Energy and Buildings 76 (2014) 422–428

Contents lists available at ScienceDirect

Energy and Buildings

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

Thermal conductivity of lime mortars and calcined diatoms. Parameters influencing their performance and comparison with the traditional lime and mortars containing crushed marble used as renders

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ARTICLE INFO

Article history:
Received 11 June 2013
Received in revised form 30 January 2014
Accepted 21 February 2014
Available online 12 March 2014

Keywords:
Render
Mortar
Lime
Diatom
Physical properties
Thermal conductivity

ABSTRACT

The adaptation of building constructions to energy saving requirements entails the study of the performance of constructive systems making up the building envelope. Since the façade is the envelope constructive system of greater impact, in terms of energy demand, the thermal characterisation of its components is of great interest. In this article, hardened lime pastes and different lime mortars with dolomite aggregate and calcined diatom additions at different temperatures are compared, firstly, in terms of thermal conductivity. Parameters such as aggregate type, binder, aggregate proportion, water content, bulk density of the mixture in hardened state and compaction time are studied as well. The wide application of lime and diatom mortars, in relation to traditional lime and mortars containing crushed marble, with reductions of their thermal conductivity up to 41.5% is proven, from the results of this research.

1. Introduction

Climate changes in the last decades, and prediction of an increase in the pollutant gases emissions in the next years [1] require the search for solutions, which allow for a reduction in energy consumption. In this regard, the residential sector is an area of great interest to mitigate the effects of global warming, taking into account that this sector implies 36% of Europe's CO_2 emissions [2]. In addition, this requirement is particularly pressing when the so-called "fuel poverty" is becoming widespread and around 50 million people face this problem presently in Europe [3].

According to the study published by Luxán et al. [4], façades are, among the thermal envelope components, the constructive system with the highest impact energy demand of buildings. As conduction is the most important mechanism in solids, due to the kinetic energy exchange between molecules, most of the researches developed during the last decades were centered on the increase of thermal resistance of the façade constructive system.

Aerial lime pastes and mortars are the most commonly used materials for façade renders in old buildings. In the case of Spain, their use was widespread well into the 20th century and they have been seminal not only in constructions still standing today but also, their importance can be traced in the classic treatises and modern literature [5]. Despite the importance of lime binder in traditional constructions and its relevance in façade constructive systems, its study from a thermal point of view, has been scarce until now. Nevertheless, due to the interest in conductivity reduction, several studies have analysed the incorporation of lightweight materials such as hemp [6–8] or phase change materials [9]. The addition of natural pozzolana stating the hydraulic character into mortars has been considered by Stefanidou et al. [10], determining the thermal performance of different lime mixes (with a 76% portlandite content), white cement and Portland cement with the addition of two types of pozzolana, without specifying their nature. Whereas Cerný et al. [11], analysed the thermal performance of hydrated lime with quartz aggregate and metakaolin to which later calcined clay and crushed enamelled glass were added [12], as well as metakaolin and metashale [13]. In addition to the aforementioned, this Czech research team has studied mortars with quartz

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http://dx.doi.org/10.1016/j.enbuild.2014.02.065
0378-7788/

Table 1
Physical properties of components.

	Grading (μm)	Mean particle size (μm)	Bulk density (kg/m^3)	Total specific surface area (cm^2/g)
Lime	0.5–16.5	6.32	392.3	174485
R	0–500	106.38	1716.5	4119
A	0.5–40	10.24	207.0	25756
B	0.5–60	13.88	240.7	21019
C	0.5–40	15.41	270.8	19550
D	0.5–40	11.09	241.6	130291

and basalt aggregates and additions of metakaolin [14]. However, none of the published researches analyses the effect of the addition of calcined diatoms, despite stating that they can be found in old mortars [15–18]. Unlike the studies with lime mortar, there are numerous researches with cement focused on lightweight mortars or concretes [19–50]. Nevertheless, on the topic of lime and cement mortars, the publications of Silva et al. [51] about the incorporation of vermiculite and perlite stand out, as well as those of Matiasovsky & Koronthalyova analysing the relation between thermal conductivity and the microstructure and porosity of the resulting material [52] are to be noticed. In addition to those, Frattolillo [53] analysed the influence of water repellent treatments in the thermal performance of lime and cement mortars.

Therefore, this article is the first one to develop on thermal performance of hydrated lime pastes and mortars with the addition of dolomite aggregate, which is normally used in the last layer of renders. These traditional mixes are compared with lime mortars and calcined diatoms, studying the effect that the latter might have upon mortars in terms of thermal conductivity. The influence of the aggregate nature, binder/aggregate proportion and water content and compaction time are likewise studied.

2. Materials and methods

2.1. Components

Calcitic lime CL90 (produced by CALCASA, Madrid, Spain), with the highest purity, was selected in accordance with the EN 459-1: 2010 standard.

A dolomitic sand of particle size 0–0.5 mm, grinded from a marble supplied by El Molino (Madrid) was used as reference aggregate (named R, for reference, along the text). This is the one commonly used in last layer renders, given its small grading and its white colouring.

Four types of commercial calcined diatoms were analysed. Two of those, C and D, were calcined at 870–1093 °C, having a pinkish colouring. They showed 64% and 96% amorphous part, respectively; whereas the other two, A and B, were flux calcined and subjected to temperatures around 1148 °C, obtaining a white colouring, in which the amorphous percentage was reduced to 30% and 31%, while the major component was cristobalite and tridimite. Their physical properties are shown in Table 1. The pozzolanic activity, measured according to the method of Luxán et al. [54] showed that diatom B had no pozzolanic character, while diatoms A, C and D had a variable pozzolanic activity.

2.2. Components characterization

The sieve-fraction and mean particle size, both in microns, were established by a Malvern Mastersizer S Long Bench laser diffractometer, with 300RFoptical lenses (reverse Fourier) for particle sizes between 0.05 and 880 microns. The apparatus was equipped with two types of complementary devices in order to perform the test in slurry or in dry state. The test was conducted at the Geology Institute of the Katholieke Universiteit of Leuven (Belgium). The samples were measured in aqueous slurry with no surfactant, and at the same time, vacuum-dry tested, with the exception of calcium hydroxide, which was vacuum-dry tested only, in order to avoid its reaction with water. Mean particle size (Table 1) is given as result of the vacuum tested in all samples except for the crushed marble sand to be in agreement with the observations of SEM images.

Bulk density, in kg/m^3, was measured following the standard UNE EN 1097-3:1999 method, which consists on pouring the material into a container of known and calibrated volume. The results were the average correlation between this method (commonly used on construction site) and the one based on compacting by vibration technique (2950 ± 50 cycles/min and 50 W of power during 10 min) proposed by several authors as the ideal one for dispersed materials [55].

Total specific surface area was determined by the BET technique and the use of the N2 adsorption technique. A Tristar 3000 of Micromeritics at a constant temperature of 77 K was used in this case. Before testing, samples were exposed to progressive heating–cooling to remove the water content. The difference in specific surface area between the diatom D and the other diatoms, being about six times higher, should be highlighted. At the same time, the particle size of dolomitic sand is significantly higher than that of diatoms, its bulk density is seven times higher and its total specific surface area is 12 times lower than the average one of the diatoms.

Table 2
Mixtures names and compositions. RM indicates the aerial lime mortar with the reference crushed marble sand, while AM, BM, CM and DM are the aerial lime mortars with the diatoms A, B, C and D, respectively. Proportion ratios are expressed as binder:aggregate:water, by volume.

RM1	AM1	BM1	CM1	DM1
1:1:0.4295	1:1:0.5062	1:1:0.4814	1:1:0.5145	1:1:0.5506
RM2	AM2	BM2	CM2	DM2
1:3:0.8996	1:3:1.0355	1:3:0.9025	1:3:1.1040	1:3:1.2557

2.3. Mortar preparation and curing

Ten types of mortar batches were prepared in order to analyse the effect of the aggregate nature and its content. Then, a complete replacement of the dolomitic marble sand by the diatoms was carried out. Two proportion ratios were selected, namely the 1:1 proportion ratio (binder: aggregate ratio), by volume, as well as the 1:3 ratio. This selection was based on a preliminary research with different materials, as well as the bibliography in which these proportions covered the most frequent range in render mortars. As the replacement of sand by lighter aggregates means a notable reduction of bulk density (and, consequently, of thermal conductivity) selected diatoms ratios were higher than the ones commonly used in the bibliography [16,37,56,57].

Water content was fixed by a penetration test with a modified Vicat machine at 20 mm, complying with the ASTM C110-04 standard to ensure a workable mixture. The names of mixtures and their composition are shown in Table 2. Furthermore, the performance of a hardened lime paste, named LP, was compared to the aerial lime mortars. In this case, water content was fixed at 1:0.3370, by volume, following the aforementioned criteria.

In addition to these batches, AM2 and CM2 were also performed with 0.5% and 0.7% extra water, respectively, in order to analyse its effect on the bulk density and thermal performance. These mortars were named AM2+ and CM2+.

Regarding the procedure, the materials were mixed in dry state for 90 s in a Hobart Planetary mixer at low speed, according to UNE EN 196-1:2005 standard. Afterwards, the arranged amount of water for each mortar was poured over the dry blend and