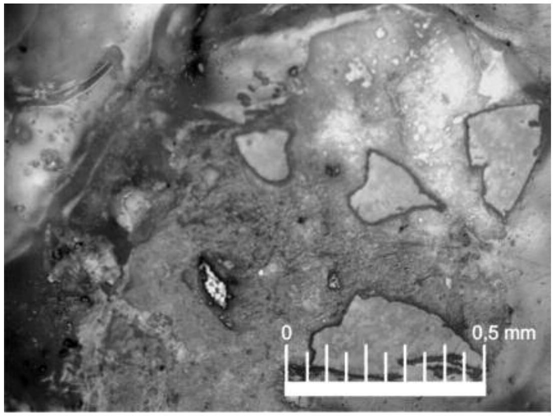

Fig. 2 Microphotography of a polished section of mortar with ceramic powder from the S. Alberto Fortress in Salvador.

Besides the European texts about construction, that were practically unanimous in recommending the good properties of lime mortar additivated with ceramic powder a "common sense", as Alberti affirmed, the following paragraphs will now address what was written and observed about this matter in Brazil, while colony of Portugal and even afterwards. This technical production was restricted among us to the military engineering profession, which was very important in the construction of the Portuguese America, since the architects only appeared with the French Mission brought by D. João VI, after 1808. The first known reference is from the Head Engineer of Brazil, Frias da Mesquita, who worked here the first 30 years of the 17th century. This document is a report about the fortress of the Three Wise Kings in the city of Natal [10]. In two segments of this document, he talks about a material called *tetim* or *tettim* that may be the ceramic powder. He says: (…) *and also the brick must*

[2] In Portugal and in Brazil it was common the employment of oils in mortars to bring hydrorepelence (and not to increase its resistance, as it is popularly affirmed).

[3] This information is found in the image 21, where the "Fortune Wheel" is represented.

[4] For this reason, the Field Master Engineer Miguel Pereira da Costa, who was born in Portugal but worked in Brazil, always used the "cocciopesto" in the parapets of the fortresses that he built..

be of good clay and well burned, and with no trace of salt water, and the "tettim" very well crushed, the mortars thoroughly rested for several days (…)[5] and also: *protected on the outside with good mortar and "tettim" for its better defense against humidity* (...) [10]. In this case, besides a better resistance, the mixture was hydrorepelent due to the presence of oil, a recipe similar to those left by Villard de Honnecourt and other writers.

The specific texts about construction are very rare in Colonial Brazil. One of them is a military engineering treatise written in Pernambuco by the Field Master Diogo da Silveira Velloso [11], a manuscript inedited until recently[6], in which the following reference related to the Vitruvian teachings is found: *It helps a lot the strength of the work (says Vitruvius) mainly in the foundations, and in damp places, the mixing of lime with crushed ceramics, pieces of tiles and bricks, which because of its dryness and roughness dries the work quickly and makes it harder.* It is interesting to observe the curious explanation for a pozzolanic reaction!

The examples in which the cocciopesto mortar is found are abundant and some samples from monuments of the city of Salvador and from other parts of Brazil have been known and analyzed. It is possible to find this material, for example, in the parapet of the walls of the fortresses of Barbalho and of São Pedro, or in the cannons platform of the little fortress of Santo Alberto (Fig. 2), when the excavations of its rampart were carried out. The material was found in very good conditions and it was extremely resistant. So, it is possible to arrive to the conclusion that this knowledge would be very important in modern restoration works, namely knowing more about the properties and better proportions of the mixture.

About recipes of ancient mortars in general, including mortars additivated with ceramic powder, a very interesting text of historical investigation by Carla Arcolao [12] was produced and deserves a special reference.

Testing and analysis

This way, the NTPR (Núcleo de Tecnologia da Preservação e da Restauração) has been trying, through systematic investigation, to better understand the behavior of the pozzolanic properties resulting from the addition of ceramic powder to mortars. About this matter, some observations will be made, many of which are already known by those who study the subject, but they may be useful as confirmation and eventually to bring some doubts to be discussed. The information obtained through tests and the observations made will be summarized so as to be compatible with the space available for this text.

Initially it is necessary to declare that the motivation of these studies is not merely academic or cultural; in this case, searching to rescue the memory of the construction science, it goes further. The constant proximity to the project and the execution of the monument restoration has demonstrated the need to find alternative technologies for its operational problems. The vastness of the Brazilian territory and, in most cases, the little resources available for intervention procedures to be carried on monuments, make necessary, to avoid the use of industrialized products, some of them imported, to face the restoration problems with solutions which are simpler or identified more closely to cultural traditions. Certainly in the field of "sanitation" mortars there are already a lot of commercialized products which are efficient. Some of them are imported, others are made in Brazil. However the final price of these plasters is around five times more than that of traditional mortars, as it has been calculated. This leads us to search for alternatives, especially in the covering of large areas.

The first question to be presented is the presumed impermeability of the mortar with ceramic powder. Really, none of the cited authors makes any reference to this impermeability – when desired they recommended the addition of oil. The tests that will be commented later on show that the mortars additivated with ceramic powder are in fact more porous, more permeable to water vapor, with a better capability of absorption of water under low pressure and present other indicatives of a "sanitation" mortar and not those of an impermeable mortar.

By definition a pozzolana (in this case the ceramic powder) must be finely pulverized to become more reactive. On the other hand, this is not recommended textually in many ancient writings and the workers did

[5] This waiting period could not be long because after 5 or 6 days the mixture could have hardened, as it was verified.

[6] Velloso's treatise was transcribed and edited with the authorization of Ajuda's Library and commented by the author of this text.

not always notice the problem, considering it is possible to find, in many Roman monuments and even in Brazil, mortars with ceramic coarsely pulverized in the mixture, with fragments superior to 4 mm (Fig. 1). Vitruvius and Azevedo Fortes, however, suggest the sieving of the material, which presumes reduced grain sizes. Frias da Mesquita talks about "tettim" very well crushed which leads us to the same conclusion. In Brazil, the theme of the size of the grain has already been explored by Nappi and Meyer [13], but other observations were performed, arriving to numbers compared among several forms of mixture. Notice, in Fig. 3, that the samples intended by CVN additivated with coarse pulverized ceramic (retained in the sieve # 12 ASTM, 1.68 mm or 10 mesh) do not increase the resistance, as expected, but on the contrary, may induce a slight reduction of the latter.

It is important to clarify that the ceramic material employed in the observations had the same origin. Initially it was used industrially burned material, but due to the knowledge of the local reality in which unfortunately there is no burning temperature control, it was decided to obtain pre-burned industrial material, to be burned in the lab under controlled temperature. It is equally important to emphasize that, even though harder to obtain, the crushing of the ceramic powder was made in a porcelain pounder, when the samples that would be chemically analyzed were made. This procedure was done to avoid iron contamination originated from the iron balls grinder available for the operation.

Another subject that deserved observation was the predominant composition of the clay mineral of the argillaceous material contained in the ceramic. It is obvious that the pozzolanic reactivity depends on its mineral components. It was observed, for example, that the white ceramic in which the clay mineral kaolinite was abundant has a much differentiated effect from that of the red ceramic where the iron oxide is more abundant. This phenomenon was emphasized equally by Silva et al. [14, p. 10]. Apparently the iron works as a material that facilitates the pozzolanic reactions. This is a matter to be discussed by chemists. It is also important to clarify that with the ceramic powder employed it was not possible to reach the level of 6 MPa,

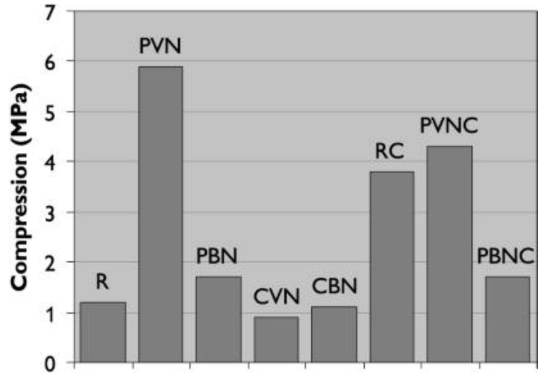

Fig. 3 Comparison of the mechanical strength. Preliminary tests with 1: 2: 1 (lime, sand and ceramic powder) in mass. Samples' codes: R= reference samples; P=powder; V=red; B=white; C= artificially carbonated; N= burned in lab.

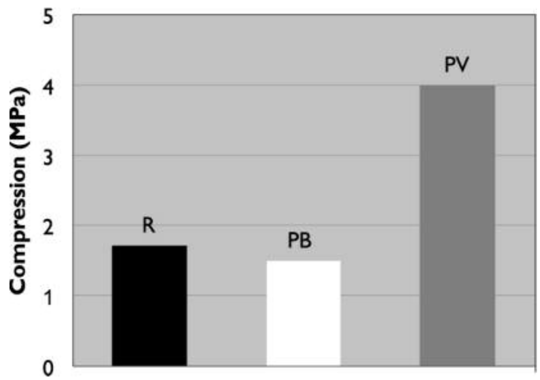

Fig. 4 Comparison of the mechanical strength. Proportions in volume, 1: 2.5: 0.5 (lime, sand and ceramic powder). Samples' codes as in Fig. 3.

(NBR-5751) suggested in the text of Silva et al. [14, p.8].

In Fig. 3, it is observed, for example, that the increase of the resistance to compression of the additivated with red ceramic powder samples (PVN) rose significantly comparing to the samples of sand and lime (R), while the white clay raised this resistance relatively less. In the case of the employment of the rough granulation (CVN and CBN), nothing was added, but perhaps lessened. On the other hand, when the samples are submitted to accelerated carbonation[7] a very interesting phenomenon happens.

[7] The objective need to develop studies, within a time limit, when working with lime mortars, in which carbonation is very slow, led to the need of creating a process of induced carbonation, which does not reproduce exactly the result given by a mortar naturally hardened, but it gives a good idea of the tendency of resistance increase. The process consists of submitting the samples to vacuum, in a special container, and after that letting in pure CO_2 until the regular pressure is stabilized.

The lime mortar (RC) naturally increases its resistance, but the samples additivated with red ceramic powder (PVNC) have a lesser increment of their resistance, compared to the ones cured naturally. This is certainly due to the fact that a part of the Ca, that would originate the calcium silicates along time, is directed to form the $CaCO_3$, which leads us to think that the result of the pozzolanic reactions increases over time. The samples employed in this experiment were tested after 6 months[8] and the carbonated ones received, after removed from the mold, 15 days of carbonation chamber.

After this preliminary evaluation, the subsequent observations were focused on the behavior of the mortars exclusively additivated with the red ceramic powder, with a larger percentage of iron (Fe) in its composition, and fine grain size (< # 20 ASTM, 0.84 mm or 20 mesh). A finer one was not tried because in practice this never happens and the ancient workers would never employ a more pulverized material. It is important to clarify that there is a reason behind the better performance, in terms of resistance, of the additivated mortars initially (Fig. 3) and the results found in the second phase (Fig. 4). In the beginning the scholarship students used the mixture in mass, with a consequent relative increase of lime and of additive (1:2:1, lime+sand+additive, which results in 1:0.28:0.48 in volume approximately) and in the second phase the mixture was adjusted to some historical parameters (1:2:1 in volume)[9] indicated by some writers for coating mortars. However, there is a coherence of results[10] from which it is possible to notice that the increase of the proportion of ceramic powder increases also the mechanical resistance of the mortar. In this matter it must be observed that for the "Venetian" pavements, Cataneo recommended equal parts of lime and ceramic powder, adding to the mixture a small part of iron scoria, also known for its pozzolanic properties.

The tests of the lime mortars' adhesion to the wall are always a problem, when time is limited, because it is not easy to induce the carbonation of the plaster in the wall. In fact, the only tests that presented any result in pull-off tests were the ones performed over mortars with ceramic red powder (between 1 and 0.6 kgf/cm^2), applied directly to a wall of bricks.

The formation of the new silicates, and possibly aluminates, may be observed by comparing the regular lime and sand mortar with the additivated mortars in the graphic of the calcimetry tests (Fig. 5), the diagram of analytical results obtained with the test of loss on ignition (Fig. 6) and the table with the x-rays fluorescence analysis (Table 1).

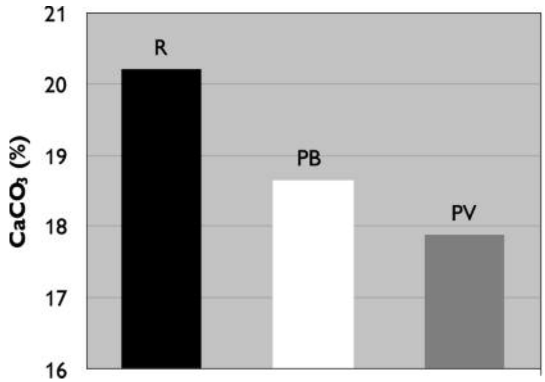

Fig. 5 Comparative graphic of the quantity of $CaCO_3$ contained in the samples. Samples' codes as in Fig. 3.

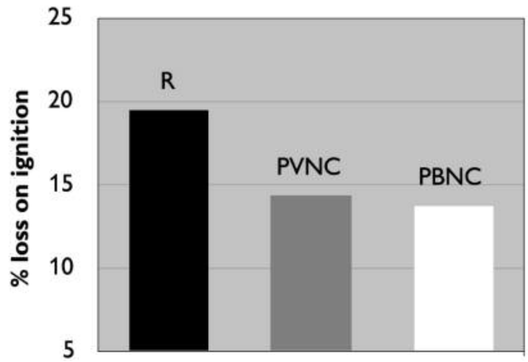

Fig. 6 Results of the tests of loss on ignition. Samples' codes as in Fig. 3.

[8] In this period the total carbonation had not occurred yet, as it was observed through tests with the phenolphthalein reactive solution.

[9] This mixture is suggested by Vitruvius, Alberti and others, but there are some other mixtures, in special mortars, in which the sand is not used, as suggested by Cataneo for the "Venetian" pavement and by Villard de Honnecourt.

[10] Regarding the proportions of lime and sand mortar in the Vitruvian texts there are no doubts: 1:2 when the sand comes from the river or sea and 1:3 when the sand comes from a quarry. On the other hand, the amount of ceramic powder additive is not clear. This subject is dealt with when it is related to the proportion 1:2 and talks about one third (tertia parte adiecerit). Will that be one third of the gross or one third of the sand? One way or another it will always be less than half the sand – 1:2:1 or 1:2:0.7.

Table 1 Comparative table of the mortar samples regarding the formation of oxides.

Analysis	Reference (B) 1 year and 3 months	Red Powder 1 year and 3 months	White Powder 1 year and 3 months
CaO	76.41 %	54.33 %	58.66 %
SiO_2	17.53 %	30.98 %	30.23 %
Al_3O_3	0.29 %	5.89 %	4.95 %
MgO	4.73 %	3.36 %	3.50 %
Fe_2O_3	0.28 %	3.41 %	1.40 %
K_2O	0.04 %	1.05 %	0.51 %
TiO_2	0.18 %	0.60 %	0.50 %
SO_3	0.34 %	0.08 %	0.13 %
ZrO_2	0.03 %	0.04 %	0.06 %
SrO	0.03 %	0.03 %	0.03 %
P_2O_5	—	0.03 %	0.02 %
Rb_2O	—	0.01 %	0.01 %
In_2O_3	0.12 %	—	—
Cl	0.03 %	—	—
Na_2O	—	0.13 %	—
MnO	—	0.04 %	—
Cr_2O_3	—	0.03 %	—

In this case, it may be observed clearly that, while the first sample of lime and sand integrates only $CaCO_3$, with the addition of the ceramic powder a part of the calcium is digressed to form calcium silicates, much more stable. This may be noticed also when we evaluate the loss on ignition (Fig. 6), because the procedure of the ABNT-NBR 6473/1998, that establishes a calcination at 950 ± 50 °C, does not affect silicates and aluminates, whose decomposition occurs at around 1500 °C.

What remains evident, besides the improvement of the mechanical resistance to axial compression and of the adhesion to the substrate, is the increase of the porosity that can be observed not only through the total water absorption tests (Fig. 7), but also through the water absorption by capillary uptake (Fig. 8) and surface water absorption (Fig. 9). It would be very important to understand the porosity distribution of the material and to verify the pore typology and size in the additivated mortar[11]. Consequently, it makes sense to compare them with the "sanitation" mortars, of which the main characteristic is the porosity.

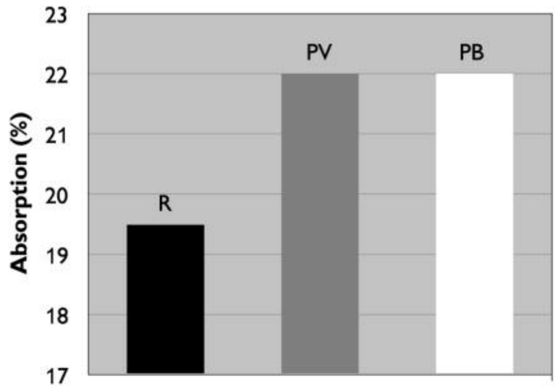

Fig. 7 Test of porosity accessible to water. Samples' codes as in Fig. 3.

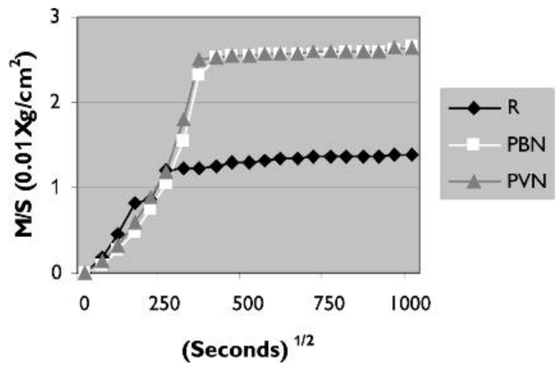

Fig. 8 Compared capillary water uptake of the different kinds of mortars. Samples' codes as in Fig. 3.

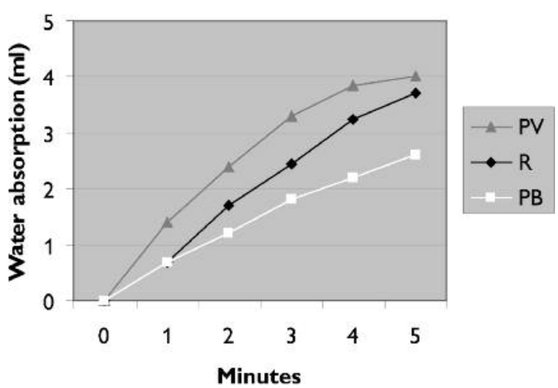

Fig. 9 Surface water absorption of the wall employing the Karsten pipes. Samples' codes as in Fig. 3.

11 Preliminary porosimetry tests were performed which indicate that the addition of ceramic powder changes strongly the pore size distribution.

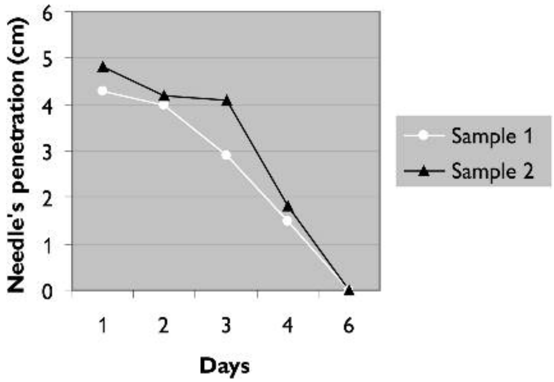

Fig. 10 Vicat's needle teste (adaptation).

The speed of hardening of the mortar was observed by the traditional Vicat's needle, demonstrating that the material was hard by the sixth day (Fig. 10).

Practical experiments

As Brandi very well indicated, the theory would not make sense if it was not to be necessarily put in practice [15, p. 55]. So, the lime mortar additivated with ceramic powder was applied in a specific and critical case of a wall with a massive presence of soluble salts. The opportunity came during the restoration of the Main Church of the historical city of Cachoeira. In this town, the occurrence of "leprosy" of the mortar (Fig. 11) is very frequent, produced by soluble salts that migrate by rising capillarity or even in isolated spots caused by contaminated construction material. The verification of the presence of soluble salts in the buildings of the referred town, including its Main Church, has been requested several times, and it was confirmed, almost always, a strong presence of NaCl and an even worse one of Na_2SO_4.

The preliminary tests for the coating of the most affected area, using a mortar similar to the one found in that same place (lime+sand+"saibro"), showed that this mortar, in little time, exhibited signs of decay, which also happened when the lime was substituted by a cementitious material. Only the mortar with ceramic powder is holding on to the present day, with the final application of mineral paint (Fig. 12).

Fig. 11 Situation before the restoration (2001).

There is no pretence of thinking that the problem has been solved definitively. The salts are still in the wall and sooner or later they might affect the surface. However, it may be affirmed that the additivated mortar is resisting better to the problem.

Conclusions

The conclusions may be summarized as follows:

- The procedure of employing ceramic powder as additive of lime mortars comes from thousands of years ago and was applied even in places where other pozzolanic materials were available.
- It is one of the most mentioned uses by the writers since Vitruvius;
- It is a process that brings, in general, meaningful improvement to the lime mortars;
- The more ceramic additive is added, the better the mechanical resistance;

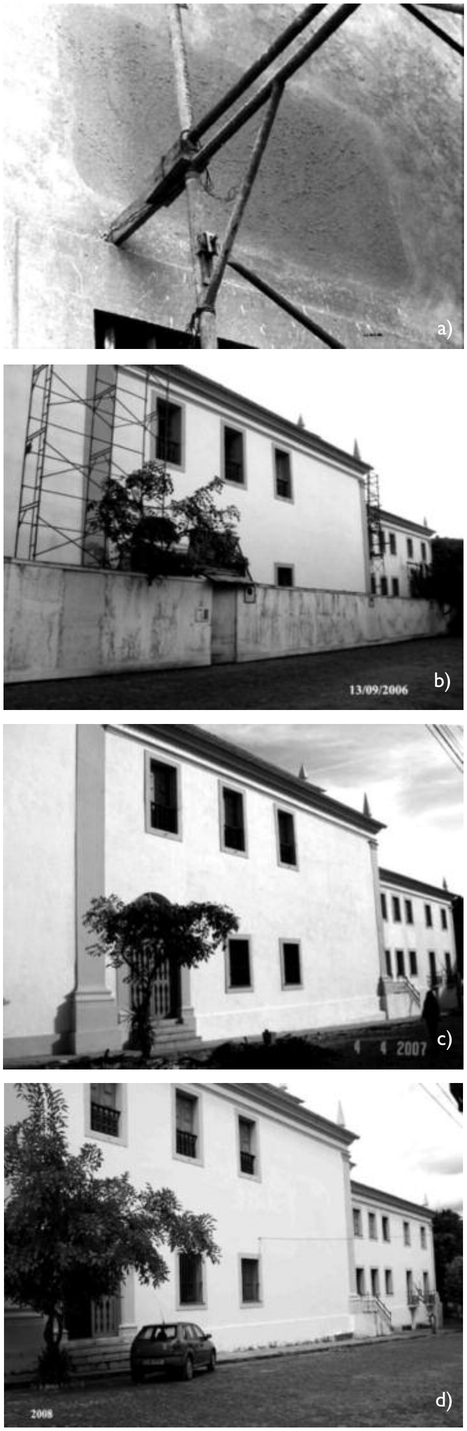

Fig. 12 a) Coating tests; b) After the application in 2006; c) Situation 2007; d) Condition in 2008.

- It was widely used in Brazil during its colonial period, especially by the military engineers in the construction of fortresses;

- It may be used as alternative material for modern restoration, not only in the lime coatings that need a faster hardening, but also in the walls contaminated with soluble salts.

Acknowledgments

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References

1 Vitruvius Pollio, M.., *On Architecture*, translation by F. Granger, William Heinemann, London (1962).

2 Plinius, *Natural History*, vol. 10, translation by D. E. Eichholz, William Heinemann, London (1962).

3 Martin, R., *Manuel d'Architecture Grecque*, vol. 1, A. & J. Picard, Paris (1965).

4 Carreira, E., *Estudos de iconografia medieval – O caderno de Villard de Honnecourt arquiteto do Século XIII*, Universidade de Brasília, Brasília (1997).

5 Alberti, L. B., *De re ædificatoria (L'Architettura)*, vol. 1, translation by G. Orlandi, , Il Polifilo, Milano (1966).

6 Cataneo, P., *I Quattro primi libri di Architettura*, Figliuoli di Aldo, Vinegia [sic] (1554). Facsimile by The Gregg Press Incorporated (1964).

7 Scamozzi, V., *Dell'Idea della Architettura Universale*, vol. 2, Presso l'autore, Venetia (1615). Facsimile by Arnaldo Forni Editore (1982).

8 Ville, C. A., *Les fortifications du Chevalier Antoine de Ville*, Chez Philippe Borde, Lyon (1640).

9 Fortes, M. A., *O engenheiro português*, vol. 2, Manoel Fernandes da Costa, Lisboa (1729).

10 Itamaraty Archives, Report and recommendations by Frias da Mesquita to the fortress of the Three Wise Kings, in Rio Grande do Norte, dated from 1619/11/01.

11 Oliveira, M. M., *Arquitetura Militar ou Fortificação Moderna escrito por Diogo da Sylveyra Vellozo*, PPG-AU/EDUFBA, Salvador (2005).

12 Arcolao, C., *Le ricette del restauro*, 2nd ed., Marsilio, Venezia (2001).

13 Nappi, S.; Meyer, T., 'Influência da granulometria do pó de tijolo nas características de uma argamassa à base de cal para utilização em obras de restauro', in. *Seminário Tiradentes, sobre a Conservação e Preservação do Patrimônio Histórico*, Tiradentes, Minas Gerais (2003) 21-24.

14 Silva, J.; Brito, J.; Veiga, M. R., 'Pozolanicidade do pó de tijolo: Uma propriedade a potenciar', *Pedra & Cal* **32** (2006) 7-10.

15 Brandi, C., *Teoria del restauro*, Einaudi, Torino (1977).

Conservation of the historical render in the Church of Nossa Senhora da Assunção in Elvas

Conservação dos rebocos históricos na Igreja de Nossa Senhora da Assunção em Elvas

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Abstract

In this paper we present a practical case of conservation of the historical renders in the pyramidal tower of the Church of Nossa Senhora da Assunção in Elvas (Portugal), carried out by the former IPPAR (Portuguese Institute of Architectonic Heritage), now Regional Direction of Culture of Alentejo. Awareness of the value and of the risks facing these renders points towards the necessity to safeguard their material authenticity.

During the works of conservation of the main façade, under the layers of non decorated recovering render, a previous decorated render, simulating stone masonry, with raised joints reproducing stone divisions and the internal structure in solid brick, was discovered.

After material and historical analysis we came to the conclusion that it was highly probable that this render was contemporary to the construction of the Church and, as such, it seemed essential to conserve and restore this covering as historical evidence and cultural heritage.

Treatment of the pyramidal tower render included removal of the non original recover mortars, survey of ancient materials, execution of technical and decorative scheme, surfaces' cleaning and consolidation of the weaker original old mortars. In order to fill the gaps in the original surface, specific lime mortars, prepared with washed sand and standard grain size, were used. Restoration techniques were used to reconstitute and integrate the lacunas. These actions not only conserved the workmanship, but also reconstructed the decorative structure and a reading clarity, allowing the identification of restoration without the connotation of a mimetic integration.

This joint action, only possible with the help of the conservation and restoration team, puts into evidence the possibility of continuous evaluation and learning. It is clear that, in cases where there are unknown, unpredictable factors, due to the specific work and value of the materials, it is possible to change the course of action and introduce new and improved measures to take into consideration new facts and new opportunities of preserving the cultural value of historical renders.

Keywords

CATHEDRAL project; Church of Nossa Senhora da Assunção; conservation; historical renders; restoration.

Resumo

Apresentamos o caso prático da conservação do reboco histórico da cobertura piramidal da torre da fachada da Igreja de Nossa Senhora da Assunção, antiga Sé de Elvas, intervenção promovida pelo antigo IPPAR, agora Direcção Regional da Cultural do Alentejo.

Acreditando na importância da divulgação, pretendemos: dar a conhecer e sensibilizar o leitor para o valor histórico e artístico destes revestimentos; apontar situações de risco neste património, e alertar para a necessidade de salvaguardar a sua autenticidade estética e material.

Durante os trabalhos de conservação da fachada verificou-se que, sob a camada de reboco final, não decorada, existia um reboco, decorado, simulando a alvenaria aparelhada com a marcação em relevo das juntas das pedras. Existindo fortes probabilidades de que este reboco fosse um testemunho contemporâneo da época da construção da Igreja, pareceu-nos fundamental alterar os trabalhos previstos e optar por conservar este revestimento enquanto reboco histórico.

A intervenção incluiu: a remoção das camadas de reboco não funcionais; o levantamento das superfícies com registo de materiais e estereotomia das juntas; a pesquisa de técnicas e materiais tradicionais; a limpeza a seco das superfícies; a consolidação das lesões; a integração das descontinuidades nas argamassas originais; a execução de um reboco de enchimento e preparação para a camada final e a realização da superfície final com a marcação das juntas, simulando a estereotomia da pedra.

Esta acção, além de conservar a obra, restituiu à estrutura decorativa uma *clareza de leitura* permitindo a identificação do restauro sem assumir a conotação de uma integração mimética.

A metodologia utilizada, a colaboração entre a equipa técnica de conservação e restauro e o director de projecto, as sinergias criadas pela transdisciplinaridade da equipa, assim como o rigor da execução demonstraram que é possível conhecer o monumento durante o processo de conservação, assim como avaliar e validar continuamente as diferentes opções tomadas.

Palavras-chave

Igreja de Nossa Senhora da Assunção; conservação; Projecto CATHEDRAL; rebocos históricos; restauro.

The Church of Nossa Senhora da Assunção

The former Sé or Cathedral of Elvas, dedicated to Nossa Senhora da Assunção (Our Lady of the Assumption), is classified as a National Monument, and it can be immediately identified by the solid force of the façade, which is an imposing presence in the square and in the landscape.

Construction of the existing Church may have started in 1517 according to the founded opinion of some authors [1, p. 1; 2, p.1]. The Church was built in the place of a previous building presumably in Gothic style. At the same time and facing the Church, a new and big urban square was defined. This big square had straight implications in the urban structure of the town, where the Church and the facing square became the central and the most important part of Elvas.

Authorship of the architectural work of the Church of Nossa Senhora da Assunção of Elvas is often attributed to Master Francisco de Arruda [2, p.1]. However, recently, some art historians doubted this authorship [1, p.7-14; 3, p.80]. According to José Custódio Vieira da Silva, the work, in "Manuelino style", of the Cathedral of Elvas "has the architectural unsuspected and revealing quality of an experienced architect" [1, p.12].

The recognition of the heritage value of this monument and the concern for its state of conservation justified the "Project of Conservation of the Cathedral of Elvas" presented to the Operational Program of Culture, in 2000. The extension of the intervention in the building and the enormous economical budget foreseen justified a phased project lasting for 6 to 8 years. Presently, the restoration has finished the last phase. The restoration aimed at improving the conditions of welcome and public delight of the building and contributing to a better knowledge and diffusion of its heritage value. Restoration of the main front façade and the bell tower were included in the several actions promoted and carried out in the scope of the conservation intervention.

The façade was undoubtedly one of the most problematic situations, due to the state and degree of alteration of the stone material and the non-functionality of the joints and also due to the architectural meaning of the façade for the whole monument and for the image of the city (fig. 1).

The axial tower composes the imposing and symbolic main façade of the Church of Nossa Senhora da Assunção. The large dimensions of the tower define, almost in exclusive, the principal façade of the cathedral. This axial arrangement of the tower is not usual in Portugal, although there are some parallelisms with the Church of Saint Magdalena of Olivença, built at the same time.

Fig. 1 Church of Nossa Senhora da Assunção before the works of conservation.

For José Custódio Vieira da Silva [1, p.12], it is not easy to outline the reasons for the choice of this façade typology. However the author refers that this formal option is firstly due to practical conditions, like the lack of space, though it does not hide the symbolic conception marked by the almost military imposition of the axial tower. Note that the Church of Nossa Senhora da Assunção, being built on a pre-existent church, could not dispose of the space required for the construction of the bell tower in a different location.

Probably, the bell tower of the church was the last part built in "Manuelino style", in 1538. The pyramid was probably built at the same time.

The intervention

As a strategy, the former IPPAR prepared a public procurement for the intervention of conservation and restoration of the old façade of the Cathedral of Elvas that was won by the firm Nova Conservação (nr. 85/IPPAR/E/03) (fig. 2).

During the works on the site we discovered, on the top of the tower, in the pyramid part, under the finishing layer of the non decorated render, a previous decorated render that simulates stone masonry with raised joints (figs. 3-7). In fact, when preparing the conservation project for the restoration of the façade we used mechanical elevators for a prior study of the conservation and materials' diagnosis but, at that time, with this equipment and weather conditions, it was not possible to observe any traces of the existence of this historical render.

Fig. 2 Church of Nossa Senhora da Assunção during the works of conservation.

After a material and historical analysis[1], we considered that there were strong probabilities that the newly discovered render, simulating stone masonry, could be a contemporary evidence from the time of the construction of the tower [4, 5]. With this hypothesis in mind, we thought it would be necessary to alter the project and the works foreseen, which included removing the degraded mortars, dry cleaning the brick masonry and executing a new render, and we decided to conserve and to restore this covering as historical evidence and cultural heritage.

Assuming the *sine qua non* condition to preserve the material, as cultural evidence, we proposed to *Nova*

Fig. 3 Initial state of conservation of the pyramidal tower.

Fig. 4 Detail of the initial state of conservation.

[1] This Church is a case study included in the research Project "CATHEDRAL"- Characterization and Conservation of Traditional and Historical Mortars from Alentejo's Religious Buildings (http://cathedral.lnec.pt).

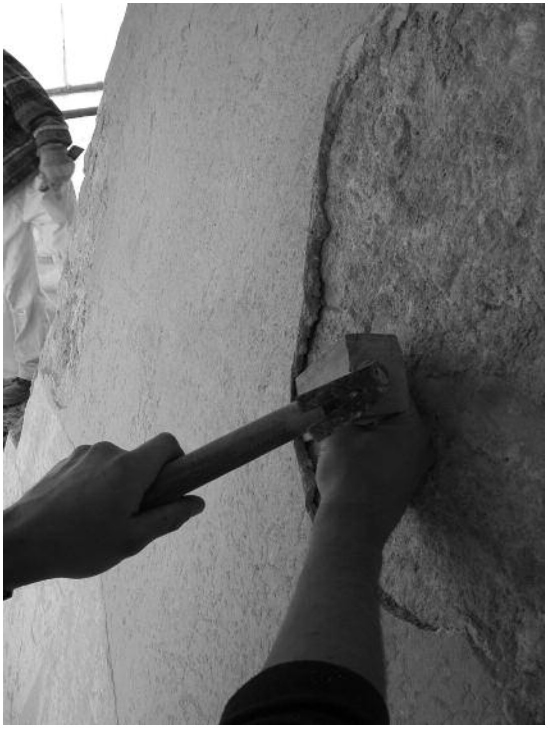

Fig. 5 Removal of the non decorated recovering render.

Fig. 7 Detail of the previous decorated render.

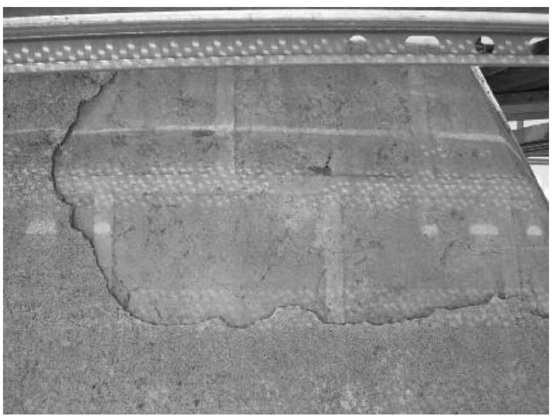

Fig. 6 The previous decorated render discovered under the layers of non decorated recovering render.

Conservação to alter the scheduled works and restore this historical covering that should maintain also its protective function. This restoration should follow an open project methodology, according to the data that eventually might be discovered through research in the lab and *in situ*.

Conservation activities

The restoration of this historical render took place from January to March 2006, at the same time of the conservation work on the façade.

Restoration activities carried out were based on the following assumptions and aspects:

- To keep the architectural function of the pyramidal tower of the Church;
- To use the traditional technical and technological way of executing lime mortars (with raised joints);
- To rehabilitate the coherence of the aesthetic value of the façade with its texture and colours;
- To conserve all the evidence of the historical renders.

The intervention process had the following steps:

- Removal of previous non-decorative and non-functional render. After removal, we could identify evidence of different types of uncovered decorated historical renders. There were renders where we could see the aesthetic appearance and formal techniques in spite of some material degradation. There were also uncountable

Fig. 8 In loco, water absorption experimental tests were made to characterise the original materials.

Fig. 9 Detail of the experimental tests.

traces that we could reconstruct visually, having a full panorama of the decorative scheme (figs. 5-7);

- Photogrammetric survey of all historical surfaces, survey of the execution of the technical and decorative scheme, record materials and decorated/raised joints;

- Photographing survey and documentation of all the historical traces and of the removing process;

- Evaluation of whether the extension of uncovered areas was enough or not to allow the recovering of the lacunas, despite the poor state of conservation of the historical render.

- Decision to preserve all the historical evidence and to reconstruct and reintegrate the lacunas with a similar decorative render. The conservation process intended not only to conserve the authenticity of the historical render, but also to regain the techniques and technology of making this kind of surfaces, resulting in a clear reading of the façade and an identification of the restoration, without the connotation with a mimetic integration.

- Characterization of the original materials, with *in loco* experimental tests, to define the restoration mortars' properties (figs. 8-9);

- Experimental tests, to define the solution for the restoration render, both from the technical and the aesthetic points of view. For these tests the conservation team worked together with specialized companies in manufacturing (Fradical, Lda. – D. Fradique lime delegate) and applying (Construtora J.M. Tripa e Filho, Lda.) lime mortars and traditional renders techniques.

- Dry-cleaning of all surfaces through controlled brushing;

- Consolidation of the damaged mortars and integration of the irregularities in the original renders. In the latter situation we used a lime mortar made of non--hydrophobic lime putty.

- Application of an *arriccio* layer using non-hydrophobic lime mortar mixed (pre-dosed) with clean and calibrated sand and aggregates;

- Application of the final decorated layer with raised joints simulating stone masonry. In this case we used a lime putty non-hydrophobic mortar with limestone aggregates and washed fine sand. The mortar mix used was: 1 unity of non-hydrophobic lime; 1 unity of Negrais yellow limestone 0 special; 1 unity of Negrais yellow limestone 00; 0.5 unity of Alvito blue limestone (powder); 0.5 unity of Coina yellow fine sand. The procedure to reconstitute and integrate the gaps of the original surface is explained in the photographs (figs. 10-25);

- Finally, use of a mineral, silicate based, surface treatment, to protect the render from aggressive weather conditions such as strong wind and rain.

Fig. 10 Preparation the restoration lime mortar, mixed with washed sand and standard grain size.

Fig. 11 Application of the restoration lime mortars, after the humidification of the support. Scattering until the render thickness was obtained.

Fig. 12 Using the mason's mortar-board to compress the mortar; before adding different coloured sands to the mortar, and with the mason's mortar-board compressing again the render.

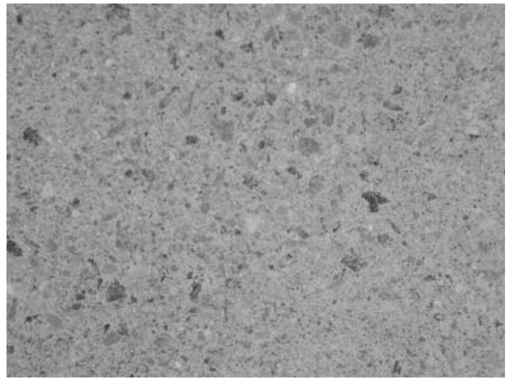

Fig. 13 To obtain this aesthetic aspect of the surface the following process was used: (1) Compressing, after the first drying, with a metallic mason's mortar-board, the surface again, through arch movements, until a "cream/gum" was formed; (2) water pulverization of the surface; (3) brushing the surface and removing the "cream/gum" using a humidified sponge until the coloured sand grains were seen.

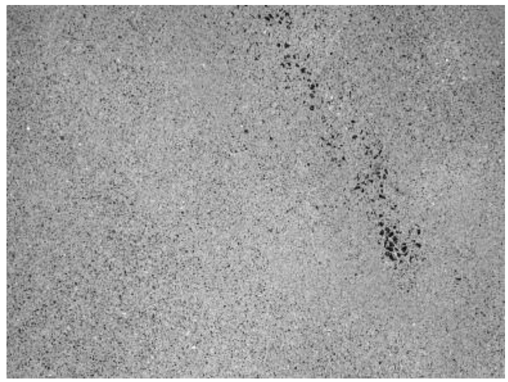

Fig. 14 Surface render's detail.

Fig. 15 Reproducing the decorative scheme. The joints were traced using nails and coloured threads.

Fig. 16 Detail of the reproducing the decorative scheme.

Fig. 17 Removing the mortar in joints with metal tools; cleaning and humidifying the furrows.

Fig. 18 Detail of the humidifying works.

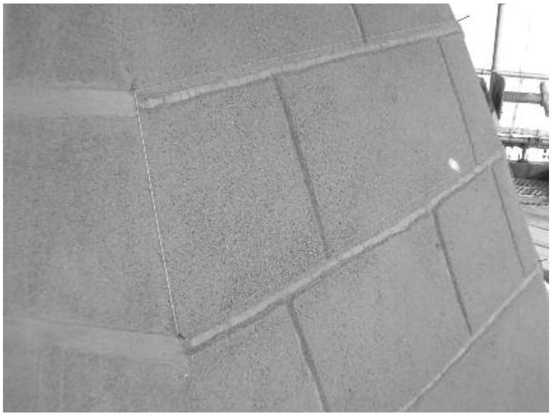

Fig. 19 Surfaces details the with the furrows.

Fig. 20 Application of the mortar in the joint area.

Fig. 21 Removing and cutting, after a first drying, the excess mortar, according to the decorative scheme.

Fig. 22 Applying a thin grain size mortar in the joint area after pressing and watering the render during the drying stage to avoid the mortar being fissured.

Fig. 23 Detail of the application of the final decorated layer with raised joints.

Fig. 24 Surfaces details after integration of the lacunas.

Fig. 25 Architectural surface after the integration of the lacunas.

Final Remarks

The case described in this paper may be considered a remarkable example for future interventions (figs. 26-27). The methodological approach, the collaboration of the conservation team and the Project coordinator to identify problems and to find solutions, the synergies created by the trans-disciplinary team, all demonstrate that it is possible to learn about the monument, its techniques and materials during the conservation process and to have a continuous evaluation and validation of different options taken along the process. It is clear that, in cases were there are unknown, unpredictable factors, due to the specific work and value of the materials; it is possible to change the course of action and introduce new

Fig. 26 The pyramidal tower after the conservation and restoration works.

Fig. 27 The main façade after the conservation and restoration works of the historical mortars.

and improved measures to take into consideration new facts and new opportunities of preserving the cultural value of historical renders.

References

1 Vieira Silva, J. C., 'Igreja Matriz de Nossa Senhora da Assunção de Elvas (antiga Sé). A obra manuelina', report commissioned by IPPAR, Évora (2004).

2 Borges, A. G. M., 'Igreja de Nossa Senhora da Assunção de Elvas (Antiga Sé)', report commissioned by IPPAR, Évora (2005).

3 Dias, P., *História da Arte em Portugal.* Vol. V., Ed. Alfa, Lisboa (1986).

4 Silva, A. S., Veiga, R., Adriano, P., Magalhães; A., Pires, J. Carvalho, A., Cruz, A. J., Mirão, J., Candeias, A., 'Characterization of historical mortars from Alentejo' religious buildings', in *International Historical Mortars Conference, 24-26 Septembre 2008*, Lisboa (2008).

5 Monteiro, P., 'Relatório sobre quatro monumentos do Alentejo; estudo sobre as fases de construção', report commissioned by IPPAR, Évora (2006).

Application and properties of pure lime façades – case study
Aplicação e propriedades de fachadas em cal pura – caso de estudo

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Abstract

The paper presents experiences obtained during application and testing of different pure lime façades that could be successfully used in restoration of historical buildings in Slovenia. The lime façade consists of a rendering layer (rough mortar), a finishing layer (fine mortar) and a protective layer of lime wash. For the design of the mortars different industrially and traditionally produced limes were chosen, based on the results of preliminary studies of the authors and experiences of a small enterprise (SE) involved in the study. The façade layers were applied to the most problematic northern wall of the historic chapel made from rubble masonry. The chapel belongs to the castle Črnelo, built at the end of the 17th century in the village Turnše, not far from Ljubljana, the capital of Slovenia. The façade layers were made by skilled workers of SE, with about one year time difference between application of rendering and finishing layers, and with a protective layer of coloured lime wash applied to one to three day old finishing layers. On the rendering layers, visual inspection, water absorption tests and determination of carbonation depth were carried out before subsequent finishing layers were applied. The same on-site tests were carried out also on finished façade layers. So far, parallel to the on-site tests, compressive and water absorption tests on prisms prepared from rough mortars were carried out in laboratory.

Keywords

Pure lime façade; workmanship; water absorption; carbonation depth.

Resumo

Este artigo apresenta experiências obtidas no decorrer da aplicação e teste de diferentes fachadas em cal pura que poderão vir a ser usadas com sucesso no restauro de edifícios históricos na Eslovénia. Cada fachada de cal é composta por uma camada de revestimento (argamassa grosseira), uma camada de acabamento (argamassa fina) e uma camada protectora de água de cal. Para a concepção das argamassas foram escolhidos diferentes tipos de cal, de produção industrial e tradicional, com base em estudos preliminares dos autores e em experiências de uma pequena empresa (SE) envolvida no estudo. As camadas que compõem as fachadas foram aplicadas na parede norte – a mais problemática – de uma capela histórica em alvenaria de pedra ordinária. Esta capela pertence ao castelo de Črnelo, construído no final do século XVII em Turnše, uma vila não muito distante de Liubliana, capital da Eslovénia. As fachadas foram efectuadas por trabalhadores habilitados da SE, com um intervalo de cerca de um ano entre a aplicação das camadas de revestimento e de acabamento, e com a camada protectora de água de cal pigmentada aplicada um a três dias após a execução das camadas de acabamento. Previamente à aplicação das camadas de acabamento, foram conduzidas inspecção visual, medições de absorção de água e determinação da profundidade de carbonatação nas camadas de revestimento. Idênticos testes in-situ foram subsequentemente conduzidos nas camadas de acabamento. Até agora, paralelamente aos testes in-situ, foram efectuados em laboratório testes de resistência à compressão e de absorção de água sobre prismas preparados com as argamassas grosseiras.

Palavras-chave

Fachada de cal pura; mão-de-obra absorção de água; profundidade de carbonatação.

Introduction

We notice buildings normally first from their façades. They give a house, church or castle its outlook in composition of elements and also in colours and decorations. In Slovenia historical façades are mainly composed of two or more layers made from lime mortar and finished with white or coloured lime wash. Although the main role of the façades has always been protection of load-bearing masonry (stone, brick or combination of the two) against weathering, protection of occupants against wind and control of hygro-thermal variations, the decorative aspect was seldom neglected.

The work of our research team, dedicated to historical materials during the last decade, has been focused mainly on the properties of lime-based mortars for clay bricklaying and rendering layer [1-6]). However, in our recent studies [7, 8], properties of lime-based façades that could be successfully used in restoration of historical buildings in Slovenia have been in focus of our interest. The façades under consideration consist of rendering layer (rough mortar), finishing layer (fine mortar) and protective layer of lime wash. Experiences obtained during previous studies and the possibility to use the northern wall of historic chapel of the castle Črnelo (built at the end of the 17th century) for a two-year study of different lime-based façades gave us the idea to examine the efficiency of different pure lime mortars for the application of façade layers on historical rubble masonry wall. Since the wall was 7.6 m long and 4.15 m high, it was possible to use much bigger test areas (about 1 m wide and 4 m high vertical test stripes) than in former studies. The façade layers were applied by skilled workers of a small enterprise, with many years of practical experience in restoration and application of pure lime renders and plasters.

Experimental work

Preparation of testing wall

Before the application of rendering layers, the rubble masonry wall was first cleaned in order to remove residues of mortar, algae, lichens and dirt. The mortar residues were removed by hammering. Then the wall was cleaned with pressurised water, which removed the algae, lichens and dirt, and also weak parts of mortar between stones (Fig. 1). Several voids between stones with volume between 1 and 3 dm^3 were filled with rough lime mortar prepared with lime putty from Tržič and smaller stones (Fig.2). Details of the mortar are given below.

Fig. 1 The test wall after cleaning.

Fig. 2 The test wall after filling of voids.

Details of used lime mortars

Limes

In the study five different types of lime were used. The first one was a soft burnt dolomitic lime putty from the village Podpeč and the second one was a soft burnt calcitic lime putty from Stranje. Both putties were burned and slaked in the traditional way, and were aged for more than 1 year. The third one was a lime putty from Žiri, produced by slaking industrially burned quick lime (burnt at temperatures between 1000 and 1200 °C) in the traditional way. This putty was aged for at least 3 months. The fourth type of lime was commercially available dry hydrate powder made from the same quick lime as the third lime putty, produced by Slovenian company SIA. The last lime putty was prepared by laying down a layer of sand, a layer of granular quicklime (the same origin as for the third and the fourth lime) and a layer of sand in a heap and slaked by pouring a defined amount of water over the heap. In this way hot lime mortar was produced, with 1 part of granular quick lime and 6.3 parts of sand (in two layers). The amount of water poured over the heap was the same as the quick lime volume.

Lime mortars

For the preparation of rough lime mortars for a rendering layer, coarse sharp limestone sand with maximum grain size of 4 mm was used. The mortars were prepared by a skilled worker of the small enterprise. Details of the mortars and their properties in fresh state are given in Table 1.

Mortars ideal for throwing on the wall, levelling and consolidation, as chosen by the workers, were RM I and RM II. Both mortars contained enough binder and their adhesion to the substrate was excellent. Also mortar RM V was assessed as good for throwing, but less appropriate for consolidation. The excess of lime binder was found to be the main source of problems and a skilled worker proposed a volume ratio of at least 1:3 for this type of lime putty. Mortar RM III was prepared by mixing dry hydrate with the coarse sand and water. During the mixing process a substantial amount of water had to be added in the mixer. However, with further mixing the mortar was becoming thicker and thicker with time. The workers again realised that the content of lime binder could be reduced also for this mortar, in order to obtain a leaner mixture. Mortar RM IV was prepared by cutting the heap vertically and putting 180 dm^3 of mixture of slaked lime and sand into a mixer. First the dry mixture of sand and lime was mixed and then about 38 dm^3 of water was added. The mixture's temperature increased slightly, which indicated that lime in the heap was not fully hydrated. Since the workers estimated that the mixture was not fat enough, about 10 dm^3 of slaked lime from the heap was added in the mixer later on. However, also in this case the mortar was becoming fatter and fatter with the increase of mixing time, and the final conclusion was that addition of extra lime was not necessary.

For the preparation of fine lime mortars for finishing layers, fine sharp limestone sand with maximum grain size of 1 mm was used. The fine mortars were prepared by the same workers as rough mortars. Details of the fine mortars are given in Table 2.

Fine lime mortar FM II was lighter (lower density was estimated by workers) than mortar FM I and it was very white. Mortar FM IV was the most watery among the four fine lime mortars.

Tests in the laboratory

In order to determine the compressive strength (SIST EN 1015-11, 2001) and water absorption (SIST EN 1015-18, 2004) of the rough mortars for rendering layers, standard 40x40x160 mm prisms were cast and tested at the age of 90 days. The test results are given in Table 3 and in Fig. 3. Water absorption coefficients were determined according to [6].

Table 1 Details of rough mortars used for the rendering layer and their fresh properties.

Rough mortar	Type of lime	Volume ratio lime:sand (dm^3:dm^3)	Water (dm^3)	Flow value (mm)	Density (kg/dm^3)
RM I	Podpeč putty	1:2.83 (54:153)	21.5	160	2.02
RM II	Stranje putty	1:2.83 (54:153)	25.0	170	1.97
RM III	Dry hydrate SIA	1:2.17 (72:156)	55.0	143	1.97
RM IV	Hot lime mortar	-	-	152	2.01
RM V/1	Žiri putty	1:2.83 (54:153)	16.4	154	2.06
RM V/2	Žiri putty	1:2.57 (21:54)	5.7	150	2.06

Table 2 Details of rough mortars used for the rendering layer and their fresh properties.

Fine mortar	Type of lime	Volume ratio lime:sand (dm^3:dm^3)	Water (dm^3)
FM I	Podpeč putty	1:1.81 (27:49)	15
FM II	Stranje putty	1:1.76 (27.8:49)	15
FM III	Dry hydrate SIA	1:1.69 (29:49)	36
FM IV	Žiri putty	1:1.78 (18:32)	10

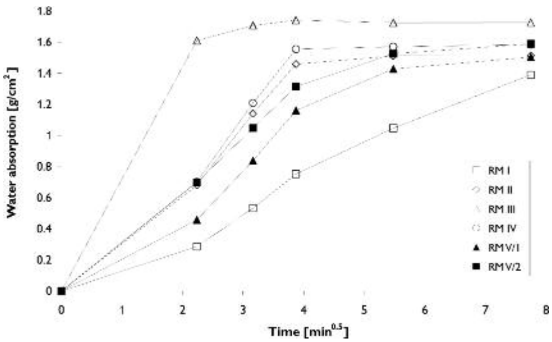

Fig. 3 Results of water absorption test on prisms from different rough lime mortars.

Table 3 and Fig. 3 show that RM III is the mortar with the coarsest pores (the most rapid water absorption) and RM I the mortar with the finest pores (the slowest water absorption); the other mortars are in-between.

On-site tests

Rendering layers

On the 11th of September 2006 rendering of the historical rubble masonry wall started. Positions of the rendering layers (vertical stripes) from different rough lime mortars are given in Fig. 4. The vertical stripes were about 1 m wide and 4 m high, except the additional rendering layer from mortar RM V/2 (between layers RM I and RM II) and the layers above and below the window. The rendering layers should be as thin as possible; however they should at the same time assure an even substrate for the finishing layers. The evenness of rendering layers was assured with the help of a leading wooden board and a floating board, without subsequent troweling. Therefore, thickness of the rendering layers was ranging between less than 1 cm and up to 3-4 cm, and effective consolidation of the layers was not carried out.

The first stripe of rendering layer applied on the wall was layer RM II, followed by layers with RM I and RM V/1 (last on the right side – Fig. 4) in the same day. During the next day layers with numbers V/2, III and IV were applied. After the rendering layers had been finished, it started to rain and it was raining for several days. Therefore some thicker parts of layers made from mortars RM I and RM IV, and from below the window were falling from the wall (Fig. 5). They were restored using the same mortar mixture and after that the renders behaved very well, as can be seen from the picture in Fig. 6, taken in October 2007.

Table 3 Results of compressive tests (6 specimens per mortar type) and average water absorption coefficients due to capillary action (Cm; 3 specimens per mortar type), determined on standard prisms.

Type of rough mortar	Average compressive strength [MPa] *(COV)*	C_{m5} g/(cm²·min$^{0.5}$)	C_{m10-5} g/(cm²·min$^{0.5}$)	C_{m15-10} g/(cm²·min$^{0.5}$)	C_{m30-15} g/(cm²·min$^{0.5}$)	C_{m60-30} g/(cm²·min$^{0.5}$)
RM I	1.87 (6%)	0.13	0.26	0.31	0.18	0.15
RM II	1.86 (2%)	0.30	0.50	0.45	0.03	0.00
RM III	1.81 (8%)	0.72	0.10	0.05	0.00	0.00
RM IV	1.95 (14%)	0.31	0.55	0.45	0.01	0.01
RM V/1	1.63 (17%)	0.20	0.41	0.45	0.17	0.03
RM V/2	2.0 (4%)	0.31	0.38	0.37	0.13	0.03

* *t – time in minutes, after which coefficient was determined*
** *t_j-t_i – coefficient between times t_j and t_i*

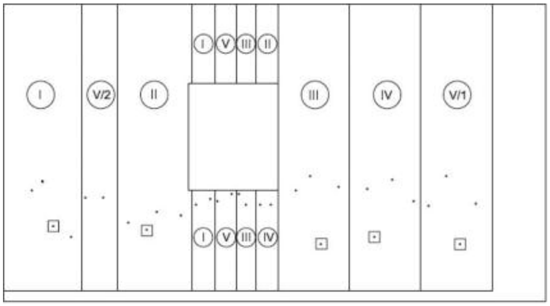

Fig. 4 Positions of the rendering layers made with different mortars and positions of water absorption test by pipe--method.

Fig. 5 Thicker parts of rendering layers were falling from the wall after rain.

After 1 year, in October 2007, fine finishing layers were applied. Just before that, the water absorption tests and the determination of carbonation depth were carried out. The pipe-method (RILEM test N° II.4 of RILEM commission 25-PEM) was used to measure the quantity of water absorbed under low pressure by a definite surface of a porous material and after a definite time. The pipe is applied on the material by interposing a tape of putty. Then the pipe is filled with water through the upper opening up to the gradation 0 (Fig. 7). The quantity of water absorbed by the material in function of time (after 5, 10, 15, 30 and 60 minutes) can be read directly from the graduated tube. The measurement positions of the pipes are given in Fig. 4, by points. The determination of carbonation depth was first carried out by the phenolphthalein method. However, by removing part of the render, noncarbonated particles contaminated the carbonated part and the obtained results were useless. In the next step we focused on removing noncarbonated parts of renders, with considerably lower resistance to scratching, using a steel brush, and measured the remaining carbonated part (Fig. 8). The parts of renders were removed on the lower side of each particular stripe, where conditions were less favourable for carbonation, due to relatively higher humidity.

Results of water absorption tests are given in Table 4 and in Fig. 9, and carbonation depths are given in Table 4. Water absorption coefficient C_{aver} was determined when water reached graduation of 4 cm^3.

Results of on-site water absorption tests conformed to the results of laboratory tests (Fig. 3) in that RM III is

Fig. 6 Rendering layers after 1 year.

Fig. 7 Water absorption tests on rendering layers.

the mortar with the coarsest pores, RM I the mortar with the finest pores, and that other mortars are in between. The expected correlation between water absorption and carbonation depth was obtained for rendering layers RM III, RM IV and RM V. However, for the render RM II a much higher carbonation depth than 7 mm, and for the render RM I a much lower carbonation depth than 14 mm, were expected, assuming that all the tested parts were exposed to the same environmental conditions. Possible reasons for these unexpected results may be important differences in humidity between micro locations on the lower sides of the rendering stripes, due to the influence of surrounding vegetation (mainly weed and non-maintained grass). Additional reasons may be connected with raw material properties and used burning and slaking regimes, since only lime putties for rendering layers RM I and RM II were produced entirely in a traditional way.

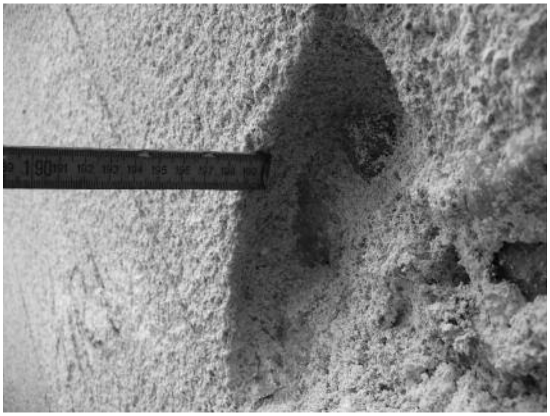

Fig. 8 Determination of carbonation depth of renders.

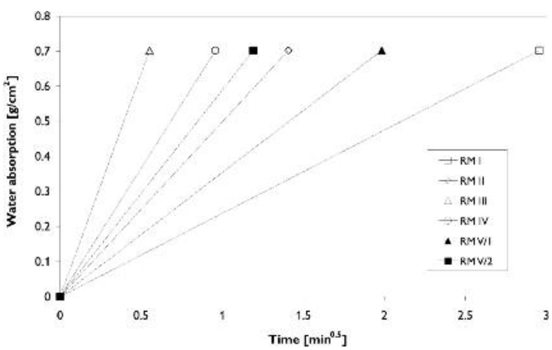

Fig. 9 Results of water absorption test on different rendering layers.

Table 4 Average water absorption coefficient (C_{aver}) and depth of carbonation of rendering layers at the age of 1 year.

Type of rough mortar	C_{aver} [g/(cm^2·min$^{0.5}$)]	Carbonation depth (mm)
RM I	0.24	14
RM II	0.50	7
RM III	1.27	23 (complete)
RM IV	0.73	15
RM V/1	0.35	14
RM V/2	0.59	14

Finishing layers

On the 24th of October 2007 the finishing layers were applied. The positions of the finishing layers (vertical stripes) from different fine lime mortars are given in Fig. 10. The vertical stripes were about 1.5 m wide and 4 m high, except layers above and below window. The finishing layers were very thin, with thickness between 3 and 5 mm. They were made in two layers (Fig. 11): 1) laying on the fine mortar and floating, 2) laying on the fine mortar and troweling with finishing trowel. The workers estimated that the fine mortar FM IV was the easiest to work with, fine mortar FM III was too lean, troweling of fine mortar FM I was rather complicated and they were satisfied with mortar FM II. The only problem of the last mortar was lumps in the lime putty, since it was not sieved before application.

On 25th and 27th of October 2007 the finishing layers were painted with lime wash coloured with yellow ochre pigment (Fig. 12) and thus the façade was completed.

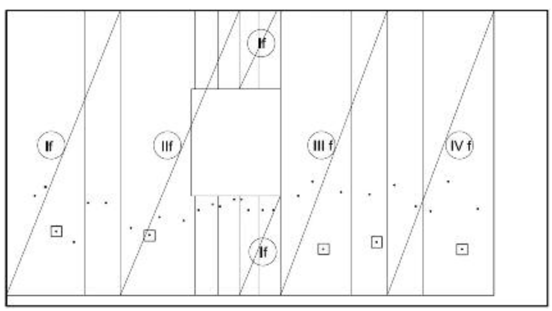

Fig. 10 Positions of finishing rendering layers made with different fine mortars.

Fig. 11 . Application of finishing layer (two-coat work).

Tests on façade were again carried out after about 1 year, in July 2008. The finishing layers were completely carbonated, which was confirmed by the application of the phenolphthalein method. The water absorption test was again the pipe-method. Due to a much lower water absorption than in the case of the rough rendering layers, the water absorption coefficient was determined as average coefficient (C_{aver}) after 60 minutes or earlier. For the second case the C_{aver} was determined after the time when water reached graduation of 4 cm^3. The results are given in Table 5 and in Fig. 13. From the results we can see that also for finished façade layers water absorption was the highest when dry hydrate was used as a binder, and among the lowest when lime putty from Podpeč was used. However, façade layer made by Žiri putty possessed better or at least the same resistance to water penetration than the "Podpeč" façade. The application of fine mortars FM III and FM IV on rough rendering layer made by hot lime mortar revealed that water absorption of the obtained two-binder façade layer was close to that of a single binder façade layer with the same lime binder as that in the fine mortar.

Fig. 12 Finished façade – after application of coloured lime wash.

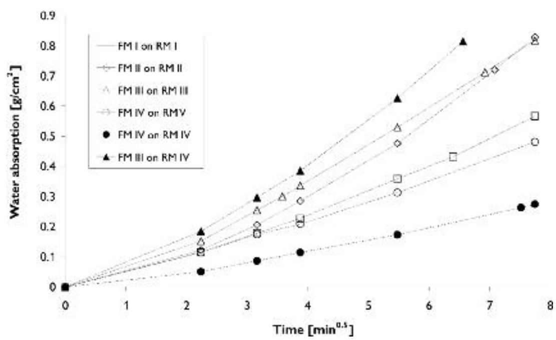

Fig. 13 Results of water absorption test on different façade layers.

Table 5 Average coefficient of water absorption (C_{aver}) of façade layers – 5 positions.

Façade	FM I on RM I	FM II on RM II	FM III on RM III	FM IV on RM V	FM IV on RM IV	FM II RM
C_{aver} [g/(cm²·min^0.5)]	0.07	0.11	0.11	0.06	0.04	0.1

** after 43 minutes*

Discussion

All rough mortars in this study attained an average compressive strength within the interval of 1.8 MPa ± 0.2 MPa after 90 days. However, their water absorption properties were very different. The highest water absorption was obtained for mortar RM III, prepared by dry hydrate lime, in laboratory and on site. The initial coefficient of water absorption was higher for rendering layers than for prisms, due to poorer compaction of the render, and this is valid for all the tested rough mortars. However, the results obtained on the prisms revealed that mortar RM III absorbed 93% of final water content only in the first 5 minutes and the rest in the following 55 minutes. The coarser porosity of this mortar is the most probable reason for such behaviour. The lowest water absorption was obtained for mortar RM I, prepared with traditional dolomitic lime putty, again in the laboratory and on site. For this mortar the initial water absorption (C_{m5}) is very low and thus after 5 min prisms absorbed on average only 20% of final water content. Afterwards, the coefficient of water absorption (C_{mtj-ti}) was increasing up to 15 min, resulting in a content of absorbed water equal to 38% and 54% after 10 and 15 min, respectively. The slow water absorption process is likely to be caused by the finer porosity of the RM I test specimens. Further on, C_{mtj-ti} started to decrease, but did not approach zero value until the end of the test. This means that mortar RM I might absorb the highest amount of water, if the test lasted longer than 60 min. Water absorption properties of mortars RM II, RM V/2 and RM IV, from calcitic lime putties, are very similar and are between properties of mortars RM I and RM III. After 15 min they absorbed between 83% (RM V/2) and 98% (RM IV) of their final water content, which was approximately the same for all the mortars.

As expected, after the application of finishing layers and lime wash, the water absorption of façade layers decreased immensely. The average coefficient of water absorption was by 3.4, 4.5, 11.5 and 8.8 times lower than for render (from the same binder) RM I, RM II, RM III and RM V/1, respectively. However, the used type of lime binder seems to have important influence also on water absorption properties of finishing layer, since the sequence of fine mortars regarding water absorption properties is very similar to that obtained for rough mortars, when the binder of rendering and finishing layer was the same. An important difference in behaviour that should be pointed out was obtained for fine mortar FM IV prepared with Žiri putty, which demonstrated the lowest water absorption among all fine mortars. Based on the obtained results we can conclude that not only properties of finishing layer but also properties of substratum (render) and/or interaction between finishing and rendering layers can influence the water absorption properties of the façade. As the porosity of the young rough rendering layer is influenced by the substrate also the porosity of the young thin fine layer is influenced by the hardened rough rendering layer. The application of the fine mortar FM IV to the render made from mortar RM IV (hot lime mortar) reduced the water absorption of the façade much more than the application of the same fine mortar to the render RM V/1. However, when fine mortar FM III was applied to render RM IV, the water absorption of the façade was almost the same, compared to the façade layer FM III on RM III.

Regarding workability of the rendering mortars, mortars RM I and RM II were selected by the skilled workers as the best solution, and mortar RM V could be an appropriate choice as well, with a slight reduction in the binder content. The workers were not satisfied with mortars RM III and RM IV. Lack of experience with mortar RM IV (hot lime mortar) is the most probable reason for their selection.

Among fine mortars for the finishing layers, the workers were most satisfied with mortar FM IV and quite satisfied with mortar FM II. However, in the future, the lime putty used for mortar FM II should be sieved before usage. It may not be excluded that the good workability of FM IV may have had a favourable effect of the density of the outer layer.

The putty from Žiri (RM V and FM IV) indicated that the traditional slaking process could be more important than burning of limestone in the traditional way. With industrially produced quick lime of uniform and good quality, slaked and matured in the traditional way, we may obtain lime putty of good and uniform quality.

The high thickness of rendering layers in some areas was estimated as problematic. We believe that the decision for an even rendering surface and thus very thick parts of rendering layers on rubble masonry was not appropriate. The rendering layer should be carried out by throwing the mortar and subsequent floating and troweling, in order to obtain compact render with maximum thickness of 2 cm.

Conclusion

Despite the relatively high thickness of rendering layers in some areas and partial falling down of the thicker parts after the rainy period, all of the finished façade layers were of good quality and some of them were excellent. We proved that skilled workers can make pure lime façades with good quality even in unfavourable environmental conditions (northern wall and high humidity in the lower part of the wall, applying of rendering and finishing layers in autumn, rainy period after application of renders, etc.). Considering all experiences and results obtained during the study so far, we would recommend calcitic lime putties from Stranje and Žiri as the most appropriate for pure lime façades in Slovenia. Adequate choice for the rendering layer could also be hot lime mortar made from the SIA quicklime. However, since in Slovenia this technology has not been in use during the last decades, it has been recently introduced by Austrian colleagues to the participants of a workshop about lime technologies, we would recommend hot lime mortar technology for Slovenia only when skilled workers master it in detail.

Acknowledgement

Test results presented in the paper were obtained during the study, part of which is also diploma work of student Primož Novak. Authors of the paper wish to thank Primož Novak for his contribution to the paper.

References

1 Bokan Bosiljkov, V.; Bosiljkov, V., 'The influence of the different types of sand and their grain distribution on the mechanical properties of masonry', in *12th International brick/block masonry conference,* Madrid, vol. 1 (2000) 267-282.

2 Bokan Bosiljkov, V., 'The use of industrial and traditional limes for lime mortars', in *Historical Constructions 2001. Possibilities of numerical and experimental techniques*, ed. P. B. Lourenço, P. Roca, University of Minho, Guimarães (2001) 343-352.

3 Bokan Bosiljkov, V., 'The use of lime mortars for sustainable restoration of ancient buildings', in *9th Canadian Masonry Symposium*, Fredericton (2001), 12 p.

4 Bokan Bosiljkov, V.; Sugo, H.; Page, A.; Lawrence, S., 'The influence of cement replacement materials on the flexural bond strength of masonry', in *13th International Brick/Block Masonry Conference*, Amsterdam (2004) 865-874.

5 Veiga, M. R.; Magalhães, A. C.; Bokan Bosiljkov, V., 'Capillarity tests on historic mortar samples extracted from site: methodology and compared results', in *13th International Brick/Block Masonry Conference*, Amsterdam (2004) 959-968.

6 Bokan Bosiljkov, V.; Valek, J., 'A comparative study of mechanical and physical properties of mortars prepared using lime putties, sand and metakaolin from different sources', in *Repair Mortars for Historic Masonry*, International Workshop, Delft (2005) (in print).

7 Bokan Bosiljkov, V.; Žarnić, R.; Čepon, F., 'Research and development of materials in historical buildings', report of the Research Group at Chair for Research in Materials and Structures, Faculty of Civil and Geodetic Engineering University of Ljubljana, Ljubljana (2006).

8 Bokan Bosiljkov, V.; Bosiljkov, V.; Žarnić, R., 'Water absorption of lime-based facades', in *14th International Brick and Block Masonry Conference (Incorporating the 8th Australasian Masonry Conference)*, Sydney (2008).

Evaluation of compatible mortars to repair 19th century natural cement cast stone from the French Rhône-Alpes region

Avaliação de argamassas compatíveis com a reparação de pedra artificial moldada em cimento natural no século XIX, da região francesa de Rhône-Alpes

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Abstract

In France, natural cements were extensively produced in the middle of the 19th century. In the French Alps, due to their ochre color, these cements were massively used, notably to produce cast stone, to simulate natural freestone. A preliminary survey revealed an overall good state of preservation of the buildings of this period. Two kinds of decays mechanisms were however identified : erosion affecting the surface of the majority of the buildings, inducing a gradual disappearance of the initial "fake-stone aspect", and a spalling phenomenon often combined with salts crystallization, observed only on a few buildings. Today, due to a lack of appropriate repair materials, the rehabilitation of these buildings mainly consists in the use of gray Portland-cement-based-mortars combined with a painting finishing, which is not satisfactory considering the conservation deontology, as the original appearance is lost. Therefore, the aim of this project was to develop and to test compatible repair materials to restore the culture heritage of this region.

Based on the preliminary characterization of a set of representative ancient buildings, combined to a literature review, specifications concerning the composition and the main properties of repair materials, which could assure a compatibility with the ancient concrete of the region were established. Then, three Prompt-cement and one Portland-cement based mortars were selected, two of them being specifically formulated. Firstly, the appearance, the workability and the mechanical and physical properties of those mortars were characterized. Secondly, to evaluate the compatibility of the selected mortars with ancient concrete, Prompt-cement-based slabs were cast using a 19th century concrete formula, and were artificially eroded. After applying the 4 mortars on the slabs, visual observations and pull-out tests will be carried out before and after artificial aging. Finally, the repair mortar presenting the best performances will be tested on site in a monument of Grenoble.

Keywords

Cast stone; compatibility; erosion; natural cement; repair mortar.

Resumo

Em meados do século XIX, os cimentos naturais eram extensamente produzidos em França. Nos Alpes franceses, devido à sua cor ocre, estes cimentos eram largamente usados, sobretudo na produção de pedra moldada, para simular pedra natural. Um inquérito preliminar revelou que os edifícios deste período apresentavam, em geral, um bom estado de conservação. Dois tipos de mecanismos de degradação foram, no entanto, identificados: erosão, que afectava a maioria dos edifícios, induzindo um gradual desaparecimento do aspecto inicial de "pedra-falsa"; e um fenómeno de lascagem muitas vezes combinado com cristalização de sais, observado em apenas alguns dos edifícios. Hoje, devido à falta de materiais de reparação apropriados, a reabilitação destes edifícios consiste essencialmente na utilização de argamassas cinzentas baseadas em cimento Portland, combinadas com uma pintura de acabamento, solução que não é satisfatória do ponto de vista da deontologia da conservação, uma vez que se perde a aparência original. Assim, o objectivo deste projecto foi desenvolver e testar materiais de reparação compatíveis para o restauro do património cultural desta região.

Baseadas em caracterizações preliminares de um conjunto representativo de edifícios antigos, em combinação com uma revisão da literatura, foram estabelecidas especificações relativas à composição e principais propriedades dos materiais de reparação que assegurassem a compatibilidade com o antigo betão da região. Foram então seleccionadas três formulações baseadas em cimento natural e uma baseada em cimento Portland para testes, sendo que duas destas argamassas foram especificamente concebidas no âmbito do projecto. Em primeiro lugar, foram caracterizadas a aparência, a trabalhabilidade e as propriedades físicas e mecânicas destas argamassas. Em segundo lugar, para avaliar a compatibilidade entre as argamassas seleccionadas e o betão antigo, foram moldados painéis em cimento natural, de acordo com uma fórmula de betão do século XIX, que foram artificialmente erodidos. Após a aplicação das quatro argamassas nos painéis, serão conduzidos observação visual e testes de aderência por arrancamento, antes e após envelhecimento artificial. Finalmente, a argamassa de reparação que apresentar os melhores resultados será testada *in loco* num monumento de Grenoble.

Palavras-chave

Pedra artificial; compatibilidade; erosão; cimento natural; argamassa de reparação.

Introduction

The most ancient concretes encountered in France date back to the middle of the 19th century. They were produced in the Rhône-Alpes region, and notably used to cast concrete blocks or quite complex ornaments, which were aiming at imitating the color and the texture of natural stone. One of their specificity is an ochre color, varying from light brown to red. Even if this cultural heritage is on the whole quite well preserved, an erosion phenomenon affects the majority of the surfaces, leading to a gradual disappearance of the concrete skin, detrimental to the initial "natural stone aspect". As the color and the composition of these concretes are very specific, there is a lack of suitable repairing mortars. Therefore, the aim of this study was to develop and to test compatible mortars to restore these erosion facies frequently encountered.

Problematics [1-2]

The natural cements from the department of Isère in the Alps were obtained by the extraction of an argillaceous limestone which was crushed and cooked in vertical furnaces similar to those used for lime manufacture. Between the middle of 19th and the beginning of the 20th century, these natural cements were produced in large amounts and used in both the industrial (water pipelines…) and the construction fields.

Preliminary survey

In a preliminary survey, more than 60 buildings using natural cements were listed in the French department of Isère. Houses and apartment buildings constituted the majority of them, but a significant proportion of churches was also identified (Figure 1).

Decay

The majority of the inspected buildings were quite well preserved. Nevertheless, two kinds of damages were identified:

- an erosion phenomenon (Figure 2), which was affecting the surface of the majority of the buildings, leading to a progressive elimination of the concrete skin and to the appearing of the coarser aggregates. Consequently, the original aspect of the concrete blocks imitating freestones is progressively lost, and a gradual degradation of the details of the sculptures is generally noticed;
- and a spalling phenomenon, which was observed only on a few buildings and which was sometimes associated with black crusts or white efflorescences.

Rehabilitation techniques

In order to rehabilitate those buildings, gray Portland cement-based mortars, combined with a yellow or

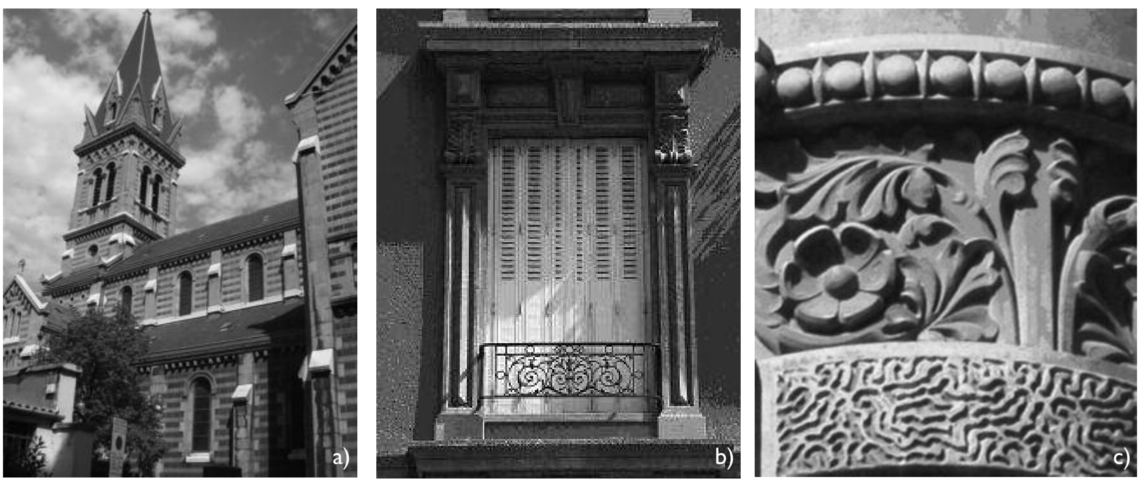

Fig. 1 Examples of natural cement applications in the French city of Grenoble: a) concrete blocks; b) window frame; c) façade ornament.

Fig. 2 Examples of erosion phenomenon observed either on sculptures (a), or on concrete blocks (b) in the city of Grenoble.

brownish painting as finishing, are generally used (Figure 3). In some cases, painting is even directly applied on the ancient concrete, without preliminary application of a surfacing mortar.

With such rehabilitation techniques, the initial mineral texture and the numerous ochre shades encountered, which are very specific and which make those fake stones look so real, are lost. Moreover, as the composition of the natural cements of the French Alps region is very distinct of that of Portland cements, incompatibilities might occur.

However, no alternative repair mortar, more adapted (physico-chemically, mechanically and aesthetically compatible) to these ancient concretes, is available, and the specific problem of erosion is tricky to treat as the layer to be re-surfaced is very thin (generally less than 1 cm).

Therefore, based on the analysis of the composition and properties of several ancient concretes of this region, the aim of this study was to formulate and to test natural cement-based repair mortars to restore eroded surfaces and to compare their performances to that of the Portland cement-based mortar currently used.

Requirements

Ancient concrete preliminary characterization [1-2]

In order to characterize these specific ancient concretes, several samples were collected on 4 representative buildings erected between 1873 and 1889, either from concrete blocks or from ornaments. Then their main properties were evaluated (Table 1).

Fig. 3 A yellowish or brownish painting is generally applied on the ancient concrete, with (a) or without (b) preliminary application of a Portland-cement-based surfacing mortar.

Table 1 Main characteristics of the concrete sampled.

Type of element	Density (kg/m^3)	Water porosity (%)	E dynamic (GPa)	Cement content (kg/m^3)	Sulfates content* (%)	Alkali content* (kg/m^3)
Concrete blocks	2253 ± 73	16.0 ± 1.8	31.6 ± 2.1	397 ± 63	4 ± 0.3	4.4 ± 1.3
Ornaments	1978 ± 105	25.9 ± 3.7	27 ± 3.7	780**	3.20**	3.92**

*Both sulfates and alkali contents are expressed by weight of cement.
** As only one sample was characterized, no standard deviation could be evaluated.

It is to be noticed that the concrete blocks showed the presence of very coarse aggregates (river shingles), whereas the microstructure of the ornamental elements had more to do with a mortar.

For all the buildings, quite high alkali and sulfates contents were measured not only on the surface but also deeper in the concrete. This indicates that their presence was linked to the composition of these natural cements and was not due to an external pollutant. SEM observations confirmed the high sulfates contents as many Ettringite crystals were generally observed, but also smaller amounts of Gypsum, Syngenite and Thenardite crystallizations.

Repairing mortars requirements [3-7]

As quite high alkali contents were measured in the ancient concretes to be restored, the use of alkali reactive (even if just potentially) aggregates had to be avoided. The aggregates size had also to be adapted to the quite small thickness of the eroded concrete to be repaired.

Concerning the binder, as a consequence of the high sulfate contents observed in the ancient concrete to be restored, to ensure a good compatibility, the cement to be used had to show a good sulfate resistance.

To ensure the durability of the restoration and to avoid further decay of the ancient concrete, the properties of the repair mortars had to be adapted to those of the ancient support, in terms of transfer properties (water vapor permeability higher than that of the support…) or mechanical performances (modulus of elasticity equal or higher than that of the support…).

But the mortars had also to be able to resist to the main stresses that repair mortars usually face (low shrinkage, high tensile strength…).

Finally, to fit with the esthetical requirements, cements able to produce an ochre color or mineral pigments had to be used.

Repair mortar selection

Based on the requirements previously established, two mortars were specifically formulated and two others were selected among the repairing mortars available on the market (Table 2).

It is to be noted that in France, in the Alps region, there is a natural cement (so called Prompt cement), still produced using the 19th century industrial process, and which composition is very close to the one of the cements encountered on the ancient concrete preliminarily characterized. Therefore this Prompt cement was used in the composition of the 2 specific formulations and in one of the ready-to-use mortar. The fourth mortar selected was a Portland cement-based one containing fibers, currently used for rehabilitation operations.

Table 2 Repairing mortars selected.

Mortar reference	Cement type	Mortar type	Comments
1	Prompt cement	Ready-to-use	Available on the market
2	Prompt cement	Ready-to-use	Specially formulated
3	Prompt cement	"On site" mortar	Specially formulated, for skilled operator
4	Portland cement	Ready-to-use	Available on the market

Table 3 Formula of concrete tested.

Components	Type	Mixture
Aggregate (from the Alps region)	4/20 mm rolled or 5/20 mm	0.8 $m^3 \rightarrow$1200 kg/m^3 [8]
		1 $m^3 \rightarrow$1500 kg/m^3 [9]
Sand (from the Alps region)	0/8 mm or 0/3 mm	0.4 $m^3 \rightarrow$560 kg/m^3 [8]
		0.3 $m^3 \rightarrow$420 kg/m^3 [9]
Cement	Prompt cement	400 kg/m^3
Water	Ratio W/C= 0.4	160 kg/m^3
Retarding agent		2.24 kg/m^3
Deactivation Product		0.2 to 0.25/m^2

Testing protocol and samples manufacture

First the intrinsic properties of the 4 selected mortars were characterized, through shrinkage, water porosity, water vapor permeability, dynamic modulus of elasticity, bending and compressive strength measurements.

Then, their compatibility with an ancient concrete is planed to be assessed by pull-out tests before and after artificial aging.

To proceed to these tests, 20 slabs (50×50×8 cm^3) were cast. Several formula extracted from documents dating back to the end of 19th century or the beginning 20th were tested (Table 3), using Prompt-cement as a binder. The final formula consists in a mix of 1600 kg/m^3 of coarse aggregates, 540 kg/m^3 of sand (both coming from the French Alps region), 400 kg/m^3 of Prompt-cement and 190 kg/m^3 of water (corresponding to a 0.47 W/C ratio).

Considering its quick setting, a retarding agent was added to the formula, and small batches were prepared (1 batch for 2 slabs), using a concrete mixer. After 28 days, the density and the compressive strength of this "Prompt-concrete" were measured on samples kept in water according to the French standard NF EN 12390-3. The density measured (2350±100 kg/m^3) is very close to results obtained on the ancient concrete blocks (2253 kg/m^3, Table 1), and a quite low compressive strength was evaluated (13±1.8 MPa).

To reproduce a surface similar to the erosion facies the more commonly encountered, 2 deactivation products were tested (Figure 4). The best results were obtained with the product inducing the higher depth of deactivation. It was then pulverized on the 20 slabs surfaces just after their casting.

After manufacturing, the slabs were kept 28 days in a room at 20 °C and 95 % RH and dried in the open air.

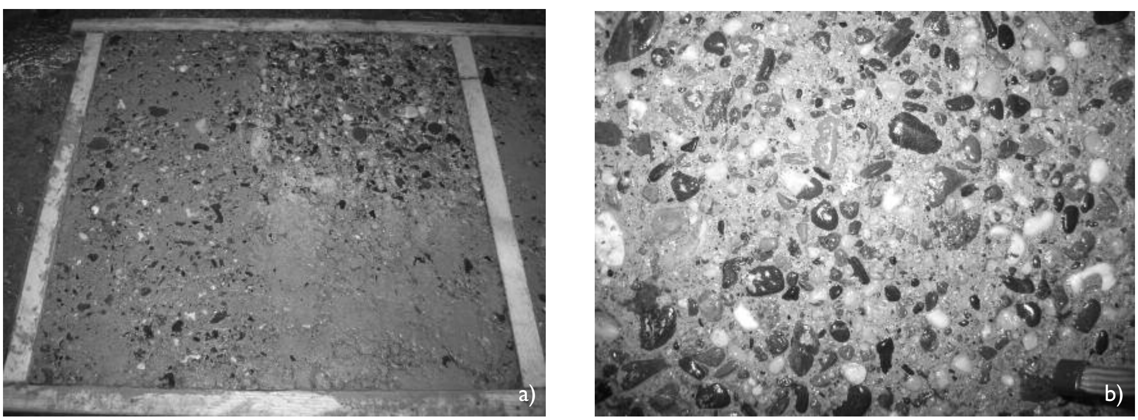

Fig. 4 To reproduce the eroded facies encountered on the ancient concrete to be restored, two deactivation products were tested, inducing 2 depths of deactivation (a) and (b).

Then the 4 selected mortars were applied (4 slabs per mortar). It is to be noticed that mortar 1 was very fluid and led to immediate shrinkage cracks, whereas mortar 4, which is dark gray, was sticking to the tools and therefore was quite hard to apply.

First results

Shrinkage

Shrinkage measurements (Figure 5) were performed according to the French standard NFP15-433, 28 days, 3 months and 6 months after the manufacture of the samples (4×4×16 cm^3 prisms), stored at 20 °C and 50 % RH.

The highest shrinkage was observed with mortar 1 (up to 0.17 % after 6 months), which was the mortar that led to immediate cracking during the preparation of the slabs for the compatibility tests. The best results were obtained with mortars 2 and 3, for which shrinkage were quite low and stable with time. Finally, surprisingly, mortar 4, which contains fibers in order to limit the shrinkage phenomenon, shows values higher than mortars 2 and 3.

It is to be noticed that in order to provide a good resistance to shrinkage cracking, several shrinkage thresholds are encountered in the literature: 0.04 % after 28 days [7] and 0.1 % after 1 year [5]. But, for the four tested mortars, the shrinkage values measured exceed the 28 days threshold.

The measurements after 1 year are not yet performed. But considering the slight constant increase of shrinkage observed for each mortar, only mortar 2 and 3 will probably fulfill the shrinkage requirement after 1 year.

Water porosity

The porosity considered was the accessible to water porosity. It corresponds to the ratio of the total volume of open pores respect to the apparent volume.

The measurement, according to the French AFPC-AFREM recommendation, consists in a series of weighing. Thus, after impregnation of water under vacuum, the sample is weighed in water a first time (M_{water}). Then, the sample, being still water impregnated, is weighed in the air (M_{air}). Finally, the sample is dried (until its weight reaches a constant value) and weighed a last time (M_{dry}).

From these values, the accessible to water porosity is calculated according to equation 1.

$$WaterPorosity = \frac{M_{air} - M_{dry}}{M_{air} - M_{water}} * 100 \qquad (Equation\ 1)$$

For the 4 selected mortars, water porosity was evaluated 28 days, 3 months and 6 months after the manufacture of the samples (4×4×16 cm^3 prisms), stored at 20 °C and 95 % RH.

The results are quite scattered (Figure 6), mortar 4 being the less porous (less than 15 %), and mortar 1 being excessively porous (more than 40 %). It is to be noticed that the water porosity of mortar 2 seriously decreases upon time.

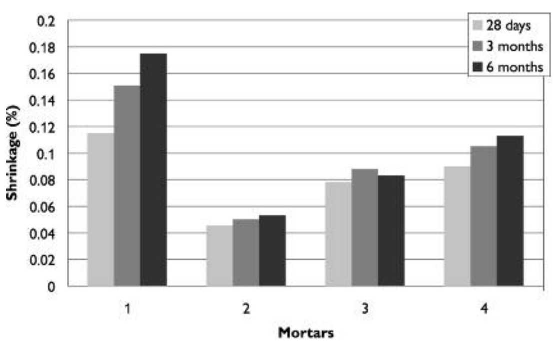

Fig. 5 Shrinkage measured after 28 days, 3 months and 6 months.

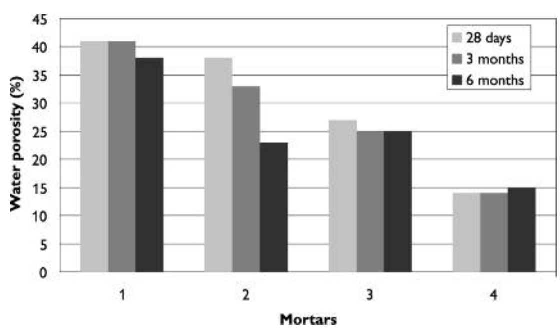

Fig. 6 Water porosity measured after 28 days, 3 months and 6 months.

Water vapor permeability

Water vapor permeability was measured according to the NF EN 1015-19 standard.

The test is performed on discs of mortar (ϕ11 cm × 1 cm) classically cured (95 % RH, 20 °C). The wax sealed discs are placed on a cup, in which the water vapor pressure is kept constant (93.2 % RH, at 20 °C), using a saturated solution of KNO_3. Then the cups are placed in a temperature controlled environment with a water vapor pressure lower than the one in the cup. Usually, a 55 % RH at 20°C environment is selected (maintained using $MgNO_3$).

The results (Table 4) reveal a quite high water vapor permeability for mortar 2, and on the contrary a very low permeability for mortar 4, incompatible with the needs of water vapor evacuation of ancient masonries.

Bending and compressive strength

The measurement of bending and compressive strengths were performed according to the French standard NF EN 1986-1, on prisms (4×4×16 cm^3), 28 days, 3 months and 6 months after their manufacture and storage at 20 °C, 95 % RH.

The results (Figure 7 and Figure 8) evidence very low performances for mortar 2, even if they increase with time. On the contrary, the Portland cement-based mortar (mortar 4) presents much higher bending and compressive strength than the 3 other Prompt-cement-based mortars.

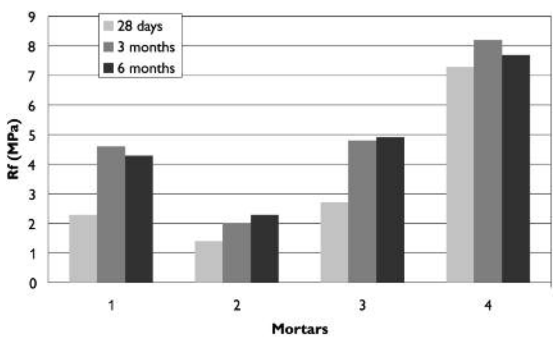

Fig. 7 Bending strength measured after 28 days, 3 months and 6 months.

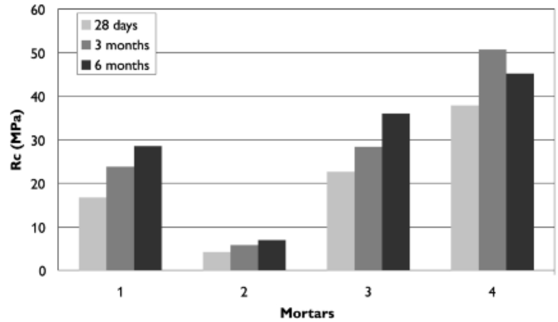

Fig. 8 Compressive strength measured after 28 days, 3 months and 6 months.

Dynamic modulus of elasticity

Ultra-sound wave velocities of propagation were measured on the samples. Then the dynamic modulus of elasticity were calculated according to equation 2; E being the dynamic modulus of elasticity (Pa), ν being the Poisson coefficient (generally $\nu = 0.2$), ρ being the density of the concrete (kg/m^3) and ν_m being the sound velocity (m/s).

$$E = \frac{(1+\nu)(1-2\nu)}{(1-\nu)} \rho \nu_m^2 \qquad \textit{(Equation 2)}$$

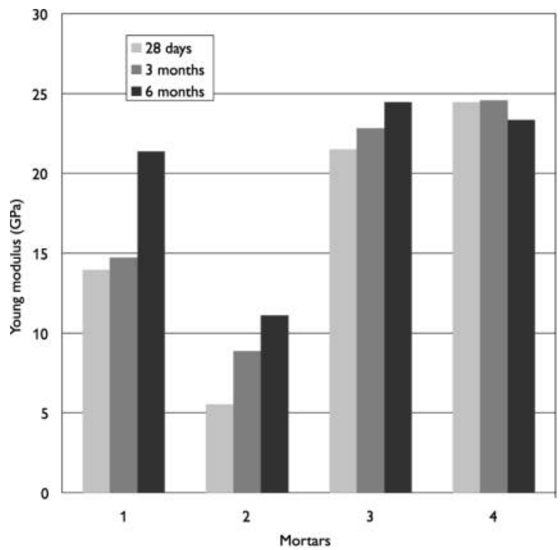

Fig. 9 Dynamic modulus of elasticity calculated after 28 days, 3 months and 6 months.

Whatever the mortar, the resulting dynamic modulus of elasticity (Figure 9) are lower than 27 GPa, which is the lowest value measured on the ancient concretes, on ornament. No incompatibility was therefore evidenced.

Conclusion

The purpose of this study was to develop and to test repair mortars compatible with the ancient concrete encountered in the French Rhône-Alpes region, which are affected by an erosion phenomenon. Those ancient concretes, which are characterized by an ochre color and which were used to cast either concrete blocks or complex ornaments, are very specific of the concrete production of the end of the 19th century in France. Therefore, they constitute a valuable cultural heritage to be preserved.

After a first characterization of the properties of a set of representative ancient buildings, 4 mortars were selected, 2 being specifically formulated. Then, based on ancient recipes encountered on the literature of the 19th century, a Prompt-cement-based concrete was developed. Concrete slabs were then cast using this formula, and artificially eroded in order to perform compatibility tests.

On the same time, the intrinsic properties of the 4 selected mortars were characterized, and the first results already revealed unsuitable performances or incompatibilities.

Thus, mortar 1 shows a clearly too high shrinkage. As a consequence, an almost instantaneous shrinkage cracking was observed when it was applied on the artificially eroded concrete slabs.

Mortar 4, which is Portland-cement-based is clearly too water vapor impermeable which might be incompatible with an ancient masonry. Its mechanical performances are also much higher than the 3 Prompt-cement-based mortars.

But the 1 year tests and the compatibility tests to be performed on the slabs before and after artificial aging, might evidence clearer compatibility or incompatibility.

In order to improve the possible comparison with the ancient concrete sample group, complementary characterization of the Prompt-cement-based concrete is also scheduled.

Acknowledgments

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References

1 Cailleux, E.; Marie-Victoire, E.; Sommain, D., 'Microstructural and weathering mechanisms of natural cements used in the 19th century in the French Rhône-Alpes region', in *International workshop on repair mortars for historic masonry*, Delft (2005).

2 Cailleux, E.; Marie-Victoire, E.; Sommain, D., 'Study of natural cements from the French Rhône-Alpes region', in *International conference on: Heritage, Weathering and Conservation*, vol. I, Madrid (2006) 77-84.

3 Thomasson, F., *Les enduits monocouches à base de liants hydrauliques*, Unitecta France, Paris (1982).

4 *Enduits Monocouches d'imperméabilisation. Certifications et classements des produits du bâtiment*, CSTB, Paris (1993).

5 Emmons, P. H.; Vaysburd, A. M., 'Factors affecting the durability of concrete repair: the contractor's viewpoint', *Construction and building materials* **8** (1994) 5-16.

6 Daubresse, A., 'Caractérisation des mortiers pour le bâti ancien', in *Exposé de la journée enduits, bétons et patrimoine* (1998).

7 Vaysburd, A. M.; Mcdonald, J. E.; Emmons, P. H.; Poston, R. W., 'Performance criteria for selection of repair materials', in *Fifth international conference CANMET/ACI*, ed. V. M. Malhotra, vol 2, Barcelona (2000) 931-947.

8 Société anonyme, Travaux Ciments, *Note sur la fabrication et la composition des pierres de taille artificielles moulurées*, Grenoble (1900) 2.

9 La Société de Ciments de la Porte de France, *Les Ciments de la Porte de France, Agenda 1958* (1958) 9.

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 $kg/(m^2.s^{½})$	*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/($m^2.h^{1/2}$));
- 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.

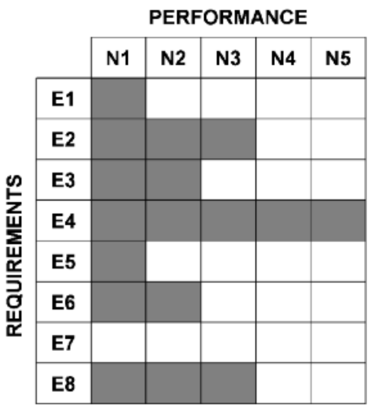

Fig. 1 Structure of a hypothetical requirements manual specifying mortars to be used in interior wall renderings.

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 mm^2	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

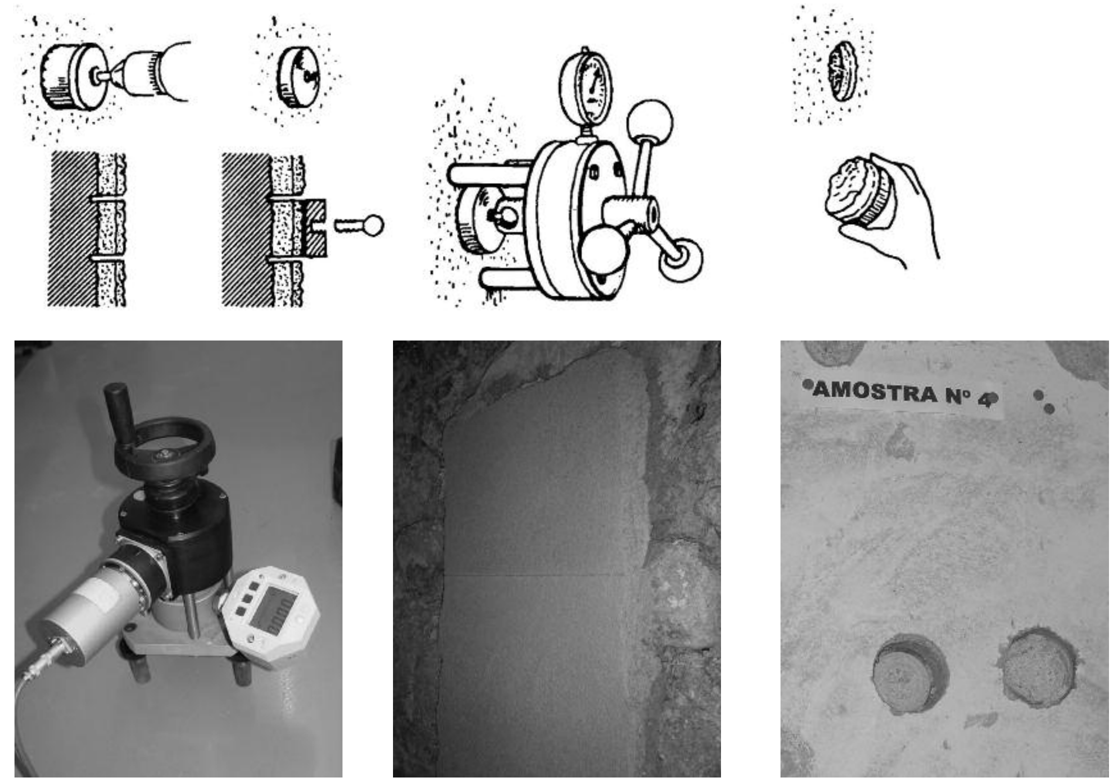

Fig. 2 Adhesive strength test apparatus and samples.

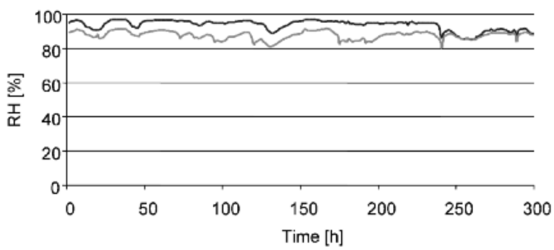

Fig. 3 Relative humidity inside a church in Northern Portugal.

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).

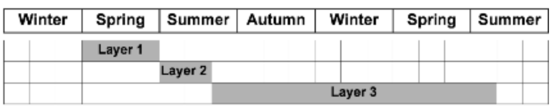

Fig. 5 Diagram showing the minimum time needed for the application of a lime mortar rendering inside a church in Northern Portugal.

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.

References

1 Rodrigues, M. P., 'Argamassas de revestimento para alvenarias antigas – Contribuição para o estudo da influência dos ligantes', PhD dissertation, Universidade Nova de Lisboa, Faculdade de Ciências e Tecnologia, Lisboa (2004).

2 Freitas, V. P.; Torres, M. I.; Ascensão, A.; Gonçalves, P., 'Tratamento da humidade ascensional na Igreja de Vilar de Frades', *Estudos/Património* **3** (2002) 54-62.

3 S.T.A.P. Reparação, Consolidação e Modificação de Estruturas, S.A., 'O.1200 – IPPAR – Igreja de Vilar de Frades – Argamassas de reboco – Ensaios de arrancamento por tracção n.º 2, 18 de Maio de 2004', relatório de ensaios (2004).

4 Freitas, V. P., 'Transferência de humidade em paredes de edifícios – Análise do fenómeno de interface', PhD dissertation, Faculdade de Engenharia da Universidade do Porto, Porto (1992).

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