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Lime–cement mortars for coating with improved thermal and acoustic performance

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HIGHLIGHTS

- An experimental characterization of lime–cement mortar performance was carried out.
- Gap-graded and lightweight aggregates and cellulose and PP fibers were used.
- Early age cracking, mechanical, acoustic and thermal performance were assessed.
- Water to binder ratio modified open porosity and early age shrinkage and cracking.
- Open porosity affected mechanical and acoustic values; density varied thermal ones.

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ABSTRACT

Coating mortars can modify significantly the thermal and acoustic performance of buildings; reducing energy consumption and improving noise control on rehabilitation, meeting the current requirements, and new buildings. To improve thermal and acoustic properties on lime–cement mortars, fulfilling other physical, mechanical and technical requirements, a gap-graded aggregate (GGA), three lightweight aggregates (LWA) (expanded clay, perlite and vermiculite) and fibers (cellulose and polypropylene) were used. The water to binder ratios were fixed in order to get a plastic consistency for all the fresh compositions.

The experimental program assessed the influence of those components on free shrinkage and cracking at early age (24 h) and physical and mechanical properties, thermal conductivity and sound absorption coefficient on hardened mortar samples.

A parametric analysis allowed to identify some relations linking water to binder ratio to open porosity, free shrinkage and cracking risk at early ages; apparent density to thermal conductivity of samples without fibers and open porosity to mechanical performance and sound absorption coefficient. Lightweight aggregates and fibers showed a different behavior, especially on thermal and acoustic performance, because of a different pore structure. The combined effect of GGA, LWA and fibers improved thermal and acoustic performance of lime–cement mortars.

1. Introduction

Traditional buildings are characterized by large energy consumption and low noise control, according to today thermal and acoustic standards. Thus, habitability improvement has become a main concern of rehabilitation techniques and materials. Building rehabilitation often requires the repair or substitution of coating mortars, due to their loss of performance. Coating mortars can be designed to fulfill the nowadays thermal and acoustic requirements. However, when conventional cement mortars are used as repairing materials, some pathologies arise due to soluble salts contents and their high strength compared to traditional lime mortars.

Besides thermal and acoustic performance, other aspects should be taken into account on new mortars design [1]: functional requirements (conservation, aesthetic, structural, service-life and construction issues); technical requirements based on exterior or interior applications; and performance requirements (general and specific technical requirements for renders and plasters).

Characterization studies usually assess mortar mechanical properties, pore structure and durability, but avoid other material requirements. Some relations among water to binder ratio, pore structure and mechanical performance have been described [2–4].

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Due to wide variations in their composition, mortars can show different characteristics and performance. The most common binders are cement, lime and mixed lime–cement. Cement based mortars have been reported to show poor compatibility and low flexibility [5]. The use of white cement is remarkable, which decreases the possibility of salt formations – the main issue of Portland cement in restoration works [6] – due to its lower alkali content [7,8]. In general, traditional binders have shown a good thermal performance [9]. Lime is usually considered the best option for restoration works [10], although lime–cement mortars are also accepted [11,12].

To improve thermal and acoustic performance, coating mortars usually incorporate other components, as lightweight aggregates, end-of-life byproducts and short fibers. Lightweight aggregates (LWA), such as expanded clay [13], perlite and vermiculite [14,15], are commonly used to reduce mortar density. LWA also modify thermal conductivity [16] and durability [17]. However, lowering the density produces a strength reduction, which can limit the direct exposition of the mortar to the environmental agents, requiring an external protection. On the other hand, the LWA microstructure and the particles broken of LWA during the mixing process affects the water to binder ratio needed to achieve a target consistency [18].

Other studies used end-of-life by-products such as rubber [19] or petroleum coke [20]. Alternative research improved acoustic absorption of concrete modifying the pore structure by the use of a gap-graded aggregate (GGA) and removing the fine contents [21–23].

Experimental studies on mortars with short fibers such as cellulose [24,25] and polypropylene [26] point out improvements on acoustic, thermal and mechanical performance. However, the effect of the amount of fibers is discussed regarding to the improvements achieved [26].

This paper presents an experimental program on a lime–cement mortar for coating application with improved thermal and acoustic performance, for repair, rehabilitation or new construction. The aim of this study was to investigate the effect of different components on mortar performance, identifying the physical and mechanical parameters involved in thermal and acoustic improvement and fulfilling the technical, functional and performance requirements of external coatings.

The binder combined aerial lime and white cement in order to allow colored mortars by the addition of pigments and to reduce pathological problems due to alkali content. To achieve material and functional requirements, gap-graded aggregate without fines content, three lightweight aggregates (expanded clay, perlite and vermiculite) and two short fibers (cellulose and polypropylene) were investigated. Early age (24 h) and hardened performance, measuring workability, free shrinkage, early age cracking, physical and mechanical properties, thermal conductivity and sound absorption coefficient were assessed.

2. Experimental program

The experimental program assessed the fresh state, early age behavior (free shrinkage and initial time, total cracked area and w/b ratio), hardened physical properties (apparent density, open porosity, capillary water absorption coefficient and suction height), mechanical performance (compressive, flexural and adhesion strength, ultrasonic pulse velocity –UPV– and ultrasonic modulus) and thermal and acoustic behavior of twelve lime–cement mixtures.

2.1. Materials and mortars compositions

The components used in the study were:

- An aerial lime class CL 90-S, designated according to the European standard [27].
- A white cement type BL II/B-L 32.5N (UNE-EN 197-1:2011 [28]) supplied by Readymix-Asland S.A.
- Two normal-weight siliceous aggregates: a continuous-graded (0–4 mm) and a gap-graded (2–3 mm).
- Three lightweight aggregates (LWA): expanded clay (A), perlite (P) and vermiculite (V). The particle size distribution of LWA changed during the mixing process, due to the breakage of large particles. Fig. 1 plots the distribution before and after the mixing process.
- Two short fibers: a cellulose fiber (FC) of 1 mm length – Fibracel® BC-1000 (Ø20 μm) – supplied by Omya Clariana S.L. and a polypropylene fiber (FPP) of 6 mm length – MASTERFIBER 21 (Ø31–35 μm) – supplied by BASF Construction Chemicals España S.L.

Table 1 summarizes the compositions of the twelve mortars considered in this study. The selected binder (lime–cement) to aggregate ratio was 1:1:6 (cement: lime: aggregate) by volume in all cases. The water to binder ratio varied to get a plastic consistency and similar fresh workability for all the samples. The composition data is in weight in order to facilitate reproducibility. The nominal apparent density of the components is also in Table 1.

A reference lime–cement mortar with continuous siliceous aggregate was prepared (REF). The aggregate was partially substituted by 25% of perlite (REFP25). The continuous aggregate was substituted by a gap-graded aggregate (REFC). Afterwards, three types of LWA replaced 25% and 50% of the gap-graded aggregate: expanded clay (A), perlite (P) and vermiculite (V). These mixtures were designated A25, P25, P50, V25 and V50. A50 was not manufactured due to the lack of some requirements, such as aesthetic issues or workability. Two types of short fibers were added: cellulose (FC) and polypropylene (FPP) fibers. The amount of FC was 1.5% and 3% of the total dried mortar's volume. These mixtures were called FC15, FC30 and P25FC30. The mixture P25FPP incorporated 810 g of FPP per cubic meter of dried mortar. The dry components, included the fibers, were mixed first and the water was added afterwards. The total mixing time did not exceed 5 min in any case.

2.2. Experimental methods

2.2.1. Workability, free shrinkage and early age cracking

The fresh mortar consistency was measured using the flow table test, according to the European standard (UNE-EN 1015-3:2000 [29]). The water to binder ratio was fixed according to the plastic consistency required for coating mortars. The slump cone test provided data about the workability due to the calculated yield stress [30] and the fresh mortar bulk density was calculated.

Early age free shrinkage was monitored on 500 × 100 × 50 mm mortar samples. During the first 6 h, a 3 m/s airflow was applied on the sample's surface. The early age free shrinkage test setup has been previously published [31].

Early age cracking risk was evaluated on 390 × 390 × 40 mm doubled restrained slabs subjected to an airflow of 3 m/s during the first 6 h, in order to maximize cracking risk. The samples were demolded after 24 h and cured for 7 days (21 ± 2 °C and 60 ± 10% RH). The cracked area was calculated measuring crack length and width, regarding the total area of the slab. The early age cracking risk test setup has been published [31].

2.2.2. Hardened performance

The characterization in the hardened state was done on 40 × 40 × 160 mm specimens. The samples were demolded at 24 h and cured until tested (21 ± 3 °C and 95 ± 5% RH).

The pore structure, apparent density and open (accessible to water) porosity were calculated using a hydrostatic balance at 28 days [31]. In addition, capillary water absorption coefficient and suction height was measured (UNE-EN 1015-18:2003 [32]). In some samples, the pore structure was assessed by direct observation using an optical microscope with a digital camera.

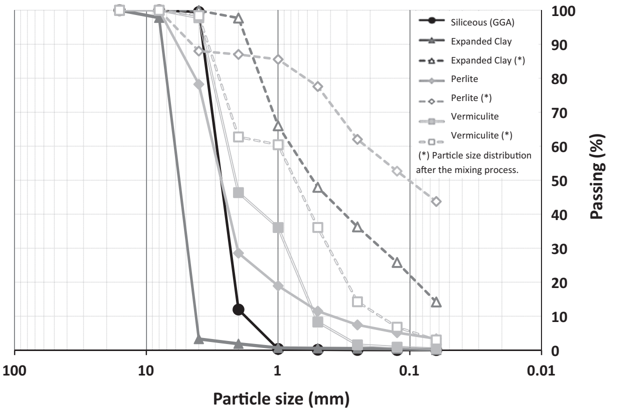

Fig. 1. Particle size distribution of aggregates before and after mixing.