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Use of phase change materials microcapsules in aerial lime and gypsum mortars

1. Introduction

Nowadays, the largest part of the energy consumption in residential sector is associated with heating and cooling. The incorporation of Phase Change Materials (PCM) in mortars for the internal coating, have the objective of keep temperatures constant. Contributing in that way, for a bigger level of comfort in internal buildings and for a biggest energetic efficiency. The benefits to the comfort inside buildings appear during the phase change of the PCM. There are transferences of energy that occur during the transitions solid-liquid through the heat storage and liquid-solid with the release of energy previously absorbed. In order that PCM will not disperse in material matrix should be microencapsulated. The exterior of the microcapsules is made with a polymer (1, 2).

Latent heat thermal energy storage, through the incorporation of PCM, presents the following advantages: narrow the gap between the peak and off-peak loads, levelling the electricity demand, decreasing the load on the network and eventual supply failure; reduce operation costs by shifting the electrical consumption from peak periods to off-peak periods; contribute to the interior thermal comfort in buildings, by using and storing solar energy (for space heating in winter) and storing natural cooling by ventilation at night during the summer, thus reducing electricity use for heating and cooling (1, 2).

Between all phase change materials possible applications in buildings, the most interesting is its incorporation in construction materials with the aim of altering these materials thermal properties. There are a series of possibilities: the PCM may be used as a mean for thermal storage for passive solar heating, by being integrated on the floor, walls or ceilings, as well as being an integrating part of the most complex energetic system, such as heat pumps and solar panels (3).

The main objective of this work was the production of a lime and gypsum mortar with incorporation of polymeric microcapsules, which must have a compromise between workability, mechanical strength and shrinkage. The quantification of shrinkage was made since the fresh state until to the hardness state. These mortars can be applied not only in the construction of new buildings, but also in rehabilitation operations.

2. Phase change material

Phase change materials (PCM) possesses the capability to alter its own state as function of the environmental temperature (3). In other words, when the surrounding environmental temperature of PCM increases until the materials fusion point, the material suffers a change from a solid state to a liquid state, absorbing and storing the heat energy from the environment. While, when the temperature decreases until the PCM solidification point, the material alters its state from the liquid state to solid state, releasing the previously storage energy to the environment (Figure 1). This application could be made in coating mortars of buildings, with advantage in the passive regulation of internal temperature with increase of thermal inertia (4).

Passing the melting point, phase change material, alter its state from solid to liquid, and if the material is free to move in the matrix material that surrounds it, this disperses changing its shape and

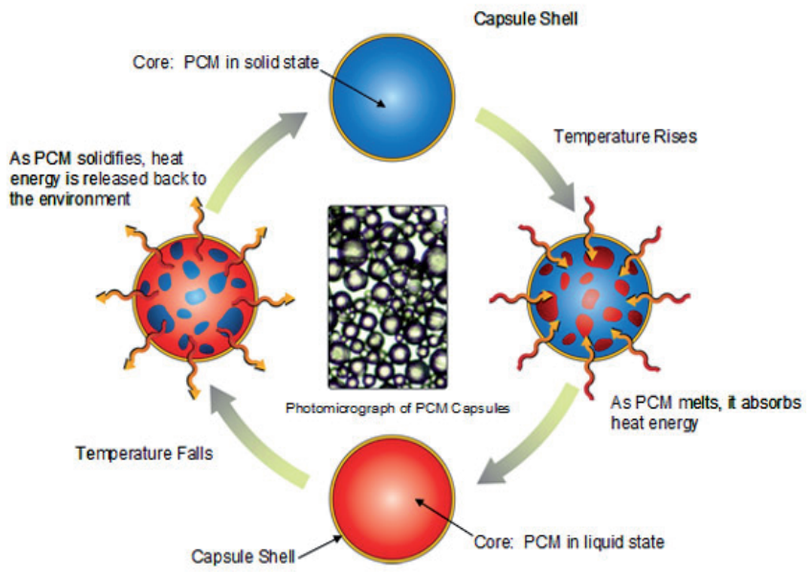


Fig. 1. Encapsulated phase change material (5)

original position. For maintain the PCM without significant changes in time, this can be wrapped in other material with capacity to resist to physic and volumetric changes. The microencapsulation of phase change material consists in engage the material particles in solid or liquid state, that will be core of material, by a material in solid state, usually a polymer, commonly known capsule, with dimensions between 0.020 μm a 2000 μm (6). The polymer used could be polymethylmethacrylate, polyurea, polyurethane, polymethylmethacrylate or polivinilacetano and should respond at some demands of operation as high heat transfer.

In 1983 emerged the first classification of substances used for thermal storage. These are classified as organic, inorganic and eutectic mixtures. The eutectic mixtures result from the combination of two or more compounds of organic and/or inorganic nature. By this way it is possible better correspond to the need of more suitable transition temperatures for the demands (4).

Not all the existing PCM can be used for thermal storage. An ideal PCM must present certain thermophysics, kinetic, chemical and economic properties. Relatively to thermophysical properties it is necessary that the selected PCM has a transition temperature in the operational temperature range desired with the intention of reassuring the storage and release of heat. Also, an elevated transition heat by volume unit, in order to storage the maximum energy possible, incorporating a minimal quantity of PCM; high sensitive heat, translated by its calorific capability in order to increase its energy storing capability; high thermal conductivity both in the solid and liquid state, so that it becomes easier to promote heat transfer with a reduced volume variation during the phase transition allowing the contention issues reduction (5).

From the kinetically point of view, the chosen PCM must have a high velocity for crystal growing, with the main purpose of avoiding the sub cooling of the liquid phase and respond to the surroundings demands (5). Concerning its chemical properties it should not present degradation after a high number of cycles; it must be non-corrosive to construction materials; non-flammable; non-toxic and non-explosive, for environmental and security concerns (5). Finally, from the economic point of view, it must be abundant, available and with a low acquisition cost, in order to become a competitive solution compared to other traditional constructive systems and thermal storing (5).

3. Materials, compositions and fabrication

3.1. Materials

This research used PCM microcapsules synthesized by polymerization process through emulsion and composed by a polymethylmethacrylate and a paraffin nucleus. The product is commercialized in powder (dry) or in emulsion, being that for this study it was decided to use a dry PCM in order to facilitate its incorporation into already prepared mortars. This PCM has a fusion temperature of about 23ºC and an enthalpy of 110 kJ/kg.

The superplasticizer used was a polyacrylate, with a density of 1.05 g/cm^3. The sand used has an average particle size of 439.9 μm. The lime used in the compositions was a hydrated lime, with a purity of 90% and density of 1100 kg/m^3. The gypsum plaster used is a traditional, with high fineness and the fibres used are synthetic fibres of nylon.

3.2. Compositions and fabrication

We studied five compositions of aerial lime and gypsum mortars from the fresh state up to 28 days (Table 1). The L100G0 is the reference mortar without any addition. From L100G0 to L100G0PCM is added 20% of PCM microcapsules incorporated in polymer. In composition L100G0PCMF are added nylon fibres, and in the compositions L100G20PCMF and L100G40PCMF is added a gypsum content of 20% and 40%, respectively.

The mixture process and specimens manufacturing was performed in accordance with the standard EN 1015-11, with slight adaptations due to the PCM incorporation (6). To evaluate the behaviour and the mechanical properties (compression and flexural strength) of all the different compositions, it was moulded 3 prismatic specimens with 40x40x160 mm^3. After its manufacturing, all the specimens were preserved during 7 days in polyethylene bags and subsequently placed into the laboratory at room temperature (about 22ºC) during 21 days.

Table 1

COMPOSITION OF MORTARS (PCM, SUPERPLASTICIZER, WATER AND FIBRES AS % OF TOTAL MASS OF SOLID PARTICLES; GYPSUM AND SAND AS % OF BINDERS MASS)

Compositions	PCM	Superplasticizer	Fibers	Gypsum	Sand
L100G0	0.0	0.0	0.0	0.0	561.4
L100G0PCM	20.0	1.0	0.0	0.0	561.4
L100G0PCMF	20.0	1.0	0.1	0.0	561.4
L80G20PCMF	20.0	1.0	0.1	20.0	561.4
L60G40PCMF	20.0	1.0	0.1	40.0	561.4

4. Test procedures

The workability tests were performed with the main goal of verifying an adequate workability for handling the developed mortars. The tests were performed based on the flow table method stated by the European standard EN 1015-3 (7). The resulting value within the test was only considered when between 160-180 mm. For evaluate the shrinkage, was developed a device capable of performing the measurement of shrinkage from the time of placing the mortar in the mould until the demoulding (Figure 2), with the possibility of continuing to monitoring the evolution of the shrinkage in time with another device after demoulding. The device consists of a base for placing the triple mould with dimensions of 25x25x250 mm³ and six displacement transducers. Two displacement transducers were used for each specimen in order to enable the measurement

of shrinkage on both sides further away from the specimen. The transducers are connected to a data acquisition system, where point values are removed from the shrinkage of mortars in time. The amount of shrinkage is given by the following equation:

$$\varepsilon = \frac{Li - Lt}{250}$$

where:

ε – Shrinkage value,

Li – First measurement value,

Lt – Value of measurements made at time t.

Fig. 2. Measuring device for evaluation of shrinkage since the fresh state

The flexural and compressive behaviour was evaluated based in EN 1015-11. The specimens used for the flexural test were prismatic. The flexural tests were performed with force control at a speed of 10 N/s. Compression tests was realized through the application of a load on the specimen with resource to a metallic piece, rigid enough to make the vertical charge uniform. The specimens used for the test were the flexural test resulting half parts. The tests were performed with a force control at a speed of 50 N/s.

5. Results and discussion

5.1. Workability

Table 2 shows the obtained results for the workability tests from the experimental results. It is possible to verify a rise in the amount of water added to the mixture, with the incorporation of microcapsules PCM. To an increase of 20% of PCM corresponds a rise in the amount of water of about 26%. This situation can be explained by the thinness of the used PCM and by the absorption of the polymeric wall of the microcapsule. The incorporation of fibers and gypsum causes a light increase in quantity of water. An increase of 20% of gypsum, resulted in a rise of about 3% of the water amount added to the mortar.

Table 2

WORKABILITY RESULTS

Compositions	Water
L100G0	23.0
L100G0PCM	29.0
L100G0PCMF	30.0
L80G20PCMF	31.0
L60G40PCMF	32.0

5.2. Shrinkage

With the device described above, it was possible to make an evaluation of shrinkage since the fresh state, due to changes caused by the introduction of polymer capsules. It was monitored the behaviour of different areal mortars from time zero to seven days. The results allowed us to verify that there is an increase in the measured value of the shrinkage with the incorporation of microcapsules. However, the addition of gypsum and nylon fibers, results in a decrease in shrinkage in the first 24 hours of monitoring (Figure 3).

The analysis of the results up to 7 days of age (Figure 4) allows the identification of different behaviors in different aereal mortars. The introduction of 20% of microcapsules (L100G0PCM), causes an increase in shrinkage of about 4 times compared to the reference mortar (L100G0). The addition of nylon fibers (L100G0PCMF), causes a decrease in shrinkage to about half compared with the mortar L100G0PCM. With the addition of gypsum (L80G-20PCMF and L60G40PCMF) is possible to observe a decrease in shrinkage. It was performed a practical application of mortar

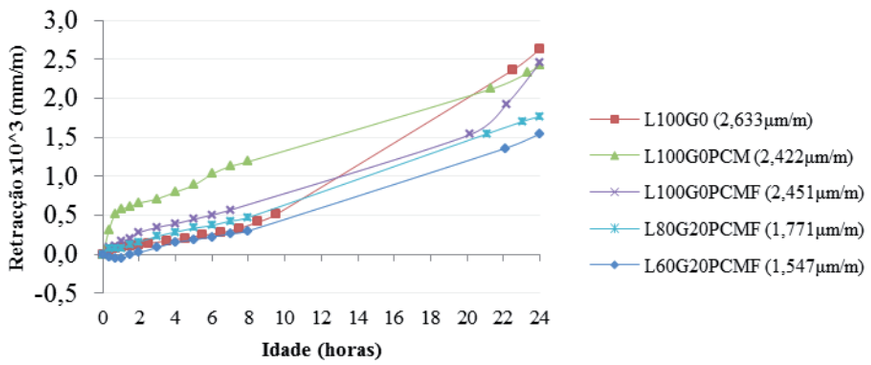


Fig. 3. Shrinkage test since moulding until 24 hours

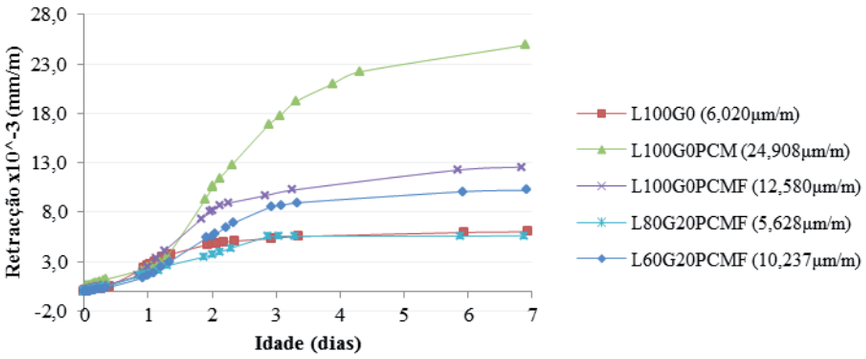
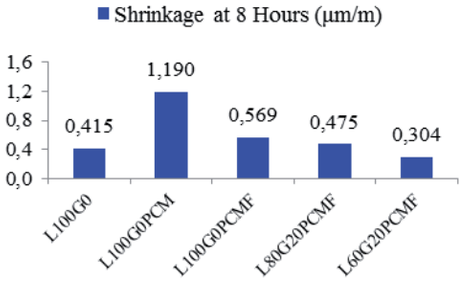


Fig. 4. Shrinkage test since moulding until 7 days



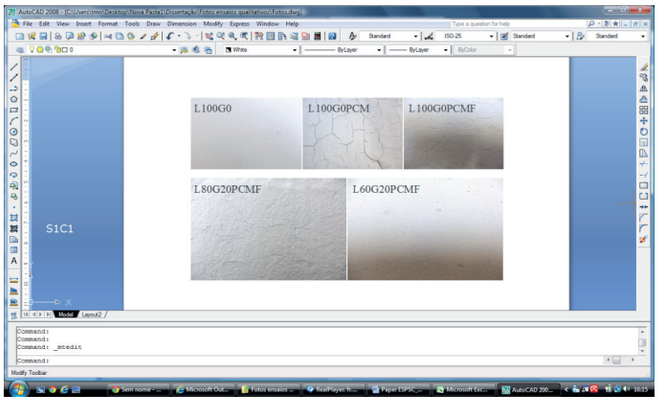


Fig. 5. Comparison between the values of shrinkage and cracking

Table 3

Flexural and compressive result

Compositions	Flexural strength, MPa	Compression strength, MPa
L100G0	0.17 [10.98]	0.25 [8.09]
L100G0PCM	0.93 [11.22]	2.22 [6.09]
L100G0PCMF	0.72 [10.57]	1.79 [5.99]
L80G20PCMF	1.36 [4.52]	2.27 [10.6]
L60G40PCMF	1.01 [12.72]	2.00 [11.7]

Note: In parentheses we present the coefficient of variation in percentage.

developed and subsequently made a comparison with the results obtained (Figure 5). For mortar L100G0 was obtained a value of 0.415 µm/m, showing no cracks in support. The introduction of 20% of microcapsules (L100G0PCM) the shrinkage value obtained was increased about 5 times, showing cracking in support. With the addition of nylon fibers (L100G0PCMF) the value obtained is about half comparatively to the mortar L100G0PCM, with consequently lower cracking the mortar before. The subsequent incorporation of 20% gypsum results in a decrease in cracking presented in support. With the increase of gypsum content of 40%, the amount of shrinkage obtained is 0.304 µm/m, which is lower than the value obtained for the shrinkage of mortar L80G20PCMF (0.475 µm/m) and also lower than the reference mortar (0.415 µm/m) with no cracking in the support.

5.3. Flexural and compressive behaviour

Concerning the mechanical strengths, in general terms and based in the obtained results, presented in Table 3, it is possible to find that the mechanical properties show an improvement with the addition of PCM microcapsules. The addition of 20% of PCM leads to an increase of the flexural strength about 450%. For the compression strength, the increase observed is about 788%. These values were obtained comparing to the composition without the incorporation of phase change materials.

6. Conclusion

The experimental work led to the conclusion that it is possible use polymeric microcapsules in mortar, obtaining a balance between the aesthetic and functional performance. The results obtained from tests for shrinkage concluded that the combined use of fibre and gypsum is a good solution for solving problems related to cracking caused by the incorporation of polymeric microcapsules. The specific devices developed at the University of Minho, has proved effective in quantitative evaluation of the shrinkage. It was also possible to make a practical application and verification of the values obtained in the laboratory.

It was even possible to verify the existence of a clear rise of the water necessary to incorporate into the mortar within the increasing of PCM percentage, this with the aim of obtaining a suitable workability. The compression and flexural resistance measured in each performed test allows observing a tendency to its increase, with a greater incorporation of PCM microcapsules. The mortar with 60% of aerial lime and 40% of gypsum with incorporation of PCM microcapsules, is more interesting because it showed an excellent compromise between high mechanical strengths and low shrinkage.

Acknowledgements

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