Construction and Building Materials 157 (2017) 132–140

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Review

Air lime mortars: What else do we need to know to apply them in conservation and rehabilitation interventions? A review

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HIGHLIGHTS

- A large knowledge about air lime mortars is referred.
- Raw materials, characteristics, degradation factors and durability are addressed.
- Results obtained by about one hundred authors are reviewed and compiled.
- Lacks in knowledge and needs of research on air lime mortars are identified.
- Human factor, time factor and local issues are identified for further study.

ARTICLE INFO

Article history:
Received 21 February 2017
Received in revised form 22 August 2017
Accepted 14 September 2017

Keywords:
Air lime mortar
Old mortar
Carbonation
Application technique
Degradation factor
Compatibility

ABSTRACT

Air lime mortars were used in construction since immemorial times until at least the beginning of the 20th century. This material may tell the history of construction, in large parts of the world, as perhaps no other may.

To retrieve the lost knowledge of air lime mortars preparation techniques and application methodologies, many scientific studies were carried out, beginning with the analysis of old mortars and the study of old treatises and continuing with research about new air lime mortars.

In spite of all those efforts and of the evidences that lime mortars are the most adequate for the conservation of old buildings, their use in conservation interventions is still rare.

What is lacking in knowledge in order to make it possible their generalized use? And what is lacking in action?

Contents

1. Introduction

Air lime mortars were used in construction since immemorial times [1] until at least the first decades of the 20th century. They are a part of almost all the old buildings, playing different roles:

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https://doi.org/10.1016/j.conbuildmat.2017.09.080
0950-0618/

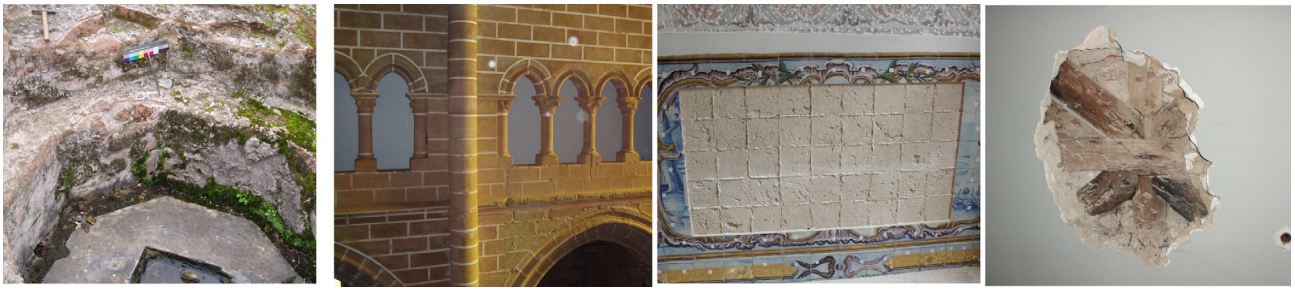

Fig. 1. Air lime mortars of historic constructions in Portugal: Troia Roman ruins; Évora Cathedral; bonding mortar of a panel of glazed ceramic tiles ("azulejos") on the wall of a Palace; wall of an 18th century building in Lisbon with anti-seismic timber-and-lime structure ("pombalina" structure).

structural functions when used to joint stones and blocks in structural masonry walls; protection of the walls against water and impacts when used in renders and plasters; bonding material for mosaics and ceramic tiles; decorative purposes when applied in coloured finishing coats, mural painting, stuccos and so many different decorative techniques (Fig. 1).

Bentur [2] points out the beginning of lime mortars' use back to 7000 BCE, by the Galilee in Israel, where a mortar floor was discovered in 1985 in Yiftah. Arizzi and Cultrone refer their use since 10,000 BCE [3] and the same is stated by Rodriguez-Navarro et al. [4], based on previous works [5,6]. According to Barbero [1], air lime renders and plasters have been found in archaeological sites of Sirian [7], Chinese [8] and Mayan [9] civilizations dated respectively from 4250 BCE, 2000 to 1700 BCE, and before 500 BCE, showing they were used all over the world.

Employed for so long, so broadly and in so many architectural and compositional forms, air lime mortars can tell the history of construction probably better than any other material.

However, after the invention of cement and especially in the second half of the 19th century, when the technological advances of the kilns used for calcination of the raw materials joined the scientific knowledge about hydraulic reactions [10], cement mortars and concretes started to be generally adopted and in a few decades the techniques related to lime were forgotten. The knowledge for the preparation and application of lime mortars, which was transmitted from parents to sons and from masters to apprentices [11], so assuring good durability and performance, as seen in old still surviving construction [12–14], has been discontinued and this lack of artisanal knowledge created difficulties for their practical use.

To compensate this disconnection, many scientific studies have been carried out about air lime and air lime mortars in the last four decades, beginning with the study of old treatises [15–17] and the analysis of old mortars [18,19,6,20–24] and going on with the research about new air lime mortars and their evolution in time. The nature, quality and proportions of the components were deeply studied [25–28,3], such as the effect of the environmental conditions [29,30], the carbonation evolution and the change of the porous structure [31–35], the influence of the mortar preparation and of the application process [36–39] and the impact of the lime production conditions [26,40–45].

In spite of so many studies and of the material evidences that lime mortars are the most suitable for conservation of old buildings, both for ethical arguments and for technical reasons [46,47], their use is still rare in the rehabilitation and conservation interventions of constructions that were originally lime-based.

What is lacking to make it possible the generalized application of such a well-known material? Knowledge? Actions?

Fig. 2. White lumps in an old air lime render.

2. Composition of existent air lime mortars

The lime mortars of historic buildings that survived until present times have very diversified compositions, in proportions, nature and quality of the main components and in types of additions. Analysis showed volumetric proportions binder: aggregate mainly in the range 1:1 to 1:2.5, or even richer in lime, but 1:3 to 1:4 and poorer are also found [15,48,49,21,50], being used for economic reasons in current constructions or resulting from loss of binder caused along time, by erosion, loss of cohesion or by dissolution as a consequence of the repeated action of water. In old mortars small white lumps of lime (Fig. 2) are often visible, sometimes attributed to non-hydrated quicklime (applied following the method of the *hot lime mix*) but which can also be due to poorly mixed hydrated powder or lime putty, or even to the re-precipitation of the calcium carbonate.

The lime: aggregate ratio is one of the factors that decisively influence the characteristics and the performance of air lime mortars and so it was studied since the modern research was started about this material. Many experiments were done with diversified proportions, with the aim of getting mortars simultaneously compatible with historic buildings and durable enough for conservation and rehabilitation works [25–28,33,32,51–53].

The volumetric proportion 1:3 (air lime: sand) was pointed out as reference, due to being indicated by Vitruvius [15] although some uncertainty exists about this reference considering that the proportion could be related to lime putty and not to hydrated lime powder, that the aggregate usually included pozzolans partially acting as binder and that translations from Latin to modern languages may have several imprecisions related to the present meaning of construction concepts [54,55].

Moreover, 1:3 is also the ratio that assures the best compaction for a well-graded sand, due to best voids fulfilling by the lime: the voids index of a well-graded sand is in the minimum 33%, while a poorly graded one may have about 48%, so requiring a volumetric