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Bentonite as a natural additive for lime and lime–metakaolin mortars used for restoration of adobe buildings

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ABSTRACT

This work estimates the behaviour of mortars based on lime, seeking their application as renders of adobe walls. Mortars with binder:aggregate 1:3 volumetric ratio were prepared as is traditionally used in old buildings in central parts of Portugal.

Due to specificity of the support, two clays, natural clay bentonite (5 wt.%) and artificial clay metakaolin (20 wt.%) were used as additives to lime mortar to prepare 3 types of blended mortars, besides the air lime reference mortar. Mortar prisms 4 × 4 × 16 cm were analysed to assess mechanical properties and salt resistance. Moreover, the mortars were placed in three ways on old adobes taken from demolished houses and their behaviour was verified by artificial accelerated ageing test. Lastly, mortars were applied on a wall made from traditional adobes, where panels were monitored and trials with adhesion strength and Karsten tubes have been conducted. The results obtained by comparison of the characteristics from all the experimental procedures reveal that mortar containing air lime and 5 wt.% of bentonite fulfils in the best way the requirements in its use as render of adobe buildings.

1. Introduction

Depending on the local tradition, various types of earthen construction were used in the central parts of Portugal, up to the beginning of the 20th century. There is an evident presence of an important legacy of adobe construction in Portugal, with a special territorial focus on the area between Murtosa and Mira/Figueira da Foz, extending as well to inland areas [1]. Currently many edifices constructed from adobe bricks still persist, both in city centres and in rural areas. Moreover; many urban adobe buildings show a cultural, historical and architectonic recognized value, for example the ornate buildings with an "Art Nouveau" style [2]. Unfortunately, the degradation has affected many of these buildings and this is particularly evident in terms of the renders, because they are the exposed external element and extremely prone to the action of weather.

Rendering mortars play an important role in the conservation of earth based walls as their application has not only an aesthetical purpose, but also the protection and reduction of the wall's deterioration. They act as a "sacrifice" element and regulate water intake and output. Rendering mortars must also attain mechanical and chemical compatibility with adobe in order to promote its conservation [3–5]. Over the centuries, historic mortars have demonstrated to be long lasting and compatible with the historic structural units. Therefore, a design of new mortars should be approached by simulating the historic materials [3,6–8].

Lime has been used as a binder in architectural heritage mortars since prehistoric times and seems to be an extremely enduring binder. For this reason, air lime mortars and/or combined with pozzolans have been studied widely, with the objective to be used as mortars for the restoration of historic buildings (e.g. [6,9–14]). Addition of high reactive pozzolans to lime creates mortars similar to historic ones that exhibit improved values of mechanical strength and an advanced durability. Positive effect of metakaolin as a pozzolanic incorporation to mortars has been verified [15,16]. Moreover scientific attention is being focused also on utilization of natural clays and clay minerals due to their unique physico-chemical properties and/or optimal morphological structure as lime binder replacement. For instance sepiolite [17–20], palygorskite [21], zeolite [22,23], vermiculite [24] and bentonite [25–27] have been added to mortars and cements to improve their characteristics.

The last mentioned clay, bentonite (from Jelšový Potok (JP) deposit, Slovakia), was also used in the present work as an additive to air lime/metakaolin mortars due to its properties and the specificity of application on earth-based buildings.

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The quality of bentonitic raw materials depends on numerous parameters such as chemical stability, rheological and exchange properties, adsorption abilities and swelling behaviour. Bentonite (JP) due to its characteristics like high cation exchange capacity and specific surface area, has been recently studied predominantly in terms of environmental protection as sealing material in landfill liners [28,29], adsorbent of toxic heavy metals [30,31] and radionuclides in dependence on its use as a sealing barrier in radioactive waste and spent nuclear fuel repositories [32–37].

The main objective of this study is to create new repair mortars to be used as renders for historical adobe buildings, fulfilling compatibility requirements and showing improved mechanical and durability properties in comparison with reference air lime mortar. As coastal parts of the Iberian Peninsula, in which Portugal is included, are typical for harsh winds [38–40] combined in the summer by lack of humidity, mortar mixtures based on lime and/or metakaolin and bentonite were prepared. The main reason of choosing bentonite as an additive is that it is a natural pozzolan [26,27], economically friendly, has a high adsorption capacity with ability to retain water, hence able to support pozzolanic activity of metakaolin in case of low humidity conditions.

2. Materials used for mortars preparation

The materials used for preparation of mortars were the following: commercial air lime (AL) (Lusical H100, Portugal) with classification CL90, commercial metakaolin 1200S (MK) (AGS Mineraux, France), commercial bentonite (B) (type A 020, non-activated, natural, content of montmorillonite 65–85 wt.%, from Jelšový Potok (JP) deposit, Envigeo a.s., Banská Bystrica, Slovakia) and commercial sand (mixture of 3 sands APAS 12, APAS 20 and APAS 30 with volumetric ratios 1:1.5:1.5, respectively; Areipor – Areias Portuguesas, Lda, Bucelas, Portugal). Bulk densities of materials are reported in Table 1.

Four types of mortars were prepared with binder: sand – 1:3 volumetric ratio.

The first type of mortar (AL) used as reference contained air lime:sand in a 1:3 volumetric ratio. Blended mortars were prepared as follows:

(a) 5 wt.% of air lime was replaced by bentonite (BAL).
(b) 20 wt.% of air lime was replaced by metakaolin (AL20MK).

Table 1
Bulk densities of materials (kg m^{-3}).

Material	Bulk density (kg m^{-3})
APAS 12	1444.4
APAS 20	1405.0
APAS 30	1381.3
Air lime	395.7
Metakaolin	296.0
Bentonite	719.3

(c) Air lime was substituted by 5 wt.% of bentonite and 20 wt.% of metakaolin (BAL20MK). To achieve required consistency and appropriate workability (similar flow table values of around 120–130 mm), 20 wt.% of water was added to mortars [41].

All types of mortars were studied and analysed (a) as prisms, (b) applied on adobes, (c) applied on adobe walls according to Andrejkovičová et al. [18].

(a) Mortar testing as prisms

Mortar specimens 4 × 4 × 16 cm were prepared and cured as follows: air lime mortar without any additives was stored during all curing periods in a chamber with a relative humidity of 65 ± 5% and 20 ± 2 °C; while mortars containing metakaolin and bentonite were placed in moulds for the first 7 days at 20 ± 2 °C with a relative humidity of 95 ± 5% and then kept for 21 days in a chamber with relative humidity of 65 ± 5% and 20 ± 2 °C according to the Standard [42]. After removing the mortars from moulds, all the probes were stored at a chamber with relative humidity of 65 ± 5% and cured up to 28, 90 and 180 days.

(b) Mortars applied on adobes

Every mortar type was applied on adobes in three ways, simulating traditional application practices, as is shown in Fig. 1: (a) one layer of 2 cm (Adobe 1), (b) two layers; each layer with 2 cm, in total 4 cm (Adobe 2), (c) one mortar layer of 2 cm under which supporting spatterdash was used (Adobe 3). In case of adobes 2 and 3, a second mortar layer was applied 1 day after, when the bottom layer had dried.

(c) Mortars applied on adobe wall

Mortars were applied on the adobe wall in the most traditional way, similarly as is illustrated in Fig. 1 – adobe 3, to control if spatterdash fulfils a function of enhanced adhesion of mortar to support. Spatterdash layer was applied under 2 cm layer of individual mortar. This mortar layer was applied the day after, when the bottom layer had dried. Mortars were applied on adobe wall as squares with dimensions of 50 × 50 cm (Fig. 2). Mortars were cured in laboratory conditions and analysed after 30, 60 and 90 days.

3. Methods

Following techniques were used for:

3.1. Materials and/or mortar prisms

Philips X'Pert diffractometer equipped with Cu Kα radiation was used to establish mineralogical composition of the specimens. The X'Pert HighScore (PW3209) program was used to analyze XRD peaks.

Fig. 1. Application of mortars on adobes.