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Thermal Mortars with Incorporation of PCM Microcapsules

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Abstract

The main purpose of this work is the production of a mortar with incorporation of Phase Change Materials (PCM) microcapsules, which must have a compromise between workability, mechanical strength and aesthetic appearance. The mortars studied in this work are mixed mortars of lime and gypsum. The proportion of PCM is 0 %, 10 %, 20 % and 30 %. In order to minimize some problems associated with shrinkage and consequent cracking of the mortars, the incorporation of nylon fibers, superplasticizer and gypsum was tested. A study of mechanical characteristics and some sensitivity tests for qualify the shrinkage of the fifteen compositions was realized. In this way, one composition for the application in tests cells was selected, with the aim of studying the thermal behaviour of these mortars. The test performed on test cells includes the study of a standard mortar without addition of PCM and a mortar with incorporation of an ideal percentage of PCM. Based on the obtained results it was possible to conclude that the incorporation of PCM microcapsules in the studied mortars causes an increase in mechanical strengths and shrinkage. The tests performed on test cells allowed to verify a time lag in maximum and minimum temperatures, as well as a slight attenuation in the temperature variation. It can be concluded that the use of PCM microcapsules in mixed mortars of lime and gypsum can be assumed as a viable solution for applications in the construction industry once these present a compromise between their resistance, aesthetic appearance and thermal behaviour.

Keywords: Mortars; Lime; Gypsum; Phase Change Material.

1 Introduction

Every year, about 5×10^{24} J of energy is powered by the sun and reaches the entire land surface. This amount is about 10 000 times higher than the actual energy consumption per year worldwide. Thus, the need to find a way to take advantage of this natural energy source is pressing [1]. Presently, the concerns related to the energy consumption of buildings are greater than ever, resulting in the need to incorporate materials in the construction products which aim the improvement of the energetic efficiency of buildings. The largest part of the energy consumption in residential sector is associated with heating and cooling. Therefore, the incorporation of Phase Change Materials (PCM) in mortars for the internal coating appears as a possible solution in an attempt to solve, or at least minimize, the massive energetic consumption related with buildings. The latent heat thermal energy storage, contributed in that way, for a bigger level of comfort in internal buildings and for a biggest energetic efficiency.

Latent heat thermal energy storage, through the incorporation of PCM, has the following advantages: narrowing the gap between the peak and off-peak loads, levelling the energetic demand, decreasing the load in the network and preventing eventual supply failure; reducing operation costs by shifting the energy consumption from peak periods to off-peak periods; contributing to the interior thermal comfort in buildings, by using and storing solar energy (for space heating in the Winter) and storing natural cooling by ventilation at night during the Summer, thus reducing the use of systems for heating and cooling [2, 3]. The benefit to the interior thermal comfort inside buildings is materialized by the phase change occurring in the PCM. The transferences of energy that occur during the solid-liquid and liquid-solid transitions are generally used to help in the temperature control of the building.

It is known that all materials interact with the environment. However most of them lack the capability to alter their own properties according to the environment characteristics in which they are applied. Phase change materials possess the capability to alter its own state as function of the environmental temperature. 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.

On the other hand, as the temperature decreases until the PCM solidification point, the material alters from the liquid state to solid state, releasing the previously storage energy to the environment

For the correct use of the PCM, it must be encapsulated, otherwise during the liquid phase there is a possibility that it moves from the original area of application. The microencapsulation of phase change material consists on covering the material particles, with a material, usually a polymer, commonly known capsule, with dimensions between $1 \mu\text{m}$ and $60 \mu\text{m}$.

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 [2].

The incorporation of PCM microcapsules in mortars brings social, economic and environmental benefits. The social benefits derive from the thermal comfort increase inside buildings, given that nowadays this is an important requirement and frequently demanded by buyers and potential sellers as an important decision parameter. The environmental aspect concerns the fossil fuels depletion, given that this technology aims at maintaining constant temperatures inside the building, consequently leading to a decrease on air conditioning equipment usage. The economic benefit is related to the technology adequacy and implementation costs.

The main objective of this work was the production of a mixed lime-gypsum mortar with incorporation of PCM polymeric microcapsules, which implies a compromise between workability, mechanical strength, aesthetic appearance and thermal behaviour. These mortars can be applied not only in the construction of new buildings, but also in rehabilitation procedures.

2 Materials, Compositions and Fabrication

2.1 Materials

This research used PCM microcapsules synthesized by polymerization process through emulsion and composed by a polymethylmethacrylate and a

Table 1: Composition of mortars (PCM, superplasticizer, water and fibers as % of total mass of solid particles; gypsum and sand as % of binders mass).

Compositions	Water	Sand	PCM	Superplasticizer	Fibers	Gypsum
0	23.0	561.4	0.0	0.0	0.0	0.0
SP10PCM	18.5	561.4	10.0	1.0	0.0	0.0
SP20PCM	29.0	561.4	20.0	1.0	0.0	0.0
SP30PCM	45.0	561.4	30.0	1.0	0.0	0.0
FSP0PCM	23.0	561.4	0.0	0.0	0.1	0.0
FSP10PCM	18.5	561.4	10.0	1.0	0.1	0.0
FSP20PCM	30.0	561.4	20.0	1.0	0.1	0.0
FSP30PCM	45.0	561.4	30.0	1.0	0.1	0.0
GFSP0PCM	23.5	561.4	0.0	0.0	0.1	10.0
GFSP10PCM	19.2	561.4	10.0	1.0	0.1	10.0
GFSP20PCM	31.0	561.4	20.0	1.0	0.1	10.0
GFSP30PCM	47.0	561.4	30.0	1.0	0.1	10.0
GFSP20PCM20G	31.0	561.4	20.0	1.0	0.1	20.0
GFSP20PCM30G	32.0	561.4	20.0	1.0	0.1	30.0
GFSP20PCM40G	32.0	561.4	20.0	1.0	0.1	40.0

paraffin nucleus. This PCM has a fusion temperature of about 23 °C, enthalpy of 110 kJ/kg, average particle size of 15.40µm and water content of 2 %. The superplasticizer used was a polyacrylate, with a density of 1050 kg/m³. 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/m³. The gypsum plaster used is a traditional, with high fineness and the fibers used are synthetic fibers of nylon with a length of 6 mm.

2.2 Formulations

In order to obtain the final composition for future thermal analysis in test cells an experimental campaign was considered, with the main goal of characterizing the produced compositions, under a mechanical point of view.

Throughout this work, for the studied mortars the PCM content was varied between 0 %, 10 %, 20 % and 30 %. In order to overcome some of the problems related with the mortar shrinkage and consequent cracking nylon fibers, superplasticizer and gypsum were incorporated.

Fifteen different compositions of aerial lime and gypsum mortars from the fresh state up to 28 days, were studied (Table 1). For every composition without PCM, it was decided not to include superplasticizer due to its dispersive effect, which caused a slight segregation of the mortar. The mixture procedure and specimens preparation was performed

in accordance to the EN 1015-11 standard [4]. To evaluate the mechanical properties (compression and flexural resistance) of all the different compositions, 3 prismatic specimens with 40x40x160 mm³ 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.

3 Test Results and Discussion

3.1 Workability

The workability tests were performed with the main goal of verifying the adequacy of application of the developed mortars. The tests were performed based on the flow table method stated by the European standard EN 1015-3 [5]. The resulting values within the test were only considered when between 160-180 mm. The tests indicate an increase in the amount of water added to the mixture, with the incorporation of PCM microcapsules. This situation can be explained by the reduced particle dimension of the used PCM and by the water absorption characteristics of the polymeric wall of the microcapsule.

3.2 Mechanical Behaviour

The flexural and compressive behavior 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 were 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 half parts resulting from the flexural test. The compression tests were performed with a force control at a speed of 50 N/s. It is possible to find that the mechanical properties show an improvement with the addition of PCM microcapsules (Fig. 1).

However, it is possible to verify a decrease in the value of compression and flexural strength with a PCM content of 30 % when compared to the 20 % PCM composition. Therefore is possible to conclude that the optimal content of PCM in terms of mechanical properties corresponds to 20 %. Nonetheless, the value obtained for a PCM content of 30 % is higher than the value presented by the mortar without PCM, which allows for the conclusion

of the beneficial effect caused by the incorporation of PCM in mortars. The addition of 10 % of PCM leads to an increase of the flexural strength of about 3 times of its original value. For the compression strength, the increase observed is about 3,3 times of the initial strength. These values were obtained comparing this composition with the one excluding the incorporation of PCM. This increase in mechanical strength is related to the increase of porosity caused by the introduction of higher water content. This increase in porosity benefits the carbonation of mortars. For the introduction of gypsum, it is possible to verify the existence of an optimal value at about 20 %. Once there is an increase in compressive strength of about 27 % and an increase of 89 % in flexural strength regarding the introduction of 20 % of gypsum compared with the mortar without gypsum.

Figure 1: Flexural and Compression Behaviour.

3.3 Shrinkage

For evaluating the shrinkage, a device capable of performing the measurement of shrinkage from the time of placing the mortar in the mold until the demolding was developed, with the possibility of continuing to monitor the evolution of the shrinkage throughout time with another device after demolding.

The device consists of a base for placing the triple mold with dimensions of $25 \times 25 \times 250 \text{ mm}^3$ 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 the values of shrinkage of mortars in time were registered. It was possible to make an evaluation of shrinkage since the fresh state, due to changes caused by the introduction of polymer capsules. The behavior of different mortars was monitored since the placement of the mortar in the mold up to seven days.

The results allowed us to verify that there is an increase in the shrinkage with the incorporation of PCM microcapsules. However, the addition of gypsum and nylon fibers, results in a decrease in shrinkage. The analysis of the results up to 7 days of age (Fig. 2) allows the identification of different behaviors in different 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 (L80G20PCMF and L60G40PCMF) is possible to observe a decrease in shrinkage. The increase in shrinkage with the incorporation of PCM microcapsules is related to a greater amount of water used, while its reduction is caused by the inclusion of fibers, which are related to the prevention of dimension variations inside the mortar. Moreover, the reduction of shrinkage observed with the addition of gypsum, is connected to the expansion which occurs with its hydration.

3.4 Thermal Behaviour

The analysis was performed in order to evaluate the thermal comfort level, when the PCM is used or not. In this experimental work, two test cells were considered as the cases for analysis, which in each of them has a partition wall in the middle of

Figure 2: Shrinkage test since moulding until 7 days.

Figure 3: Monitored temperatures of the test cells with PCM and without PCM.

the cell which divided the space to two zones (North and South) with multilayer in Guimarães, Portugal. The dimensions of the cell are 4.4 m (length) x 2.1 m (width) x 2.4 m (height) which is adjacent to the outside. In one of the test cells 20 % of PCM was added to the composite material (lime, gypsum and fibers). This mortar was applied to the partition wall surfaces. The ambient temperature was measured by the data logger sensors. The experiment started at beginning of cold season (autumn) and progressed till the summer days in order to covering one year.

To aid the analysis, two typical days of summer are chosen to evaluate the effect of the system with and without PCM on the indoor temperature. Regarding the monitored values registered for both test cells under summer day's conditions, shown in Fig. 3, it can be observed that the maximum internal temper-

ature inside test cell "no PCM" was 34.2 °C, whereas the corresponding temperature in test cell "PCM" was 31.7 °C. This peak temperature represents a difference of 2.5 °C. The melting temperature of the used PCM is 23 °C and the maximum temperature of the test cell PCM is more close to the melting point PCM.

The minimum interior temperature inside the both of test cells is almost similar. The delay between the maximum temperature recorded inside the test cell "no PCM" and exterior temperatures was of 2 h. The PCM test cell had a large corresponding delay of 2.5 h.

It is clear that the PCM effectively decreases the indoor temperature amplitude, putting it closer to the comfort temperature levels.

4 Conclusion

Based on these results, it can be concluded that the use of PCM polymeric microcapsules in lime based mortars can be seen as a viable solution for applications in the construction industry. It is possible to achieve a viable compromise between their strength and aesthetic appearance.

The results obtained from tests of shrinkage concluded that the combined use of fiber and gypsum is a good solution to solve problems related to cracking caused by the incorporation of polymeric microcapsules.

It was even possible to verify the existence of a clear rise of the water necessary to incorporate into the mortar with the increasing of PCM percentage, this with the aim of obtaining a suitable workability. The compression and flexural strengths measured in each performed test allows observing a tendency to its increase, with a greater incorporation of PCM microcapsules.

Concerning the thermal behaviour is possible to observe that the PCM effectively decreases the temperature amplitude and improved the indoor temperature comfort level. The solution with PCM makes the maximum indoor temperature with delay of 2.5 h in summer, comparing with the solution without PCM.

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, low shrinkage and satisfactory results in thermal behaviour.

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References

1. M. Diamanti, M. Ormellese, M. Peddeferri, *Characterization of photocatalytic and superhydrophilic properties of mortars containing titanium dioxide*, Cement and Concrete Research, **38** (2008) 1349–1353.
2. Y. Zhang, G. Zhou, K. Lin, K. Zhang, H. Di, *Application of latent heat thermal energy storage in buildings: State-of-the-art and outlook*, Building and Environment, **42** (2007) 2197–2209.
3. A. Castell, I. Martorell, M. Medrano, G. Pérez, L. Cabeza, *Experimental study of using PCM in brick constructive solutions for passive cooling*, Energy and Buildings, **42** (2010) 534–540.
4. European Committee for Standardization, *EN 1015-11- Methods of test for mortar for masonry - Part 11: Determination of flexural and compressive strength of hardened mortar* (1999).
5. European Committee for Standardization, *EN 1015-3 - Methods of test for mortar for masonry - Part 3: Determination of consistence of fresh mortar (by flow table)* (2004).

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