Mahmoud M. Reda Taha *Editor*

International Congress on Polymers in Concrete (ICPIC 2018)

Polymers for Resilient and Sustainable
Concrete Infrastructure

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Chapter 24

Physical and Mechanical Properties of Cement Mortars with Direct Incorporation of Phase Change Material

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The world economic evolution causes a significant intensification in the energy consumption. So, the energy efficiency of buildings is very important because this is one of the principal areas, responsible of the energy consumption in developed countries. The phase change materials (PCM) are smart materials, with the capacity to control the temperature variation, due to their capacity of absorbing and releasing energy. The PCM can be integrated into construction materials using different techniques, such as encapsulation, shape stabilization, direct incorporation, and immersion. The most common form of this material utilization is through encapsulation. It should be noted that, currently, there are still high production costs involved with PCM encapsulation. Thus, it is imperative to develop mortars with PCM incorporation based on raw materials and techniques with lower costs, such as PCM direct incorporation, to address the high production costs of macro- or microencapsulated PCM. The main objective of this work was the study of the physical and mechanical properties of mortars with direct incorporation of PCM, with a melting temperature of about 22 °C. Based on the results obtained, it can be concluded that the addition of this material caused some changes in the fresh and hardened properties of cement mortars.

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1 Introduction

The energy efficiency of buildings is now one of the main objectives of national and international energy policy [1]. The residential sector is one of the leading sectors in energy consumption in developed countries, representing 40% of energy consumption and CO₂ emissions to the atmosphere, in the European Union.

The thermal energy storage systems, based in PCM such as an energy storage technology, have a high potential for increasing the energy efficiency of buildings. The PCM has the ability to reduce the temperature difference, due to their capability to regulate the temperature, based in their capacity to absorb and release the energy to the environment. The working procedure is activated with the change in its properties, in accordance with the surrounding temperature, absorption, and release of stored energy to the environment [2, 3].

The PCM can be integrated into construction materials using diverse techniques, such as encapsulation, shape stabilization, direct incorporation, and immersion [4]. The PCM is generally used encapsulated. There are two types of encapsulation: macroencapsulation and microencapsulation. The use of PCM encapsulated in building materials presents some limitations, such as high costs of the PCM, due to the encapsulation processes and the decrease of the mechanical strengths of the materials doped with PCM microcapsules. Thus, the development of new construction materials based in techniques or raw materials is crucial, with high thermal performance and low cost. In the construction sector, the utilization of mortars for interior coating is a technique very used to finish walls and ceilings. Thus, it becomes imperative the development of these materials, with direct incorporation of nonencapsulated PCM. Thus, it is possible to reduce the high costs of the materials doped with macro- or microencapsulated PCM.

The main objective of this work is to study the influence of direct incorporation of PCM in interior mortars. Thus, the main physical and mechanical properties were studied. The evaluated properties were the workability, density, water absorption by capillarity, water absorption by immersion, microstructure, hydration process, flexural strength, and compressive strength. All the properties were determined based on three different ambient temperatures (10 °C, 25 °C, and 40 °C). Four different mortar compositions were also developed, with different content of PCM (0%, 2.5%, 5%, and 7.5%).

2 Materials, Compositions, and Test Procedures

The used cement was CEM II B-L 32.5 N with density of 3030 kg/m³. The sand used has an average particle size of 439,9 µm and a density of 2600 kg/m³. Based in the granulometric distribution, the parameters D50, D10, and D90 were obtained. The D10 corresponds to 150 µm, D50 corresponds to 310 µm, and the D90 corresponds to 480 µm. Synthetic polyamide fibers with a length of 6 mm, thickness of 22.3 µm,

Table 24.1 Mortar compositions (kg/m³)

Composition	Cement	Sand	PCM	SP	Fibers	Water	Liquid/binder
CEM-0PCM	500	1279	0	15	5	325	0.65
CEM-2.5PCM	500	1290	32.2	15	5	275	0.61
CEM-5PCM	500	1244	62.2	15	5	250	0.62
CEM-7.5PCM	500	1204	90.3	15	5	225	0.63

and density of 1380 kg/m³ were used. The superplasticizer used was a polyacrylate, with a density of 1050 kg/m³. Finally, the PCM used is paraffin with temperature transition between 20 and 23 °C, enthalpy of 200 kJ/kg, and densities of 760 kg/m³ and 700 kg/m³, respectively, in solid and liquid states.

Based on these materials, four compositions were developed. The principal objective was to evaluate the possibility of using PCM direct incorporation into mortars for interior coating of building walls. The compositions were evaluated during all the curing process, from the fresh state up to 28 days. In the fresh state, the workability was studied. In hardened state, the water absorption by capillarity, microstructure, flexural strength, and compression strength were evaluated. The developed mortars are presented in Table 24.1.

The hardened state tests were performed after the specimen's submission, during 24 h, to three different ambient temperatures: 25 °C (reference temperature), 10 °C, and 40 °C. The selection of the testing temperatures took into account the PCM transition temperature. The tests performed at 10 °C evaluate the properties of the cement mortars with the PCM in the solid state. On the other hand, the tests performed at 25 °C and 40 °C evaluate the mortars with the PCM in the transition state and in the liquid state, respectively.

The workability tests were performed based on the flow table method stated by the European standard EN 1015-3 [5]. The resulting value within the test was only considered when equal to 160 ± 5 mm.

The observation of the microstructure of the developed mortars was performed using a scanning electron microscope; cylindrical specimens with diameter and height of 1 cm were prepared.

The water absorption by capillarity tests was performed based on the European standard EN 1015-18 [6].

The flexural and compressive behaviors were determined based on the standard EN 1015-11 [7]. The flexural and compressive tests were performed at loading rates of 50 N/s and 150 N/s, respectively.

3 Results and Discussion

Regarding the workability results, it was possible to observe that the incorporation of 2.5% of nonencapsulated PCM leads to a reduction superior to 15% in the water content. However, it should be noted that the liquid material/binder ratio remains

Fig. 24.1 Microscope observation: (a) 0% of PCM; (b) 2.5% of PCM; (c) 5% of PCM; (d) 7.5% of PCM

constant. This behavior can be justified by the introduction of the PCM in mortars in the liquid state, which in part can operate as agent for the development of a homogeneous mortar, substituting part of the water.

The electron microscope observations showed a good correlation between different materials evidenced by the absence of cracks in the microstructure of the mortars which reveals an adequate process of mixing, application, and curing of the mortars. Other observations were performed in order to evaluate the micropore distribution in the developed mortars. In the mortars doped with PCM, a reduction in the pore amount and in its size was observed (Fig. 24.1). The mortar with 7.5% of nonencapsulated PCM incorporation shows a more compact microstructure when compared to the mortar without PCM. This behavior can be related with the reduction of the water content in the mortars with PCM incorporation. It was also possible to observe that the mortars without PCM incorporation present a more crystalline microstructure, resulting from the increase cement hydration, when compared to the mortars doped with PCM. This behavior can be justified by the

Fig. 24.2 Capillary absorption coefficient of the developed mortars

porosity decrease, since there is less space in the PCM mortar microstructure to the cement hydration reactions.

Concerning the water absorption by capillarity (Fig. 24.2), it was possible to verify that the nonencapsulated PCM incorporation leads to a reduction in the capillary absorption coefficient superior to 73%. This behavior is associated with the partial or total occupation of the mortar pores by the PCM. On the other hand, it was also possible to observe that the mortars with PCM incorporation showed a similar capillary absorption coefficient when submitted to different ambient temperatures. Thus, it was possible to conclude that even in different states (solid, transition, and liquid), the PCM did not move outside the mortar pores. Regarding the mortars without PCM incorporation, it was possible to verify a higher capillary absorption coefficient, due to the presence of empty pores in the mortars.

Figure 24.3 presents the flexural and compressive strengths of the developed mortars when submitted to different temperatures. It was possible to verify that the incorporation of nonencapsulated PCM did not cause significant changes in the flexural and compressive strengths. This behavior can be justified by the PCM contained inside the pores, not weakening the mechanical strength. On the other hand, a liquid material/binder ratio similar for all developed compositions was observed.

Fig. 24.3 Mechanical behavior of the developed mortars

4 Conclusions

Based on the results obtained, it can be concluded that the PCM direct incorporation causes some changes to the properties of cement mortars in fresh and hardened states. The amount of water added to the mixtures decreased with the PCM incorporation. However, the liquid material/binder ratio of the mortars is similar. This indicates that all mortars generally require the same amount of liquid (water and PCM) to form a homogeneous paste. Concerning the water absorption by capillarity tests, it was detected that the direct incorporation of nonencapsulated PCM led to a reduction in the capillary absorption coefficient, due to partial or total occupation of the mortar pores by the PCM. According to the flexural and compressive strengths, it can be concluded that the direct incorporation did not cause significant changes in the mechanical behavior of the mortars. Thus, it is possible to conclude that the utilization of nonencapsulated phase change materials can be seen as a good and more economical solution for the energy efficiency of the buildings.

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