INCORPORATION OF PHASE CHANGE MATERIALS (PCM) IN CERAMICS FOR BUILDING APPLICATIONS

Hélio Jorge and Luc Hennetier

Centro Tecnológico da Cerâmica e do Vidro (CTCV), Parque Tecnológico de Coimbra (Coimbra iParque), Lote 7, Antanhol – Coimbra, Portugal

1. ABSTRACT

The application of phase change materials (PCMs) in building materials is an emerging field, aimed at improving the energy efficiency of buildings. This article presents part of the work of developing methods for the incorporation of PCMs in ceramic materials for application in construction.

The tests performed show the variability in the incorporation ratio of the PCM incorporation process in materials with different pore sizes and porosities, indicating conditions where there is a greater incorporation and some critical differences between the two methods tested.

2. INTRODUCTION

The need for the improvement of energy efficiency has been a driver in the search for the improvement of buildings. Buildings have thus been designed to reduce energy consumption and to provide smart control of the inner temperature. The use of PCMs in building applications is emergent and has a great potential response to these issues.

Storage of thermal energy can be done by sensible and/or by latent heat. Storage of sensible heat has been used for centuries in building to absorb and release thermal energy in a passive way. However, a great volume of material is needed to store the same amount of heat compared with the use of latent heat, as is the case of PCM use.

The first PCM applications found in the market are divided into four groups: thermal insulation, inner temperature control, cooling and heating systems, and solar thermal energy storage.

The use of PCMs with a melting point in the 20-40ºC range makes it possible to obtain storage and release effects for thermal comfort in buildings, particularly with regard to thermal energy storage and thermal insulation [1,2]

In this study, the production of ceramic materials for building with a new PCM energy storage functionality is proposed. Two methods are presented for the incorporation of PCMs in ceramics porosity, tested in a two-layer, dense–porous ceramic material produced by adding organic porosity generators [3, 4]. The incorporation of PCMs in porous materials has been tested in materials such as concrete, plaster or polymeric foam, though no references have yet been found regarding their incorporation into ceramic materials [6, 7].

3. EXPERIMENTAL METHODS

Experiments of PCM incorporation into ceramic tiles were carried out by diffusion through the porosity of the sintered ceramic material. Two methods were tested: infiltration of molten pure PCM and infiltration of aqueous suspensions of PCM microcapsules (Table 1). In the former, a PCM at 60ºC penetrates through the porous layer. In the latter, the suspension was forced to penetrate by an air pressure of 8 bar on the porous surface.

Method	Hot infiltration	Cold infiltration
PCM type	Non-encapsulated pure PCM	Aqueous suspension of microencapsulated PCM
Incorporation process	Infiltration of molten PCM by capillary force with no auxiliary pressure	Infiltration of suspension under pressure

Table 1. *Methods of PCM incorporation.*

The ceramic tiles used in the tests consisted of a body made up of two layers, of porcelain–earthenware material (Figure 1), involving a thick dense layer and a thick porous layer. Porosity was generated by organic agents [3, 4]

The ceramic tiles were produced with different pore-former agent concentrations and particle sizes. Particle size is proportionally correlated with the pore size generated, and the agent concentration is proportionally correlated with the porosity fraction. The indirect relationships are used to understand the PCM incorporation efficiency with pore size and fraction.

Figure 1. *Double layer dense–porous porcelain–earthenware material.*

3.1. HOT INFILTRATION

PCM Rubitherm RT, with 21ºC melting point, 174 kJ/kg thermal energy storage in the 10-30ºC range was used in the hot infiltration tests. Table 2 presents the characteristics of the ceramic tiles. In some tiles, the infiltration tests were improved by vacuum at 100 mbar, in order to increase the filling in thinner and lower porosity materials.

Pore-forming agent		Sintered tile characteristics			Infiltration methods
Particle size	Concentration (%m)	Tile thickness (mm)	Porous layer thickness (mm)	Porous layer porosity (%)	
-500 microns	15%	9.0	6.8	29%	Natural
-500 microns	25%	9.0	6.7	41%	Natural
250-425 microns	15%	9.0	6.8	29%	Natural
250-425 microns	20%	9.0	6.7	35%	Natural
-250 microns	10%	9.0	6.8	24%	Natural
-36 microns	10%	7.4	3.7	39%	Natural
-75 microns	5%	8.5	4.2	17%	Natural
-75 microns	5%	8.5	4.2	13%	Vacuum

Table 2. *Characteristics of the ceramic tiles used in the hot infiltration tests.*

3.2. COLD INFILTRATION

Cold infiltration consisted of contacting the rear face of the ceramic tile – porous side – with the PCM suspension under an isostatic air pressure. PCM BASF Micronal with 23ºC melting point, with 100 kJ/kg heat storage capacity was used. Table 3 presents the characteristics of the ceramic tiles used.

Pore-forming agent		Sintered tile characteristics			Infiltration methods
Particle size	Concentration (%m)	Tile thickness (mm)	Porous layer thickness (mm)	Porous layer porosity (%)	
-500 microns	15%	9.0	6.8	27%	Overpressure
250-425 microns	20%	9.0	6.8	34%	Overpressure
-500 microns	25%	9.0	6.8	43%	Overpressure

Table 3. *Characteristics of the ceramic tiles used in the cold infiltration tests.*

3.3. TEST OF THE PCM EFFECT IN CERAMIC TILES

To verify and to demonstrate the effect of the incorporation of PCM in the ceramic materials tested, the results are presented of the tile heating test with cold infiltrated materials (Figure 2). Initially set at 18ºC, the tiles were heated at the dense side surface with 60ºC air and the temperature of the opposite porous side was recorded.

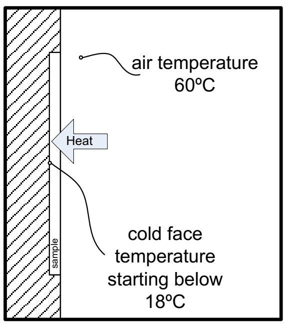

Figure 2. *Assembly of the PCM-incorporated ceramic tiles heating test.*

4. RESULTS AND DISCUSSION

4.1. HOT INFILTRATION

Figure 3 presents the efficiency parameter of the incorporation method (or filling rate), measured by the ratio between liquid PCM filled porosity volume and total open porosity of the material, for different combinations of the pore-former agent, particle size and concentration. The results show a wide variation in the filling rate, from 45% to 98%. The most filled material has a higher porosity and higher pore size.

Moreover, low porosity and low pore-size materials can be fully filled if infiltrated under vacuum (Figure 4). A material with only 5% pore-former and fine particle size such as -75 microns can achieve 100% filling after 2 hours under vacuum.

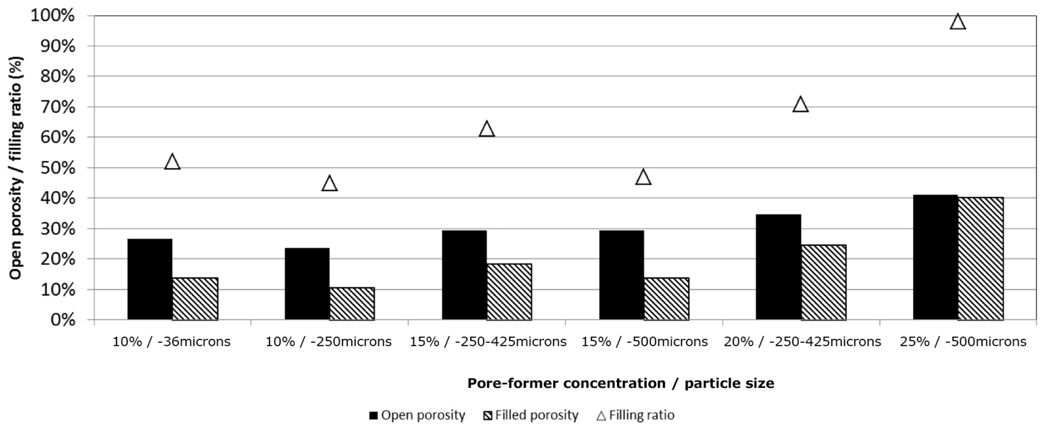

Figure 3. *PCM filling rate in dense–porous, porcelain–earthenware, in tiles produced with different pore-former compositions – particle size and concentration.*

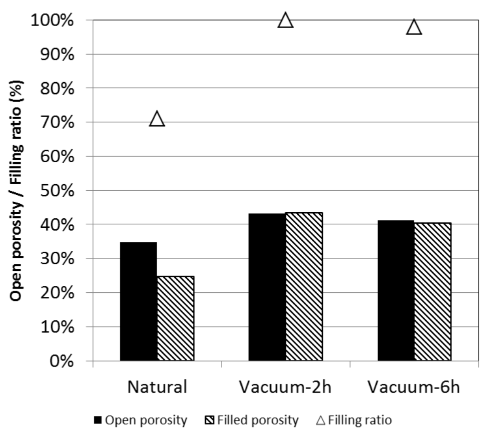

Figure 4. *PCM filling rate in dense–porous, porcelain–earthenware under vacuum (tile produced with 5% pore-former and -75 microns particle size).*

4.2. COLD INFILTRATION

Microencapsulated PCM infiltration was performed using a suspension, i.e. using water as the capsule transport medium into the ceramic tile core. Since the capsules have a similar dimension to the ceramic pore size, infiltration was achieved by overpressure.

The filling rate was 82% for the porous earthenware produced with 25% pore-former at -500 microns, consequently in specimens with the highest porosity and pore size.

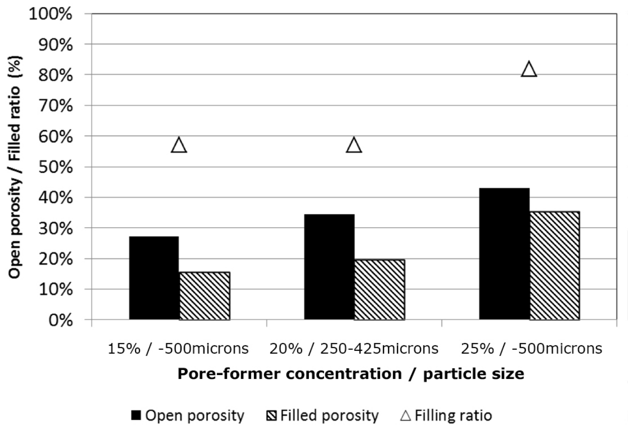

Figure 5. *Filling rate of the microencapsulated PCM suspension in porous earthenware, in tiles produced with different pore-former compositions – particle size and concentration*

4.3. THERMAL EFFECT OF PCM INCORPORATED IN CERAMIC TILES

Table 4 presents the latent heat storage capacity given by PCM incorporated in ceramic tiles. The capacity in pure PCM materials is higher than in encapsulated PCM in all samples, because in the latter only a fraction of PCM is infiltrated together with water (example: sample 250-425 microns / 15% - 128 and 50 kJ/m^2 and -500 microns / 25% - 280 and 90 kJ/m^2).

Figure 6 shows the PCM effect in the ceramic material, highlighting a delay in the temperature curve when the PCM is melted, in the 23ºC range. The delay is greater in higher thermal capacity samples, where more PCM is incorporated. That test demonstrates the increase in thermal inertia of the ceramic material, but not by increasing temperature.

Pore-former particle size	Pore-former concentration	Incorporation process	Filling rate	Energy storage capacity (KJ/m^2)
-75 microns	5%	Natural	20%	12
-75 microns	5%	Vacuum	62%	45
-250 microns	10%	Natural	45%	74
-36 microns	10%	Natural	52%	53
-500 microns	15%	Natural	47%	96
250-425 microns	15%	Natural	63%	128
250-425 microns	20%	Natural	71%	171
-500 microns	25%	Natural	98%	280
-500 microns	15%	Pressure	57%	33
250-425 microns	20%	Pressure	57%	50
-500 microns	25%	Pressure	82%	90

Table 4 *PCM latent heat storage capacity added to the ceramic materials tested.*

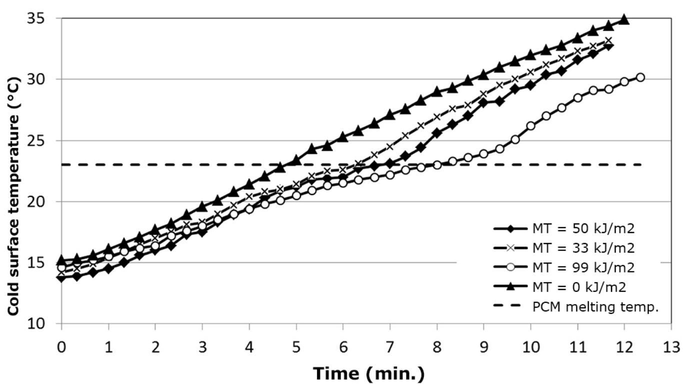

Figure 6. *Heating curves of the cold face temperature of ceramic tiles with different microencapsulated PCM amounts.*

5. CONCLUSIONS

This paper presents two methods for PCM incorporation into ceramic materials, using porosity to hold that material. Direct PCM incorporation and microencapsulated PCM were tested, which can be applied according to different applications (Table 5).

The results show a wide variation in the filling process efficiency relating to two ceramic material characteristics: porosity volume and pore size. Therefore, these must be considered for process optimization.

	Hot infiltration	Cold infiltration
PCM type	Pure, non-encapsulated PCM	Aqueous suspension of microencapsulated PCM
Incorporation process	Infiltration of molten PCM by capillary action, not pressure assisted	Suspension infiltration by pressure
Main characteristics	• Recommended for microporous ceramics • Need for encapsulation of ceramic–PCM system • Higher amount of PCM incorporated, higher thermal inertia	• Recommended for macroporous ceramics • No need for encapsulation of ceramic–PCM system • Lower amount of PCM incorporated, lower thermal inertia

Table 5. *Characteristics of the methods for PCM incorporation into ceramics.*

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