

Thermal and durability performances of mortar and concrete containing phase change materials

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Abstract. Thanks to their latent heat storage, phase change materials (PCMs) continue to attract the interest of many researchers and industrialists. Microencapsulated and macroencapsulated PCMs are generally added directly or immersed into conventional buildings materials to improve thermal inertia and provide a better comfort to users. However, many drawbacks related to PCMs were noticed when they are incorporated into cement-based materials. This paper summarizes previous research concerning the use of PCMs on the thermal, mechanical and durability properties of mortar and concrete. Despite the obvious reduction of the mechanical strength, PCMs are still found to be good candidates to enhance the overall thermal performances of cement-based materials. It is therefore suggested that future researches should focus more on mitigating the impact of PCMs on the mechanical strength in order to gain a wider application of PCMs in concrete building applications.

1. Introduction

With the current enhancement of living standards and comfort levels, the energy demand of buildings is expected to increase significantly. As outlined by several studies [1, 2], building systems such as heating, ventilation and air-conditioning (HVAC) consume about 30 to 40% of the total energy consumed by a building. To practically solve this issue, reducing the energy demand through energy storage systems with the use of phase change materials (PCMs) in buildings has been proposed. It has been reported that the use of PCMs in buildings can result in a reduction of summer electricity consumption, annual electricity cost and demand of HVAC by about 17%, 24% and 21.8%, respectively [3-5]. Therefore, recent studies are increasingly encouraging the use of PCMs in cementitious materials [6]. After years of research, organic solid-liquid PCM, particularly paraffin, has been chosen to be used for building applications due to its suitable phase change temperature and high thermal energy storage capacity [7]. At present, both micro and macro encapsulation techniques are regarded as one of the simplest approach to facilitate the incorporation of PCMs into cement-based materials. Microencapsulated PCM (micro PCM) is typically referring to paraffin wax encapsulated in a very thin layer of polymeric materials known as the shell, whereas macroencapsulated PCM (macro PCM) is developed by absorbing PCMs in the liquid form into porous or highly porous inorganic materials such as diatomite [7], expanded clay [8], expanded graphite [9], etc. This paper summarizes previous studies concerning the development and the use of micro and macro PCMs in cement-based materials with a particular focus on the effects of these PCMs on the thermal, mechanical and durability performances of mortar and concrete.



2. Phase change materials for cement-based materials applications

In the past decades, different type of micro and macro PCMs have been widely developed. They can be synthesised through different encapsulation techniques and using various containers (shell or porous materials). Several organic and inorganic polymers (e.g. polystyrene, starch and calcium carbonate) are used as a shell to form micro PCMs [12-14]. In general, the developed micro PCMs possess a spherical shape, uniform size and excellent thermal properties [12-14]. However, it is worth mentioning that most of the micro PCM capsules are easily to break during the mixing process of cement-based materials [16]. To overcome this problem, some researchers propose to impregnate PCMs into porous materials to form macro PCMs. Due to the high porous structure and high thermal conductivity, materials such as diatomite, expanded clay and graphite have been widely studied and used [7-9]. Some results indicated that these porous materials are able to retain up to 70% wt of PCM [7]. However, the high amount of the impregnated PCM may significantly reduce the thermal conductivity of macro PCMs.

3. Effect of PCMs on the performances of cement-based materials

3.1. Thermal properties

The thermal property is one of the most important characteristics to be considered for PCMs mortar or concrete [15-19]. According to Hunger et al. [15], the addition of PCMs into concrete results in a reduction of the thermal conductivity. In fact, they observed a reduction of about 38% when 5% of PCMs were added to concrete (by total mass). In addition, they noted a significant increase of the concrete heat storage capacity and thus able to improve the energy savings by about 12%. Similar results were reported by other studies [3, 4, 16]. Recently, the thermal performances of macro PCMs have been experimentally investigated in a full-scale test room [18]. The PCM was installed on the inner surface of the walls. The temperature change on the internal surface of the walls and the center of the room with and without PCM were measured. The results (Figure 1) showed a reduction of the temperature raise during daytime and compared to the reference room (without the use of PCM) the temperature peak was also reduced by about 2.5°C.

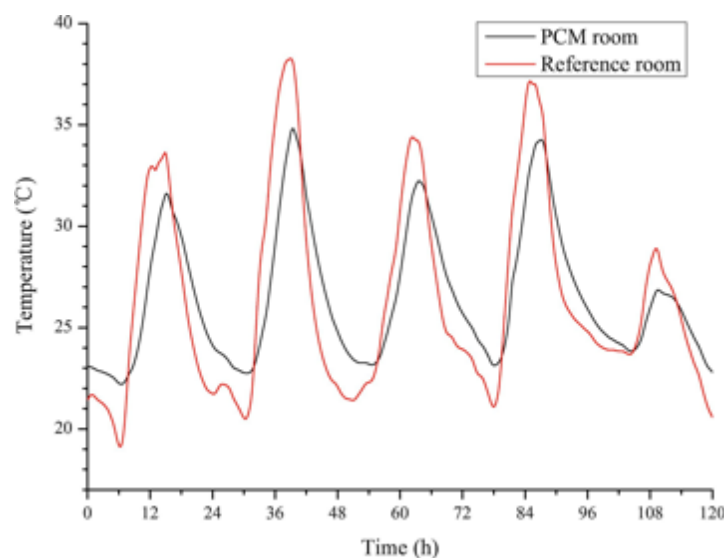


Figure 1. Comparison of the indoor room temperature with and without PCMs [18].

Additionally, Qian et al. [19] studied the heat storage behaviour of a small test room equipped with a glass vessel. The effect of PCM was investigated by comparing the results obtained with and without PCM. The experimental results showed a decrease of the temperature by about 7°C.

3.2. Mechanical strength

Most of the existing studies showed that the addition of (micro or macro) PCMs decreases the mechanical strength of mortar and concrete. The results of 28 days compressive strength of mortar and concrete containing PCMs is summarized in Table 1.

Table 1. Percentage of 28-day compressive strength reduction of mortar and concrete containing PCMs.

Reference	Form of PCM	Amount of PCM	% Decrease in strength
[15]	Micro PCM	5% (concrete-addition-by total mass)	71
[20]	Micro PCM	5% (mortar-addition-by mass of cement)	29
[22]	Micro PCM	10% (concrete- addition- by total weight)	38
[21]	Micro PCM	5%	43
	Macro PCM	(concrete-addition-by total weight)	33
[19]	Macro PCM	5% (mortar-addition-by mass of cement)	22
[23]	Macro PCM	6% (concrete-addition- by total weight)	42

In general, most of the studies pointed out that the main reasons for the reduction in strength are due to the leakage of PCM and the poor bonding (Figure 2) between the PCM and the cement paste. The decrease of the concrete density with the presence of PCMs was also found to contribute to the reduction of the mechanical strength of mortar and concrete [15, 16, 19-21, 24- 26].



Figure 2. Microstructure of cement paste incorporating PCM [26].

3.3. Durability performances

Some recent work was undertaken to evaluate the durability of concrete containing PCMs. Researchers [15, 19] highlighted that the use of PCMs increases significantly the porosity of cement-based materials.

According to [19], the open porosity of cement mortar increased from 18% to 130% when 30% of PCM was added. It is known that the increase of concrete porosity could have a significant negative impact on the durability. However, Cellat et al. [22] reported that PCMs didn't affect the corrosion behaviour of reinforced concrete. The authors showed that the incorporation of PCM enhances the corrosion resistance by forming a protective film on the rebar surface even when the concrete developed a higher porosity compared to reference concrete (without PCM). This results in a polarization resistance similar to that of reference concrete. On the other hand, PCMs were also proposed for use in low temperature applications. As observed by Esmaeeli et al. [27] PCMs can reduce the time and depth of freezing in concrete by at least 10%. Hence, PCMs can be considered as an alternative to de-icing salts to reduce the number of freeze thaw cycles and potential cracks formation in concrete.

4. Conclusion

Phase change materials (PCMs) were proposed to enhance the thermal inertia and improve the thermal comfort in buildings. In general, PCMs can be used in either microencapsulated or macroencapsulated form in mortar and concrete. Based on the literature, the incorporation of PCMs decreases the thermal conductivity and increases the thermal energy storage of cement-based materials. In addition, PCMs showed an adverse effect on the mechanical and durability properties of mortar and concrete. Moreover, PCMs increase the concrete porosity which can adversely affect the mechanical strength and durability performances of concrete. Therefore, for successful use of PCMs in concrete building applications, future research work is still needed to mitigate the strength reduction and durability issues of concrete.

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5. References

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