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Influence of adding phase change materials on the physical and mechanical properties of cement mortars

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HIGHLIGHTS

- Four compositions were developed with incorporation of non-encapsulated PCM.
- The influence of the non-encapsulated PCM in mortars was evaluated.
- The incorporation of PCM did not affect the density and the mechanical strengths.
- The incorporation of PCM leads to a decrease in the water absorption.
- The ambient temperature did not affect the compressive strength.

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ABSTRACT

During the last years several studies of construction materials with incorporation of encapsulated phase change material (PCM) have been published. However, the utilization of non-encapsulated PCM is one of the main gaps. The main objective of this work was the study of physical and mechanical properties of cement mortars with incorporation of non-encapsulated PCM. It was possible to conclude that the utilization of non-encapsulated phase change materials can be seen as a good and more economical solution for the energy efficiency of the buildings, without prejudice of the properties.

1. Introduction

The rapid world economic growth has led to an increase in the energy consumption. The fossil fuels dominate the world energy market, with a share of about 81% [1]. However, the fossil fuels are running out and present high costs. On the other hand, its use is related with the emission of harmful gases into the environment. Thus, the energy efficient use and the possibility of the use of renewable sources of energy are becoming increasingly important.

The energy efficiency of buildings is now one of the main objectives of regional, national and international energy policy [2]. Buildings are one of the leading sectors in energy consumption in developed countries. In the European Union the buildings represent 40% of energy consumption and CO_2 emissions to the atmosphere [3–4].

The solutions based into the use of renewable energy contribute to the increase the energy efficiency, to decrease the use of fossil fuel reserves and to reduce the pollutant emissions into the atmosphere. The utilization of renewable energy sources, like solar energy, is becoming a crucial measure promoting energy efficiency and sustainability of buildings. In addition, the use of renewable energy sources is a key factor to reduce the energy dependence of the buildings. Therefore, the heat storage possible with phase change materials is a strategy for the development of construction projects with high energy performance.

The phase change materials have the ability to reduce the temperature variation, due to their capability in absorbing and releasing energy to the environment. The PCM operating principle consists in change their status, according to the environment temperature. The PCMs absorb and store energy, suffering a change from a solid state to a liquid state, while temperature increases. On the other hand, the material possesses the capability to release the previously stored energy when the temperature decreases, suffering in this case a change from a liquid state to a solid state [4–6].

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The PCM can be incorporated into building materials using different methods, such as encapsulation, shape-establization, direct incorporation and absorption by immersion or capillarity [1,7–12]. The most common form of this material utilization is the encapsulation. There are two types of encapsulation: macroencapsulation and microencapsulation [7–8]. Cunha et al. [13], developed a study dealing with the incorporation of microencapsulated PCM in mortars based in different binders. They concluded that the incorporation of PCM in mortars causes significant changes in their properties in fresh and hardened state, such as an increase in the amount of water added to the mortar and a decrease of the mechanical strengths. The shape-stabilized PCM is prepared by integrating the PCM into the supporting material. The shape-stabilized PCM are mainly classified as composite PCM and are fabricated by embedding PCM into shape stabilization supports such as high density polyethylene, styrene, polystyrene resin, etc. However, this process is complex [9]. In the absorption by immersion, the construction product is immersed in the liquid PCM [8]. Hawes et al. [11] developed a study in order to examine the PCM absorption mechanisms in concrete to achieve the diffusion of the desired PCM amount and hence the required thermal storage capacity.

It should be noted that currently there are still high production costs for the encapsulation of PCM. Taking into account the current costs in the market, the cost of the non-encapsulated PCM is about 7 times lower than the cost of the microencapsulated PCM. Thus, it becomes urgent the development of new construction materials based in techniques and raw materials, with high thermal performance at low cost. These solutions become extremely competitive when compared with traditional solutions with low contribution to energy efficiency. It is imperative the development of mortars for interior coating with incorporation of PCM based on inexpensive raw materials (non-encapsulated PCM), contradicting the production costs of materials based on macro or microencapsulated PCM.

During the last years, several studies of construction materials with incorporation of encapsulated PCM have been published. The incorporation of PCM microcapsules in gypsum plaster boards [14–17], concrete and mortars based in different binders has been a target of recent investigations [13,18–20]. Other studies were also published such as incorporation of PCM in PVC panels, blocks and bricks [21–23].

The main objective of this work was the study of the influence of incorporation of non-encapsulated phase change materials in mortars, evaluating their physical and mechanical properties. Other objective was the evaluation of the possible PCM leakage from the interior of the mortars. Thus, several tests were performed with 4 different compositions at 3 different ambient temperatures (10 °C, 25 °C and 40 °C). The proportion of PCM studied was 0%, 2.5%, 5% and 7.5% of the sand mass. Some properties were evaluated, in the fresh and hardened state, such as workability, density, water absorption by capillarity, water absorption by immersion, microstructure, hydration process, flexural strength and compressive strength.

2. Experimental program

2.1. Materials

Cement based mortars were developed in order to understand the influence of adding non-encapsulated phase change materials. The materials selection for this research was based in other works developed by the authors [4,13,20,24].

The used cement was CEM II B-L 32.5N with density of 3030 kg/m^3. The sand used has an average particle size of 439,9 μm and a density of 2600 kg/m^3. Synthetic fibers of polyamide with a length of 6 mm, 22.3 μm of thickness and density of 1380 kg/m^3, were used. The superplasticizer used was a polyacrylate, with a density of 1050 kg/m^3 [4,13,20,24].

Finally the PCM used is non-encapsulated, composed by paraffin with temperature transition between 20 and 23 °C, enthalpy of 200 kJ/kg, density in solid state of 760 kg/m^3 and in liquid state of 700 kg/m^3 [25].

2.2. Compositions

Four compositions were developed with the main goal to evaluate the possibility of use non-encapsulated PCM in interior coating mortars. These compositions were evaluated from the fresh state up to 28 days. The studied compositions are presented in Table 1. The PCM content was fixed in 0%, 2.5%, 5% and 7.5% of aggregate mass.

2.3. Test procedures

The developed mortars were evaluated in the fresh and hardened state. In the fresh state the workability was determined. In hardened state, the density, water absorption by capillarity, water absorption by immersion, microstructure, hydration process, flexural strength and compression strength, were evaluated.

The density, water absorption by capillarity, water absorption by immersion, flexural strength and compression strength were performed with the specimens at three different temperatures. So, the specimens were maintained, during 24 h, before the tests, at three different ambient temperatures with resource to an oven and a climatic chamber. The temperatures tested were 25 °C (reference temperature), 10 °C and 40 °C. These temperatures were selected taking into account the PCM transition temperature. Therefore, the tests were performed for the different mortars with PCM in the solid state (10 °C), with the PCM in the transition state (25 °C) and with the PCM in the liquid state (40 °C). Thus, it was possible to evaluate the influence of adding PCM non-encapsulated in mortars, but also the influence of the PCM state in the physical and mechanical properties of the mortars.

The test procedures used for characterize the physical and mechanical properties of the developed mortars were based in European standards and other works developed by the research team [4,24].

Based on the European standard EN 1015-3 [26], the workability tests were performed by flow tests. The resulting value was only considered when equal to 160 ± 5 mm.

After the preparation, all the specimens were stored during 7 days in polyethylene bags and subsequently placed in the room with temperature of about 22 °C and 65% of humidity during 21 days, according to the standard EN 1015-11 [27].

The observation of the microstructure of developed mortars was performed using a scanning electron microscope. For each composition, two cylindrical specimens with diameter and height of approximately 1 cm were prepared [24].

The products present in the hardened mortars were evaluated with thermogravimetric tests (DSC-TGA). The tests were performed in argon atmosphere, with flow rate of 100 ml/min and heating rate of 10 °C/min in a range of temperature between 22 °C and 1000 °C. The test sample mass was 0.2 g of material removed from the surface of the specimen, at 28 days.

The water absorption by capillarity tests were performed based on the European standard EN 1015-18 [28]. The water absorption by immersion tests were based on the specification LNEC E 394 [29]. The tests were performed in three different temperatures