DURABILITATEA UNOR MORTARE CU ÎNCORPORARE DE MICROCAPSULE, CARE CONȚIN MATERIALE CU SCHIMBARE DE FAZĂ
DURABILITY OF MORTARS WITH INCORPORATION OF PHASE CHANGE MATERIALS MICROCAPSULES

SANDRA CUNHA[1], JOSÉ AGUIAR[1*], VICTOR FERREIRA[2]
University of Minho, Campus de Azurém, 4800-058 Guimarães, Portugal
University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal

The construction is responsible for high consumptions of energy and raw materials. It becomes imperative to develop new sustainable constructive solutions. The mortars with incorporation of phase change materials (PCM) have the ability to regulate the temperature inside buildings, using only the energy supplied by the sun. The main focus of this study was the microstructure and durability of mortars with PCM incorporation. The binders studied were aerial lime, hydraulic lime, gypsum and cement. The proportions of PCM studied were 0% and 40% of the mass of the sand. It can be concluded that the incorporation of phase change material in mortars causes significant changes in their properties, in fresh and hardened state, such as microstructure, water absorption by capillarity and immersion, and degradation by freeze-thaw. Consequently, the addition of this material affects the durability and microstructure of the mortars developed.

Keywords: Durability; Microstructure; Mortars; Phase Change Materials (PCM); Freeze-thaw resistance; Water absorption.

1. Introduction

In a society increasingly concerned with sustainability and good construction practices, it becomes urgent to develop and study new and durable constructive solutions. The durability of construction materials is directly related to their sustainability. The more durable materials lead to minor rehabilitation actions, which consequently results in lower consumption of raw materials, energy and waste production. The durability of mortars is closely linked to the characteristics of binders and aggregates, the ratios aggregate/binder and water/binder, water absorption by capillarity, presence of additives and curing conditions [1].

In the last years, a huge need of protection and improvement of the environment, were witnessed. The construction industry is responsible for high energy and raw materials consumption. Thus, it is important to minimize these high consumptions by taking advantage of construction solutions with high durability and energy saving. The incorporation of Phase Change Materials (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 PCM possess the capability to alter its own state as function of the environmental temperature [2]. 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. Thus, the use of this material allows the regulation of temperatures fluctuations, keeping them closer to the desired temperature range for a longer period, reducing the need to use heating and cooling equipment, using only solar energy as a resource. This application could be made in coating mortars of buildings, with advantage in the passive regulation of internal temperature with increase of thermal inertia [3]. However, it is important adequate the durability of the mortars with PCM in order to reduce the consumption of raw materials and needs of rehabilitation operations. Thus, it is possible reduce the consumption of raw materials and energy from non-renewable sources.

The incorporation of PCM microcapsules in mortars brings social, economic and environmental benefits, demonstrating a significant contribution to a construction with a higher value of sustainability. 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 increase of thermal comfort is achieved by the thermal capacity of the PCM, allowing store and release of energy,

keeping the interior temperature sensibly constant, or at least with less variation. 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. These should be supported and easily amortized by the user. It may also be noted that the economic benefits of reduced energy consumption and lag times for lower demand, are evident and can be achieved with the use of PCM.

The PCM must be encapsulated for its correct use, otherwise during the liquid phase there is a possibility that it moves from the original area of application. There are two main forms of encapsulation: macroencapsulation and microencapsulation. The macroencapsulation is based in the introduction of PCM into tubes, panels or other large containers. It is usually carried out in containers with more than 1 cm of diameter and presents a better compatibility with the material [4]. 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 µm to 60 µm. The advantage of this encapsulation process is the improvement of heat transfer, through its large surface area [4-6]. 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. [7].

Some studies had been published incorporating PCM in construction products. PCM can be used in solutions for walls, floors and ceilings. There are several authors who had investigated constructive solutions with incorporation of PCM for application on floors. These solutions are varied, such as electric heating under floor systems incorporating polyethylene plates impregnated with PCM, incorporation of PCM in concrete slab and the application of two types of PCM with different transition temperatures [6, 8-10]. The application of PCM in walls is the preferential solution for exploring the potential of these materials. 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 [11-14]. Darkwa et al. [13], investigated the behaviour of two solutions with incorporation of PCM in gypsum plasterboard. In one side, plasterboard with 12 mm of thickness, all impregnated with PCM, was used, in order to compare with another situation in which they applied

single plasterboard 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 and bricks [4, 15]. Cabeza et al. [4], constructed and monitored the behaviour 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, south and west walls. During the summer and without ventilation a decrease in maximum temperature and a time lag of about 2 hours were recorded.

The introduction of micro and nanomaterials in the mortars matrix can cause microstructural changes. Thus, other studies possessed the main interest in the analyse of the material and microstructure behaviour of construction materials doped with PCM. Lucas et al., evaluated the hardened state performance and internal microstructure of different PCM-mortars, proving that exist a correlation between thermal performance and the mortars microstructure [16].

The thermal behaviour of mortars with incorporation of PCM is extremely important however, the evaluation of other properties is essential for the proper functioning of the mortars. This is a premise for its application and dissemination in the construction industry. Thus, the adequacy of physical, mechanical behaviour and durability, it is very important to apply mortars in the building sector.

The scientific community has conducted studies in the framework of the durability of materials. However, the study of the durability of mortars incorporating phase change materials is one of the main knowledge gaps in this area. Therefore, the main objective of this work was the study of the durability and microstructure of mortars based on different binders, with PCM incorporation. In this study, tests were performed in 12 different compositions, evaluating the water absorption by capillarity, water absorption by immersion, freeze-thaw behavior and microstructure.

2. Experimental program

2.1. Materials

The selection of the materials took into account previous work [17,18]. The influence of adding PCM in mortars for interior coating was studied. Mortars were developed based on the following binders: aerial lime, hydraulic lime, gypsum and cement. The used aerial lime had a purity of 90% and density of 2450 kg/m^3. The gypsum corresponds to 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. CEM II B-L 32.5N cement with density of 3030 kg/m^3 was also used. 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. Based in 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. Finally, the used fibers are synthetic fibers of polyamide, with a length of 6 mm, 22.3 µm of thickness and density of 1380 kg/m^3. The used PCM is composed by a wall in melamine-formaldehyde and a core in paraffin with temperature transition of about 22.5 °C and enthalpy of 147.9 kJ/kg. This exhibits a transition temperature of 24 ºC in the heating cycle and 21 ºC in the cooling cycle. In order to determine the dimensions of PCM microcapsules, granulometry tests were performed using a laser particle size analyzer. 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 and an average particle size of 44 µm.

2.2. Compositions and fabrication

In order to develop this study an experimental campaign was considered, with the main goal of evaluating the durability of mortars with incorporation of PCM. Twelve compositions were developed and evaluated when submitted to extreme environmental conditions.

Table 1 presents the mortars formulation in kg/m^3. The used compositions have different contents of PCM and different binders. The PCM content was fixed in 0% and 40% of mass of aggregate. In order to overcome some of the problems related with the low flexural and compressive strength verify in the aerial lime based mortars with incorporation of microcapsules of PCM, it was decided to incorporate a higher content of binder. Regarding to the presence of some problems related with the mortar shrinkage and consequent cracking, polyamide fibers were incorporated. The fibers content was fixed in 0% and 1% of total mass of binder. The contents of binder, PCM, fibers and superplasticizer were based in previous works [17, 18].

The mixture procedure and specimens preparation for the water absorption by capillarity tests and water absorption by immersion tests were performed in accordance to the standard EN 1015-11 [19]. For the freeze-thaw tests five cubic specimens with 50x50x50 mm^3 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 22ºC) during 21 days.

2.3. Methodology of durability evaluation tests

The durability was considered regarding the water absorption by capillarity, water absorption by immersion and freeze-thaw resistance. This choice was based in the standard NP EN 998-1 which considers these the most important properties for mortars for interior coating [20].

The water absorption by capillarity tests were performed based on the European standard EN 1015-18 [21]. The samples were obtained by cutting the prismatic specimens with dimensions of 40×40×160 mm^3, previously subjected to flexural tests. For each composition three specimens were prepared, resulting in six samples after flexural tests. For each specimen it was decided to put the failure surface resulting from the flexural test in contact with the water. Thus, it was possible to ensure that the porosity presents in the surface in contact with the water was close to the real porosity presents in the studied mortars. This removes the possibility of analysing one surface with higher content of material of small dimensions, which would affect the results of these tests. The quantification of absorbed water was performed by conducting successive weightings in specimens. These weight measurements were made according to a previously established weighting plan, beginning with the first contact of the specimens with water. In order to evaluate the progress of water absorption until the weight stabilization, periodic measurements were performed during nine days. The obtained results allowed us to determine the water absorption by capillarity of the different mortars. The capillary absorption coefficient was determined according to expression 1.

$$C = (M_2 - M_1)/((t_f - t_i)^{(1/2)}) \qquad (1)$$

Table 1

Mortars formulation (kg/m^3)

Composition	Binder		Sand	PCM	SP	Fibers	Water
CA500-0PCM	Aerial Lime	500	1447.2	0	15	0	225
CA800-40PCM	Aerial Lime	800	451.2	180.5	24	0	272
CA800-40PCM-F	Aerial Lime	800	425.2	170.1	24	8	288
CH500-0PCM	Hydraulic lime	500	1351.1	0	15	0	270
CH500-40PCM	Hydraulic lime	500	571.6	228.6	15	0	310
CH500-40PCM-F	Hydraulic lime	500	567.2	226.9	15	5	310
C32.5N500-0PCM	CEM II B-L 32.5N	500	1418.8	0	15	0	275
C32.5N500-40PCM	CEM II B-L 32.5N	500	644.3	257.7	15	0	280
C32.5N500-40PCM-F	CEM II B-L 32.5N	500	622.2	248.8	15	5	295
G500-0PCM	Gypsum	500	1360.4	0	15	0	280
G500-40PCM	Gypsum	500	540.1	216.0	15	0	350
G500-40PCM-F	Gypsum	500	535.8	214.3	15	5	350

Where:
C - Capillary absorption coefficient (kg/(m^2.min$^{0.5}$);
M$_1$ - Mass of the specimen in contact with water at the instant 10 minutes (kg/m^2);
M$_2$ - Mass of the specimen in contact with water at the instant 90 minutes (kg/m^2);
t$_f$ – Final time, instant 90 min;
t$_f$ – Initial time, instant 10 min.

The water absorption by immersion tests were based in the specification LNEC E 394 [22].

The samples were obtained by cutting the prismatic specimens with dimensions of 40×40×160 mm^3, previously subjected to flexural tests. For each composition, three specimens were prepared, resulting in six samples after flexural tests. Initially the specimens were dried in oven until the constant mass. Subsequently, they were saturated with resource to a container with water at a temperature of 20± 3°C. Finally, after saturation, the hydrostatic mass was determined. The obtained results allowed us to determine the water absorption by immersion of the different mortars. This was determined according to the expression 2.

$$W=(M_1-M_3)/(M_1-M_2)\times100 \qquad (2)$$

Where:
W – Water absorption by immersion (%);
M$_1$ - Mass of saturated specimen (g);
M$_2$ - Hydrostatic mass of saturated specimen (g);
M$_3$ – Mass of dried specimen (g).

The resistance of mortars to freeze-thaw cycles is related to their ability to absorb water, the speed of water absorption, the presence of porous structure and the capacity for resist to volume variations when the water changes to the liquid state to a solid state. Thus, cyclic freeze-thaw test has an important and decisive role in the durability of mortars. These tests consist on submitting the specimens to cycles of positive and negative temperatures. When there are negative temperatures, the water inside the structure of the mortars freezes and consequently increases its volume. If the pores of the mortar are not saturated, the problems that can arise are minimal, since the volume of frozen water is inferior to the volume of the pores. However, if the pores are saturated, the resulting increase in volume of freezing gives rise to pressure on the microstructure of mortars, which can cause cracking and even the partial destruction of the specimens.

The freeze-thaw tests were developed based in the standard CEN/TS 12390-9 [23]. The equipment used for the tests was programmed with a law of temperature and humidity. Each freeze-thaw cycle has duration of 24 hours, a total of 56 cycles were performed. During each cycle of freeze-thaw, temperature ranges between the maximum of 24ºC and the minimum of -18 °C.

Initially the specimens were saturated and then submitted to the temperature cycles. During the test the specimen was placed in contact with water. This was carried out with the purpose of reabsorbing the water lost by evaporation and also by the action of the ventilation of the equipment itself. Thus it was possible to ensure the constant saturation of the specimens. The equipment was also programmed with a constant relative humidity of 90%, in order to avoid large losses of water by evaporation. In order to determine the variation of mass, each sample was individually placed in a container able to retain its mass losses resulting from degradation suffered during the freeze-thaw cycles. The quantification of mass losses was performed by conducting successive weightings of the specimens. These weight measurements were made according to a previously established plan of weighting, beginning in the first cycle.

The observation of the microstructure of the developed mortars was performed using a ultra-high resolution field-emission scanning electron microscope (NanoSEM - FEI Nova 200). The aim of these observations was evaluating the porosity. For each composition two cylindrical specimens with diameter and height of approximately 1 cm were prepared. After their preparation all the specimens were stored during seven days in polyethylene bags and subsequently placed in the laboratory at regular room temperature (about 22ºC) during 21 days. The samples were also coated with a thin palladium-gold layer.

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 [24]. According to Figure 1 it is possible verify changes in the amount of water added to the mortars with the incorporation of PCM microcapsules. It was possible to verify an increase in water/binder ratio with the incorporation of PCM microcapsules. The incorporation of 40% of PCM microcapsules causes an increase in the amount of water superior to 15% for mortars based on hydraulic lime, aerial lime and gypsum. The cement based mortars showed an increase of 2%. This increase in water content can be explained by the reduced particle dimension of the used PCM. It was also possible to observe that the gypsum based mortars present higher ratios of water/binder and that the aerial lime based mortars exhibit lower contents of water. For the used range of fibers fraction the incorporation of this material in the mortars with PCM did not cause significant changes in the amount of water added to the mortar.

3.2. Water absorption by capillarity

Figure 2 shows the behavior of the studied mortars during the nine days of testing. It was verified that the incorporation of 40% of PCM in mortars caused some changes in the water absorption by capillarity compared with the
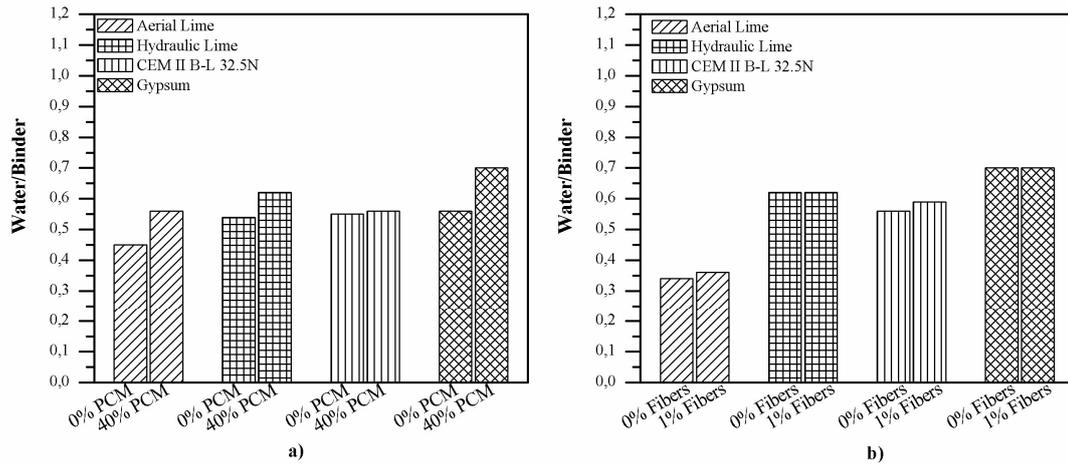
Fig. 1 - Water/Binder ratio: a) Variation with PCM content, b) Variation with fibers content.
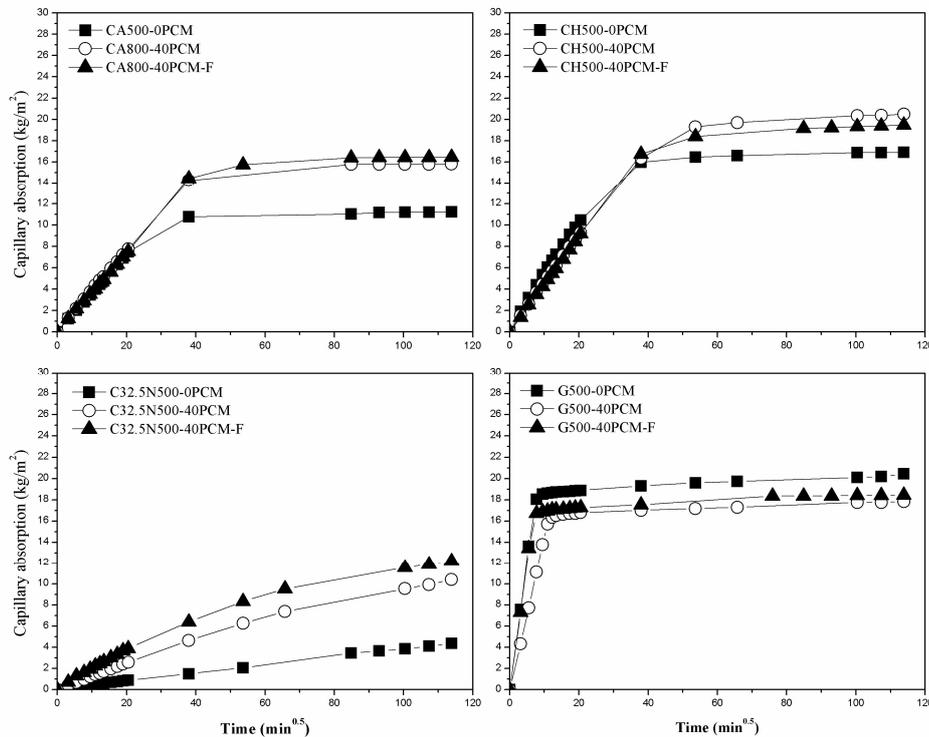

Fig. 2 - Water absorption by capillarity.

reference mortars. According with the results it was observed that the incorporation of PCM leads to an increase in the water absorption by capillarity, which can be explained by the increase of micropores verified in the microstructure observations (Figure 3 to Figure 6). The incorporation of 1% of polyamide fibers had the main objective of control the shrinkage in the developed mortars. Their presence in mortars caused a decrease in the capillary absorption coefficient of about 13% in the gypsum based mortars and 69% in the cement based mortars. The hydraulic and aerial lime based mortars did not present any change in the capillary absorption coefficient with the incorporation of fibers.

According to Figure 3 to Figure 6 it was also observed a good connection between the different

materials (PCM, fibers, aggregate and binder) evidenced by the absence of cracks in the microstructure of the developed mortars. It was observed changes in the pore distribution with the incorporation of 40% of PCM and 1% of fibers, for the aerial lime, hydraulic lime, gypsum and cement based mortars. It was verified an increase in the microporosity with the incorporation of 40% of PCM. It was also observed a presence of micropores with higher dimensions in the mortars with incorporation of PCM compared with the reference mortar. The internal structure of the reference mortars is more cohesive in comparison with the mortars with incorporation of PCM that exhibits biggest pores. The presence of higher microposity can be explained by the presence of higher water content
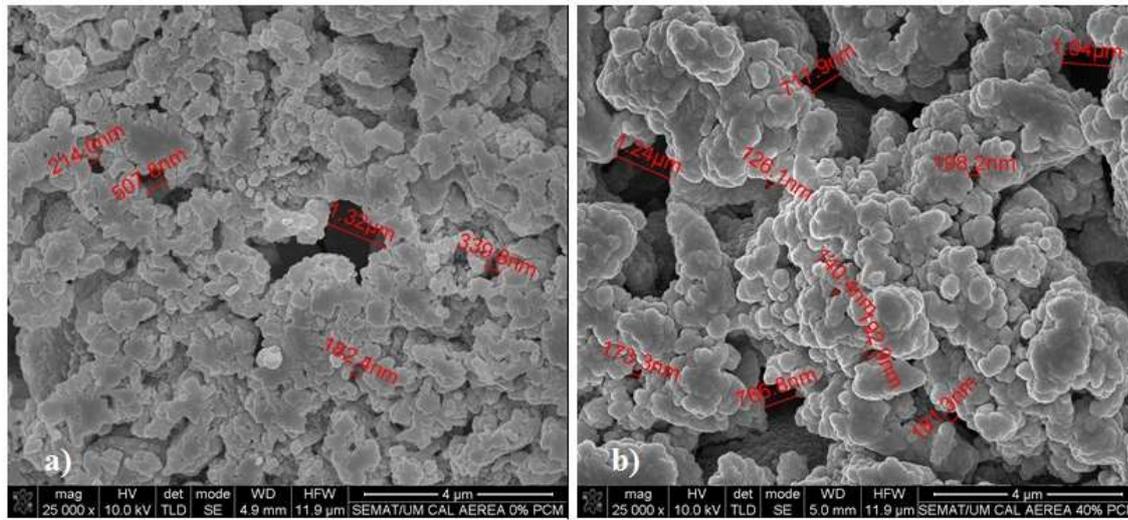
Fig. 3 - Microscope observation of aerial lime based mortars, enlargement of 25000x: a) Mortar without incorporation of PCM microcapsules; b) Mortar with incorporation of 40% of PCM microcapsules and 1% of fibers.
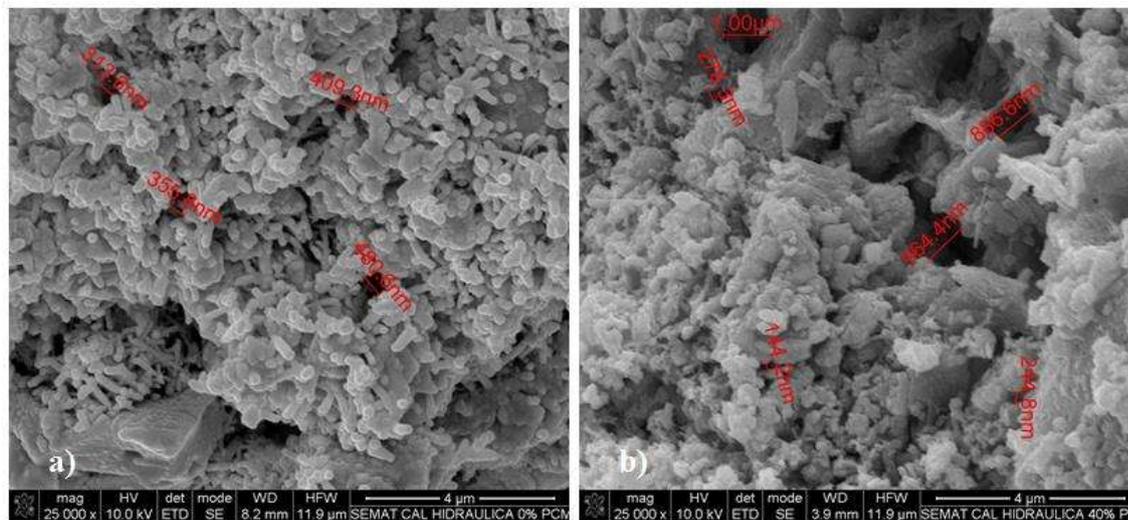

Fig. 4 - Microscope observation of hydraulic lime based mortars, enlargement of 25000x: a) Mortar without incorporation of PCM microcapsules; b) Mortar with incorporation of 40% of PCM microcapsules and 1% of fibers.
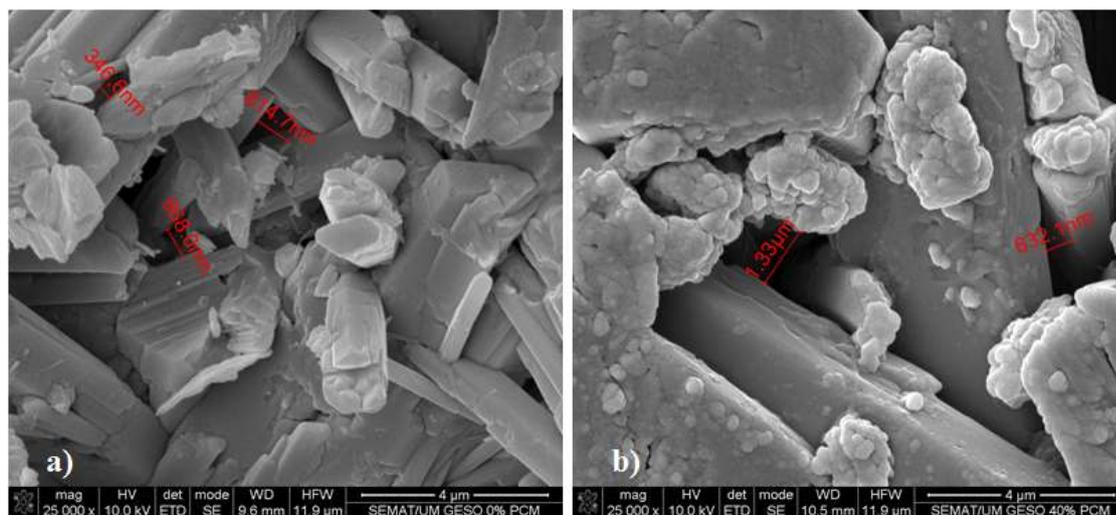

Fig. 5 - Microscope observation of gypsum based mortars, enlargement of 25000x: a) Mortar without incorporation of PCM microcapsules; b) Mortar with incorporation of 40% of PCM microcapsules and 1% of fibers.
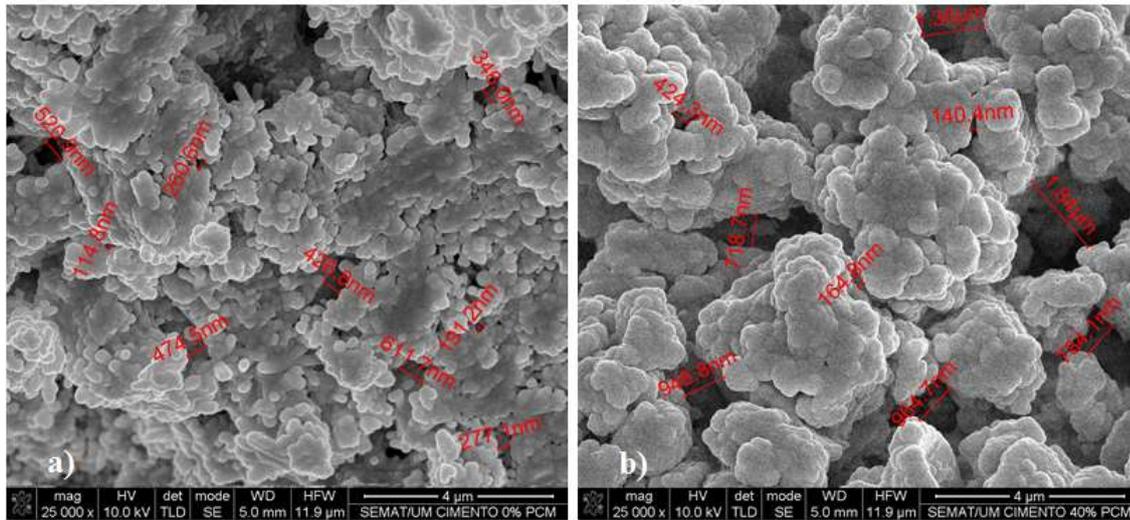
Fig. 6 - Microscope observation of cement based mortars, enlargement of 25000x: a) Mortar without incorporation of PCM microcapsules; b) Mortar with incorporation of 40% of PCM microcapsules and 1% of fibers.

Table 2

Capillary absorption coefficient (kg/(m^2.$min^{0.5}$)

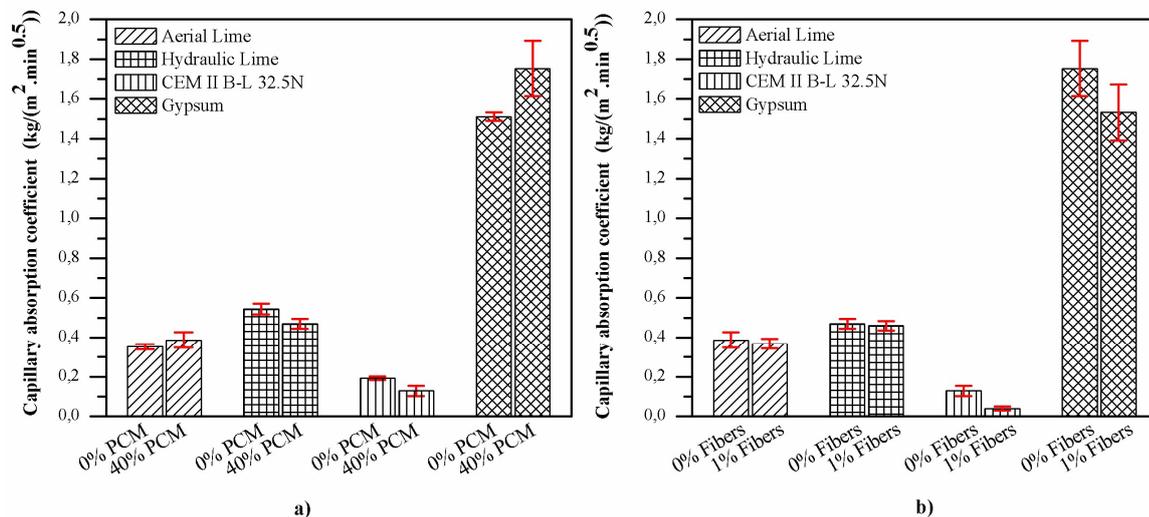| Composition	Binder	Capillary absorption coefficient (kg/(m^2.$min^{0.5}$))	Classification NP EN 998-1:2010
CA500-0PCM	Aerial Lime	0.35	W1
CA800-40PCM	Aerial Lime	0.39	
CA800-40PCM-F	Aerial Lime	0.37	
CH500-0PCM	Hydraulic lime	0.54	W0
CH500-40PCM	Hydraulic lime	0.47	
CH500-40PCM-F	Hydraulic lime	0.46	
C32.5N500-0PCM	CEM II B-L 32.5N	0.19	W2
C32.5N500-40PCM	CEM II B-L 32.5N	0.13	
C32.5N500-40PCM-F	CEM II B-L 32.5N	0.04	
G500-0PCM	Gypsum	1.51	W0
G500-40PCM	Gypsum	1.75	
G500-40PCM-F	Gypsum	1.53	

Fig. 7 - Capillary absorption coefficient: a) Variation with PCM content, b) Variation with fibers content.

in the mortars doped with PCM, due to the reduce particle size of the incorporated material.

The gypsum based mortars have a faster saturation process, presenting all specimens statured after 150 minutes in contact with water and presenting the higher capillary absorption coefficient, due to the higher dimension of the micropores verified in the microstructure observations (Figure 5). The cement based mortars showed a slower velocity of saturation, tending to stabilize after 7 days of testing presented the lower value of capillary absorption coefficient.

In order to evaluate the influence of the presence of PCM and fibers in the water absorption coefficient classification, the mortars were classified according to standard NP EN 998-1 (Table 2) [20].
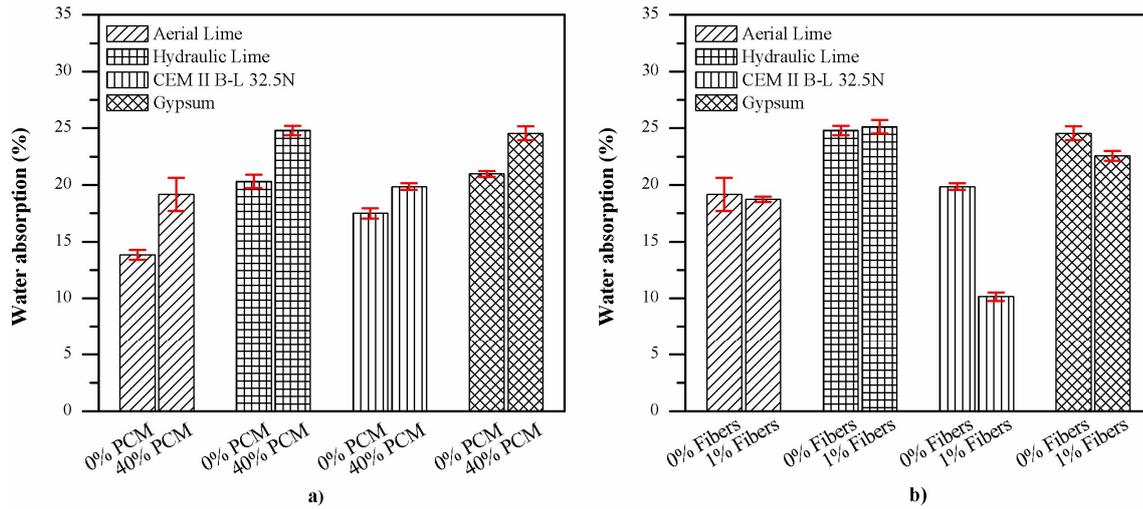
Fig. 8 - Water absorption of the mortars: a) Variation with PCM content, b) Variation with fibers content.
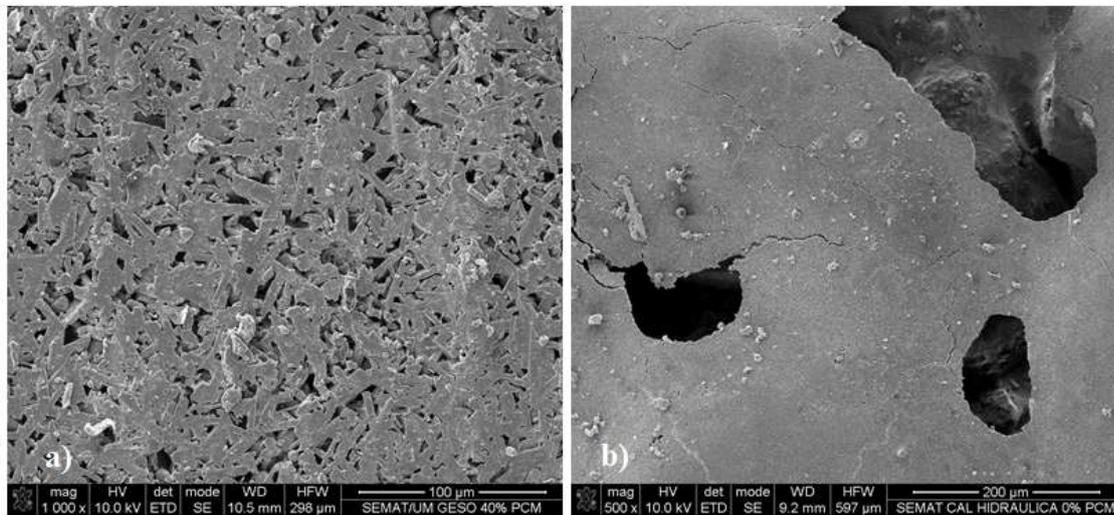

Fig. 9 - Surface of mortars: a) Gypsum based mortar, enlargement of 1000x, b) Hydraulic lime based mortar, enlargement of 500x.

It was verified that the incorporation of PCM and fibers did not cause any variation in the classification of mortars. It was also observed that the classification is directly connected with the type of used binder.

Figure 7 shows the capillarity water absorption coefficient. The incorporation of 40% of PCM caused a decrease in the capillary absorption coefficient of 13% in hydraulic lime based mortars and 33% in the cement based mortars. On the other hand, it was also possible to observe an increase in capillary absorption coefficient of 11% for aerial lime based mortars and 16% for gypsum based mortars.

3.3. Water absorption by immersion

According to Figure 8, it was observed that the incorporation of 40% of PCM microcapsules in mortars caused an increase in water absorption greater than 14%, which can be justified by the increase in the microporosity. However, the incorporation of 1% polyamide fibers resulted in a decrease of water absorption greater than 8%, with the exception of hydraulic lime based mortars, which value did not suffer any change. It was also possible to identify that the gypsum based mortars and hydraulic lime based mortars presented the higher water absorption values. On the other hand, the cement based mortars showed lower water absorption. It is important note that the water absorption by immersion is related with the high dimensions pores (Figure 9). Thus, this behavior can be justified by the water content present in the mortars, since that the gypsum and hydraulic lime based mortars presented the higher water/binder ratio.

3.4. Freeze-thaw resistance

According to Figure 10, it is possible to observe the behaviour of the mortars during the freeze-thaw cycles. The mortars showed different behaviours when subjected to freeze-thaw cycles. In general, it can be concluded that the cement-based mortars are those that exhibit a higher resistance to freeze-thaw action, since that they do
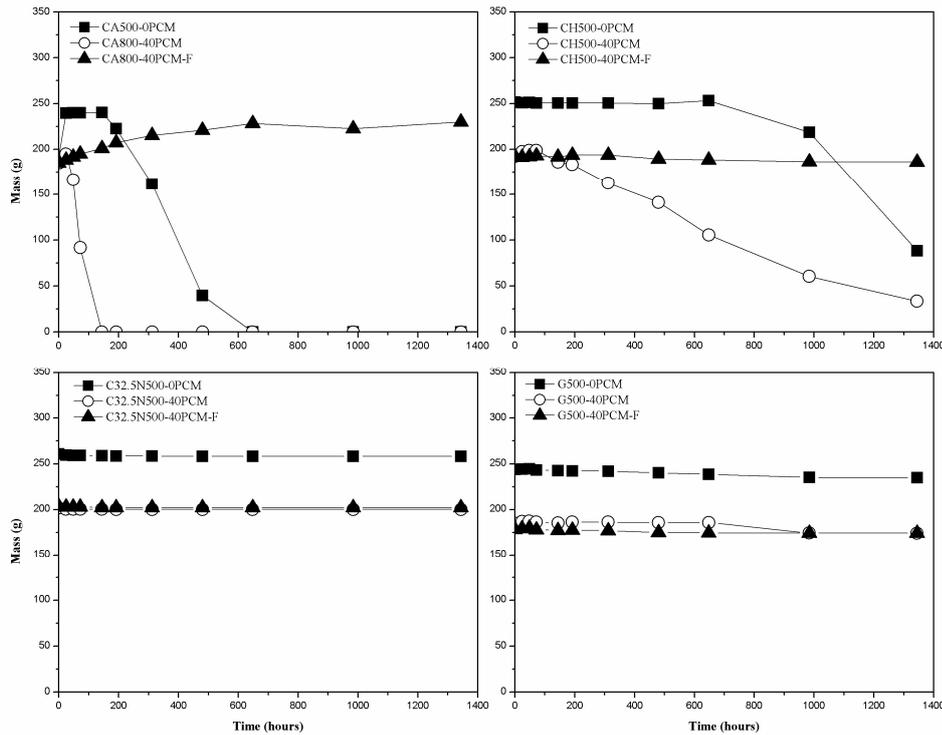
Fig. 10 - Behavior of the mortars to freeze-thaw cycles.

Table 3

Mass losses in the freeze-thaw tests at 56 cycles

Composition	Binder	Mass losses (%)
CA500-0PCM	Aerial Lime	Total destruction at cycle 27
CA800-40PCM	Aerial Lime	Total destruction at cycle 6
CA800-40PCM-F	Aerial Lime	24.3
CH500-0PCM	Hydraulic lime	64.9
CH500-40PCM	Hydraulic lime	82.6
CH500-40PCM-F	Hydraulic lime	3.4
C32.5N500-0PCM	CEM II B-L 32.5N	1.1
C32.5N500-40PCM	CEM II B-L 32.5N	0.7
C32.5N500-40PCM-F	CEM II B-L 32.5N	0.6
G500-0PCM	Gypsum	3.6
G500-40PCM	Gypsum	5.9
G500-40PCM-F	Gypsum	2.1

not present significant losses in their mass. On the other hand, the aerial lime based mortars are more sensitive because they show a total loss of the specimens in few cycles. This behavior can be justified by the ability to resist to the internal movements generated by the volume change of the water present in the pores, since that the cement mortars showed a higher mechanical strengths when compared to the aerial lime based mortars [25]. For other hand, this behavior is also related with the macro and microporosity in the mortars.

Table 3 shows the total degradation suffered by the specimens of the different compositions tested. It was observed that the incorporation of PCM generally resulted in higher losses of the material during the freeze-thaw action, demonstrating, in this way, that with the incorporation of PCM microcapsules the mortars become more susceptible to be attacked. This behaviour is related with the facility that the

aggressive agents have to penetrate into the mortars, which leads to the higher and faster degradation of mortars with incorporation of PCM compared with the reference mortars. Moreover, the incorporation of fibers in all tested mortars allowed observing a decrease in mass loss, providing a higher resistance to the passage of the aggressive agents. This behaviour can be justified by the restriction of movement in the mortar microstructure, conferred by the presence of fibers. On the other hand, the benefit of the incorporation of fibres which leads to a reduction of mass loss during the tests it was also related to the reduction of water absorption by capillarity and immersion.

4. Conclusion

In this study, the effect of the incorporation of PCM microcapsules in mortars for inner wall coating was studied. It can be concluded that the

incorporation of phase change materials in mortars causes significant changes in their properties in fresh and hardened state, which affects the durability and microstructure of the developed mortars.

Regarding to the workability, it was verified that the incorporation of PCM microcapsules caused an increase in the amount of water added to the mortar in order to give a suitable workability. This increase in the water content is related to the fineness of PCM microcapsules. Based on the water absorption tests, it was observed that the incorporation of PCM caused an increase in the porosity of the mortars. This increase also resulted in a higher sensitivity to the freeze-thaw test, promoting a higher deterioration of the mortars. However, this ease penetration of aggressive agents may be decreased by incorporation of polyamide fibers.

Taking into account the behaviour of the different mortars, it can be concluded that the cement based mortars presented a lower sensitivity to freeze-thaw actions, consequently presenting a better performance regarding to the durability. Moreover, the aerial lime based mortars showed a higher deterioration in the freeze-thaw test, presenting a more sensitive behaviour to the aggressive agents.

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