Construction and Building Materials 160 (2018) 136–144

Contents lists available at ScienceDirect

Construction and Building Materials

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

A multiscale model for pervious lime-cement mortar with perlite and cellulose fibers

I. Palomar *, G. Barluenga

Department of Architecture, University of Alcala, Madrid, Spain

HIGHLIGHTS

- Pervious lime-cement mortar (PLCM) with perlite and cellulose fibers was characterized.
- A three-phase macrostructural model and a multiphase paste microstructure described.
- The multiscale model considered mortar voids and paste porosity.
- Active void size and paste thickness were related to PLCM performance parameters.
- Perlite and cellulose fibers modified both paste thickness and active void size.

ARTICLE INFO

Article history:
Received 14 July 2017
Received in revised form 29 September 2017
Accepted 10 November 2017

Keywords:
Pervious lime-cement mortar
Multiscale model
Cellulose fibers
Perlite
Thermal properties
Acoustic performance

ABSTRACT

A pervious lime-cement mortar (PLCM) with perlite (P) and cellulose fibers (FC) was studied for better understanding the relationships among mortar composition, microstructure and properties, especially thermal and acoustic performance. Mortar microstructure was studied by optical and scanning electron microscopy, water absorption and nitrogen adsorption/desorption tests. A multiscale model for PLCM with and without P and/or FC was proposed: a three-phase macrostructural model consisting on a gap-graded aggregate, a paste shell and a continuous void network; paste phase was described as a multiphase microstructure. Paste thickness and active void size were identified as PLCM macrostructural parameters. The use of P and FC widened the paste shell, reducing the active void size. While the effect of P depends on particle size rather than the proportion used, the effect of FC depended on fiber amount. The model could be useful for optimizing the design of PLCM and predicting thermal and acoustic performance.

1. Introduction

Lime-cement mortars are used as rendering for building walls due to their good compatibility with wall materials and their large plasticity. Some components as gap-graded aggregate (GGA), lightweight aggregates (LWA) and short fibers have been incorporated to improve their thermal and acoustic performance [1,2]. The type and amount of those components modify the hardened microstructure that would turn into changes in their properties [3]. The main characteristic of mortars with GGA is the lack of fine aggregate particles that creates an interconnected void network, producing a pervious lime-cement mortar (PLCM). Accordingly, mortar microstructure is composed by a porous network and heterogeneous components with different phases: paste, aggregate and air voids and pores.

The closest reference to understand PLCM microstructure can be found in the literature about pervious concrete (PC). PC is modelled as a three-phase material, where hard core spherical particles of aggregate are surrounded by a "soft" shell of cementitious paste and placed within a bulk phase of interconnected voids [4,5]. It has been described that a highly interconnected void network of PC would produce better insulation performance and noise reduction [6–9]. Accordingly, the design of PC composition relies on paste volume optimization, preventing fulfilling the voids among aggregate particles [10]. Some authors pointed out paste shell thickness as the key parameter of pervious concrete performance [11]. The effect of aggregate size and gradation on mechanical properties, permeability [9] and acoustic absorption [8] has been also

* Corresponding author at: Departamento de Arquitectura. Escuela de Arquitectura, Universidad de Alcalá, C. Santa Úrsula, 8. Alcalá de Henares, 28801 Madrid, Spain.

E-mail addresses: irene.palomar@uah.es (I. Palomar), gonzalo.barluenga@uah.es (G. Barluenga).

https://doi.org/10.1016/j.conbuildmat.2017.11.032
0950-0618/

reported. However, as the voids in PC have different shapes and sizes, the effective porosity volume varies depending on the property considered [12].

The paste shell has to be also taken into account when modelling PLCM because the paste can be also considered as a multiphase composite. Considering both the air voids among aggregate particles and the paste porosity, a coupling effect between the different characteristic sizes of the pores in double porosity materials may occur [13].

The number of publications on the paste shell modelling of pervious mixtures is very limited. Lime-cement paste microstructure is a mix of cement gel structure, lime crystals and micropores [14,15]. In addition, other solid phases as aggregates' finer particles or fibers may be part of the paste. Lightweight aggregates (LWA), such as perlite (P), modify fresh properties and hardened properties of traditional cementitious materials [16]. Some authors have described the influence of LWA in bulk paste microstructure between 10 and 50 μm from the aggregate surface [17]. Alternatively, perlite particles can break into smaller crushed particles during the mixing process due to its low strength [18]. The smaller aggregate particles jointly with the LWA crushed particles can be considered as extra solid components of the paste [10,19].

Experimental studies on mortars with short cellulose [20] or polypropylene fibers [21] pointed out relationships among mortar's composition, amount of fibers, matrix microstructure and mortar's properties.

Regarding the air phase of the mortar, the pore network can be described as a multiscale pore structure defined by total porosity, connectivity of pore network and pore size distribution [22]. Pore size can be classified into micropores for width < 2 nm, mesopores and macropores for width > 50 nm [23]. Other authors classified pore size for cement-based materials in three groups: gel pores with width < 10 nm, corresponding to interlayer spaces, micropores and small capillaries; capillary pores for width > 10 nm consisting on medium and large capillaries and entrapped air voids with width > 100 μm [24]. From an experimental point of view, multiple techniques are usually required to quantify and characterize the pore structure of cement or lime based materials at different pore and void scales [25–27].

This paper presents an experimental program to investigate the effect of perlite and cellulose fibers on PLCM microstructure combining several testing techniques as optical and scanning electron microscopy, water absorption and nitrogen adsorption/desorption. The aim of the study was to identify microstructural parameters to better understand the relationships among composition, microstructure and properties of PLCM. The experimental results and observations were used to propose a multiscale model of PLCM that would be useful for optimizing the design of pervious mortar and predicting thermal and acoustic performance.

2. Experimental program

2.1. Materials and mortar compositions

The binder used in this study was a mixture of lime class CL 90-S and white cement BL II/B-L 32.5 N (supplied by Cementos Portland Valderrivas S.A.). Two types of aggregate were used: a normal-weight siliceous gap-graded aggregate (2–3 mm and 44 ± 2% of inter-particle voids) and a lightweight aggregate (LWA) perlite (P) (0–2 mm). Fig. 1 presents the particle size distribution of aggregates, where perlite increased the fines content due to the crushing of large particles during the mixing process [2]. Cellulose fiber (FC) of 1 mm length, Fibracel ® BC-1000 (Ø20 μm) supplied by Omya Clariana S.L., was also used.

Table 1 summarizes the compositions of the four PLCM in this study. Cement-lime-aggregate ratio was 1:1:6 by volume for all the mixtures. Water to binder ratio (w/b) was adjusted to get a plastic consistency and similar workability for the fresh mixtures. Two PLCM with cellulose fibers, 1.5% (FC15) and 3% (FC30) of the total dry mortar's volume, and two mixtures with 25% of the aggregate replaced by perlite (P), P25 and P25FC30 were prepared. Fig. 1 shows that 13% of the aggregates' particles were smaller than 125 μm after mixing.

2.2. Experimental methods and characterization

2.2.1. Microstructural and void characterization

Direct and indirect methods were used to characterize the microstructure and pore network of PLCM. Direct observation of the microstructure morphology was done with optical microscopy (OM) and scanning electron microscopy (SEM). Open porosity accessible to water (P_O), capillary water absorption coefficient (C) and water vapor permeability (P_V) were calculated according to the indirect measuring techniques of EN 1936, EN 1015-18 and EN 1015-19, respectively. The open porosity accessible to water (P_O) was calculated using a hydrostatic balance at 28 days, weighing dry, water saturated and submerged of 40 × 40 × 160 mm specimens. The capillary water absorption coefficient (C) was estimated weighing the 40 × 40 × 160 mm specimens which absorbed water from the bottom face. The water vapor permeability (P_V) was determined by wet-cup method containing a saturated saline dissolution (75% RH) and using cylindrical specimens with 35 mm diameter and 40 ± 2 mm thick.

Pore size distribution, average width pore (W_P) and pore surface area (S_{BET}) were assessed by nitrogen adsorption/desorption technique (calculation method BJH). The device recorded pore diameter from 1 Å to 3000 Å, covering the whole mesopore size range (20–500 Å) [24]. Although nitrogen adsorption method has limited application to lime mortars [26], other authors defined it as appropriate for cement-based mixtures characterization [27].

2.2.2. Mechanical and physical characterization

Several mechanical and physical parameters were characterized. The experimental set-up and test procedures have been previously published [2,3]. Compressive (f_{cm}) and flexural (f_{ctm}) strength on 40 × 40 × 160 mm prismatic samples at 28 days were tested according with EN 1015-11. Previously, P- and S-wave (54 and 250 kHz) transmission velocities were measured on those hardened samples. Dynamic Young modulus (E) and bulk modulus (K) were calculated by ultrasonic pulse tests, combining apparent density (D) and P- and S-wave velocities [3].

Apparent density (D), thermal conductivity (λ) and sound absorption coefficient (α_{NRC}) were calculated according to EN 1015-10, a testing method described in a former paper [2] and EN ISO 10534-2, respectively. A thermally insulated box was used to estimate thermal conductivity (λ) on 210 × 210 mm^2 and 24 ± 2 mm thick samples. The temperature on the inner and outer surface of the sample, inside, and outside the box was monitored until a steady thermal state was reached to calculated λ, according to Fourier's Law [28]. An impedance tube was used to measure the sound absorption coefficient (α_{NRC}) between 50 and 1600 Hz using cylindrical specimens with 96 ± 2 mm diameter and 40 ± 2 mm thick [2].

Table 2 summarizes the experimental results of the PLCM considered in the study. Some correlations among the composition, properties and ultrasonic parameters have been also reported [2,3].