Construction and Building Materials 98 (2015) 89–101

Contents lists available at ScienceDirect

Construction and Building Materials

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

Effect of temperature on mortars with incorporation of phase change materials

Sandra Cunha *, José Aguiar, Fernando Pacheco-Torgal

University of Minho, Campus de Azurém, 4800-058 Guimarães, Portugal

HIGHLIGHTS

- Twelve different mortars were developed with phase change material incorporation.
- The aim of this study was evaluate the effect of the high temperatures on mortars.
- The exposure to high temperatures leads to a decrease in the mechanical strengths.
- The behavior to high temperatures of the PCM mortars is similar to reference mortars.

ARTICLE INFO

Article history:
Received 27 March 2015
Received in revised form 29 July 2015
Accepted 9 August 2015
Available online 24 August 2015

Keywords:
Mortars
Phase change materials
Temperature effect
Mechanical properties

ABSTRACT

Mortars with incorporation of phase change materials (PCM) have the ability to regulate the temperature inside buildings, contributing to the thermal comfort and reducing the use of heating and cooling equipment. However, it is important that they present a good behavior when subjected to aggressive conditions. The main purpose of this study was the effect of high temperatures on mortars with PCM. It was observed that the exposure to high temperatures leads to a decrease in the flexural, compressive and adhesion strengths. However, the behavior of the mortar with PCM is similar to reference mortars.

1. Introduction

The growing energy demand worldwide is an ever-increasing issue with regard to climate change and energy supply. The world consumes large amounts of fossil fuels that drive climate changes and empties the supplies of fossil fuels more rapidly. One method to benefit energy usage globally is to increase the energy efficiency of buildings [1]. It is important to remember that the European building sector is responsible for about 40% of the energy consumption [2]. A possible solution to face the increasing energy demand worldwide and reduce the negative environmental impacts is the higher utilization of environmentally friendly renewable energy technologies [1].

The incorporation of phase change materials (PCM) into construction materials has been proposed as a passive means of decreasing the overall heating and cooling demand of a building [3]. Thus, the incorporation of PCM in mortars for the interior appears as a possible solution in an attempt to solve, or at least minimize, the massive energetic consumption related with buildings. The use of this material allows the regulation of frequency of temperatures fluctuations, keeping them closer to the desired temperature range for a longer period, using only solar energy as a resource, or at least reducing the need to use heating and cooling equipment.

The phase change materials possess the capability to alter its own state as function of the environmental temperature [4]. In other words, when the surrounding environmental temperature of PCM increases until the materials fusion point, it suffers a change from a solid state to a liquid state, absorbing and storing the heat energy from the environment. On the other hand, when the temperature decreases until the PCM solidification point, the material alters from the liquid state to solid state, releasing the previously stored energy to the environment. This application could be made in coating mortars of buildings, with advantage in the passive regulation of internal temperature with increase of thermal inertia [5].

The PCM is generally used encapsulated. There are two types of encapsulation: macroencapsulation and microencapsulation. The

* Corresponding author.
E-mail addresses: sandracunha86@gmail.com (S. Cunha), aguiar@civil.uminho.pt (J. Aguiar), torgal@civil.uminho.pt (F. Pacheco-Torgal).

http://dx.doi.org/10.1016/j.conbuildmat.2015.08.077

macroencapsulation is based in the introduction of PCM into tubes, panels or other large containers. It is usually done in containers with more than 1 cm in diameter and presents a better compatibility with the material, improving the handling in construction [6]. The microencapsulation consists on covering the material particles, with a material, usually a polymer, commonly known capsule, with dimensions between 1 μm and 60 μm [6,7]. Recently, this problem of encapsulation was solved by using shape-stabilized PCM. These shape-stabilized PCM can be prepared by integrating the PCM into the supporting material. The shape-stabilized PCM are mainly classified as composite PCM and are usually fabricated by embedding PCM into shape stabilization supports such as high density polyethylene, styrene, butadiene, polymethacrylic acid, polystyrene resin, etc [8].

In the last years several studies were published related to construction materials with incorporation of PCM. The incorporation of PCM in gypsum plasterboard has been the subject of several studies performed, due to its low cost and various possibilities of application [9–12]. Darkwa et al. [11] investigated the behavior of two solutions with incorporation of PCM in gypsum plasterboard. In one side the plasterboard used had 12 mm of thickness, all impregnated with PCM in order to compare with another situation in which they applied single plasterboards with 10 mm of thickness, covered by PCM laminate with 2 mm. The amount of PCM incorporated in both cases was the same. The results showed that the use of PCM laminate is more efficient since it contributed to an increase in the minimum temperature. However, other solutions had also been developed like alveolar PVC panels with PCM macroencapsulated, blocks, bricks and mortars [6,13,14]. Cabeza et al. [6], constructed and monitored the behavior of concrete test cells, with and without addition of 5% of PCM microcapsules. The incorporation of PCM was made in the concrete used on the roof and south and west walls. During the summer and without ventilation a decrease in maximum temperature and a time lag of about 2 h were recorded. Other studies demonstrated more interest in evaluates the influence of adding PCM in the main properties of the materials. Cunha et al. [14] developed a study incorporating two different PCM in mortars evaluating the influence of these materials in the fresh and hardened state of the mortars. It was verified that the use of PCM microcapsules provides different characteristics in the different mortars, which is related to the type of polymer used in the wall of the microcapsules and also to their size. Other studies had interest in studying some characteristics of materials doped with PCM. The incorporation of PCM in concrete has shown some promising results through lower thermal conductivity and an increase in thermal mass at specific temperatures. However, the concrete with incorporation of PCM has shown some undesirable properties such as lower strength, uncertain long-term stability and lower fire resistance [15].

The safety requirements for materials used in buildings is a crucial point for the PCM, it should not be toxic or flammable [1]. Bearing this in mind it is important to understand the behavior of the materials in aggressive conditions. The exposure of the construction materials at high temperatures has a huge influence in their properties, since when subjected to this action they can present a very distinct behavior compared with the normal conditions. The materials used in buildings can significantly affect the characteristics of a developing fire. Thus, the investigation of the behavior of construction materials in high temperatures is essential, due to their potential impact on the overall fire safety of a building [3].

The scientific community had conducted studies in the framework of the reaction to fire and high temperature behavior. However, the study of the behavior at high temperatures of mortars incorporating phase change materials (PCM) is one of the main knowledge gaps. The commercially available organic PCM are mainly paraffin blends since they exhibit a range of desirable characteristics, such as high latent heat, ability to control the phase change temperature, low cost, non-corrosive characteristics and chemical stability. However, these materials exhibit two main weaknesses, the low thermal conductivity and increased flammability which can compromise the fire safety characteristics of a building [3]. Thus, the main objective of this work was the effect of the high temperatures on mortars with incorporation of PCM, based on different binders. The binders studied were aerial lime, hydraulic lime, gypsum and cement. The use of lime based mortars are especially important in building retrofitting in which render compatibility must be assured [16]. The proportion of PCM studied was 0% and 40% of the sand mass. Tests were performed with 12 different compositions at 3 different temperature ranges, evaluating the flexural, compression and adhesion strengths.

2. Experimental program

2.1. Materials

The selection of the materials took in account previous works [14,17–19]. The influence of adding PCM in mortars for interior coating was studied. Mortars were based on the following binders: aerial lime, hydraulic lime, gypsum and cement. The aerial lime used has a purity of 90% and density of 2450 kg/m^3. The gypsum used is a traditional one, with high fineness and density of 2740 kg/m^3. The hydraulic lime was a natural lime (NHL5) with density of 2550 kg/m^3. The cement used was a CEM II B-L 32.5N with density of 3030 kg/m^3.

The PCM used is composed of a wall in melamine-formaldehyde and a core in paraffin with transition temperature of about 22.5 °C, enthalpy of 147.9 kJ/kg and density of 880 kg/m^3 (Fig. 1). The process of fabrication is polycondensation by addition and the material is commercialized by the Devan Chemicals, with the commercial name of Mikathermic D24. This PCM exhibits a transition temperature of 24 °C in the heating cycle and 21 °C in the cooling cycle. Granulometry tests were performed, using a laser particle size analyser, in order to determine the dimensions of PCM microcapsules. It was possible to observe a particle size distribution between 5.8 and 339 μm, with 80% of particle size between 10.4 and 55.2 μm (Fig. 2). The average particle size is 43.91 μm.

The superplasticizer used was a polyacrylate, with a density of 1050 kg/m^3. The sand used has an average particle size of 439.9 μm and a density of 2600 kg/m^3. Finally, the fibers used are synthetic fibers of polyamide, with a length of 6 mm, 22.3 μm of thickness (Fig. 3) and density of 1380 kg/m^3.

2.2. Compositions

In order to develop this study an experimental campaign was considered. Twelve compositions were studied with the main goal of characterizing the effect of high temperatures, based in the mechanical properties changes.

The studied compositions are presented in Table 1. The used compositions have different contents of PCM (0% and 40%) and different binders (aerial lime, hydraulic lime, gypsum and cement). In order to overcome some of the problems related with the low flexural and compressive strengths verified in the aerial lime based mortars with incorporation of microcapsules of PCM, it was decided to incorporate a higher content of binder.

2.3. Mechanical characterization

The mixture procedure and specimens preparation for the compression and flexural tests followed the standard EN 1015-11 [20]. For each composition and exposure temperature, 3 prismatic specimens with $40 \times 40 \times 160$ mm^3 were prepared. Regarding the adhesion tests, the mixture procedure and specimens preparation followed the standard EN 1015-12 [21]. For each studied composition and exposure temperature, 5 circular test areas with a diameter of 50 mm were prepared. After their preparation all the specimens were stored during 7 days in polyethylene bags and subsequently placed in the laboratory at regular room temperature (about 22 °C) during 21 days.

The flexural and compression behavior was determined based in the standard EN 1015-11 [20]. The flexural tests were performed with load control at a speed of 50 N/s. Compressive tests were realized through the application of a load on the specimen with resource to a metallic piece, rigid enough to make the vertical load uniform. The specimens used for the test were the half parts resulting from the flexural test. The compressive tests were performed with a load control at a speed of 150 N/s.

The adhesion tests were performed based on the standard EN 1015-12 [21]. It was possible to estimate the adhesion of the mortars at 28 days, when applied to a ceramic substrate frequently used in the construction industry to perform masonry. The tests were performed only for the reference compositions (0% PCM) and those with incorporation of 40% of PCM and 1% of polyamide fibers, since the