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Study on functional and mechanical properties of cement mortar with graphite-modified microencapsulated phase-change materials

Hongzhi Cui[a], Wenyu Liao[a,b], Xuming Mi[a,*], Tommy Y. Lo[b], Dazhu Chen[c]

[a] Guangdong Provincial Key Laboratory of Durability for Marine Civil Engineering, College of Civil Engineering, Shenzhen University, Shenzhen 518060, China
[b] Department of Architecture and Civil Engineering, City University of Hong Kong, Hong Kong, Hong Kong
[c] College of Materials, Shenzhen University, Shenzhen 518060, China

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ABSTRACT

To achieve high heat exchange efficiency of a microencapsulated phase change material (MPCM) and energy storage for buildings, a graphite-modified MPCM (GM-MPCM) was prepared and incorporated into the cement mortar to develop a type of cement mortar with both high heat storage efficiency and considerable mechanical strength. The thermophysical properties of the GM-MPCM and the thermal and mechanical properties of the GM-MPCM mortar were investigated. The results indicated that more than 50% of the paraffin (PCM used in this study) could be effectively encapsulated in the GM-MPCM. A thermal cycle test showed that thermal energy storage capacity of the GM-MPCM had not been reduced undergoing 10 thermal cycles. In addition, the diameters of the most GM-MPCM with approximately 7.74 μm polyurea shell ranges from 150 to 350 μm. Thermal performance tests using room models revealed that the small room models prepared with GM-MPCM-CM panels can reduce both the temperature fluctuations and maximum indoor centre temperature effectively. The cement mortars with GM-MPCM can be used for thermal energy storage in buildings. Moreover, adding GM-MPCM into cement would also lower and delay the hydration heat, which is helpful to reduce the thermal cracking of cement-based materials. Although adding GM-MPCM can weaken the mechanical strength of cement mortar, the compressive and flexural strengths of cement mortar with 20% GM-MPCM by weight of cement were still as high as 32.9 MPa and 7.6 MPa, respectively. Therefore, the cement mortars with different GM-MPCM are suitable structural and functional building materials.

1. Introduction

Cement-based materials in buildings work not only as a structural material but also as a functional material for thermal energy storage. The approach to store and release latent heat utilising phase-change materials (PCMs) has been considered a simple and effective technology for application to building envelopes to increase energy efficiency of buildings [1,2].

Paraffin is one type of organic PCM, and it has been widely used in many studies [3]. However, the low thermal conductivity of 0.19–0.24 W/m K is its main weakness that decreases the rates of storing and retrieving heat during melting and crystallisation processes. Thus, carbon fibres and expanded graphite with low weight and high thermal conductivities have been used to promote heat diffusion in paraffin and other PCMs [4–8]. Fethi et al. [9] observed a noticeable improvement in the effective thermal conductivity of graphite/paraffin composites, in which graphite was added as fibres, fins or foam, compared with the PCM by experimental verification.

Microencapsulation is a technology that envelops PCM particles in a thin and sealed high-molecular-weight polymeric film in order to avoid leakage of PCM during the phase transition [10,11]. In addition, microencapsulated PCM (MPCM) not only has a capability of resisting volume change during the phase-change process, but also has a larger surface area per unit volume which is good for heat transfer. So paraffin is microencapsulated in many applications [12]. However, although the microencapsulation can enlarge the specific surface area of paraffin to improve its thermal productivity, the MPCM shell is usually an organic polymer, such

Abbreviations: MPCM, microencapsulated phase-change material; GM-MPCM, graphite-modified MPCM; CM, cement mortar; OCM, ordinary cement mortar; OCP, ordinary cement paste; OCMP, ordinary cement mortar panel; GM-MPCM-CP, GM-MPCM cement paste; GM-MPCM-CM, GM-MPCM cement mortar; GM-MPCM-CMP, GM-MPCM cement mortar panel.

* Corresponding author. Tel.: +86 755 26916424.
E-mail address: mixm@szu.edu.cn (X. Mi).

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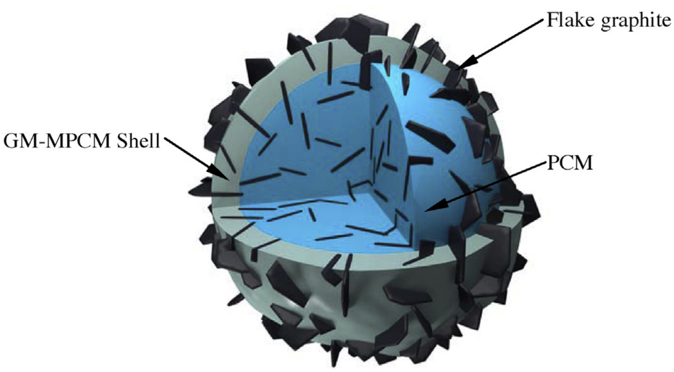

Fig. 1. Schematically graphical drawing of the GM-MPCM.

Fig. 2. GM-MPCM in powder form.

as melamine–formaldehyde resin, urea–formaldehyde resin, and polyurethanes which possess low thermal conductivities. This will definitely affect the rate of transferring heat between the outside and the PCM in the shell materials. Moreover, the low thermal conductivity of paraffin mentioned above decreases the heat exchange efficiency of the MPCM as well. According to Sari et al. [13], the thermal conductivity of micro/nano-encapsulated paraffin eutectic mixtures with polymethylmethacrylate shells was measured to be 0.21–0.23 W/m K. According to the research of Joulin et al. [14], the thermal conductivity of cement mortar is 0.65 ± 0.02 W/m K. Therefore, when applying the polymer-based MPCM in cement-based construction materials, the low thermal conductivity of the MPCM will strongly hinder heat transfer from the construction materials to the paraffin, which is detrimental to the heat storage efficiency of thermal energy storage construction materials with MPCM. To solve this problem, some researchers using inorganics with high thermal conductivity to prepare organic–inorganic hybrid microencapsulated PCM. Xuan et al. [15] used iron nanoparticles to improve thermal conductivity of MPCM. And, in their study, iron nanoparticles were added into melamine urea formaldehyde resin which used as shell of the PCM microcapsule. Yin et al. [16] utilized SiO2 to prepare for microencapsulated phase change materials with polymer–silica hybrid shell. In this study, the authors use flake graphite to improve thermal conductivity of MPCM. Interfacial polymerization method was used to prepare for the graphite-modified MPCM (GM-MPCM). Due to flake graphite can be distributed both inside PCM and microcapsule shell, therefore, the thermal conductivity of GM-MPCM can be improved effectively. Schematically graphical drawing of the GM-MPCM is presented in Fig. 1.

To date, based on our literature review, few studies have focused on functional and mechanical properties cement mortar with GM-MPCM. Therefore, in this research, GM-MPCM was synthesised by adding flake graphite powder into the MPCM to enhance its thermal conductivity. Furthermore, to develop cement-based materials with good mechanical properties and function for thermal energy storage engineering applications, this research focused on both the thermal property and the mechanical property comparatively less reported in the existing literatures of the hardened cement mortar with GM-MPCM.

2. Experimental

2.1. Preparation of GM-MPCM

In this study, the following experimental materials were used: paraffin (RUBITHERM RT 28HC, Ruhr Tech. Co., Ltd.), styrene-maleic anhydride (SMA; Scripset 520, Beijing Thk Sci. Co., Ltd.), flake graphite powder (FGP; 800 mesh, Qingdao Tianyuan Graphite Co., Ltd.), diethylenetriamine (DETA; 99.5%, Dow Chemical Company), isophorone diisocyanate (IPDI; 99.5%, Bayer Material Science Taiwan Limited).

GM-MPCM was prepared using the interfacial polymerisation method. During the synthesis process, paraffin, IPDI and flake graphite powder were added to the aqueous solution of 1.3% SMA, which was used as the dispersant, according to a certain proportion with constant stirring at a high speed at 60 °C, and this emulsification reaction lasted for 1 h. Then, DETA and IPDI were slowly added to the obtained emulsifier with a mass ratio of 3:2 at 60 °C, and the MPCM suspending solution was obtained after 3 h. After the process of centrifugation with frequency of 50 Hz, filtration, and desiccation, the GM-MPCM with paraffin core and polyurea shell was obtained, and its final form is presented in Fig. 2. Measuring with a Microtrac S3500 laser particle size analyser (Microtrac Inc., USA), the particle size distribution of GM-MPCM is as follows:

Particle size smaller than 150 μm = 10%

Particle size ranging from 150 to 350 μm = 90%

The morphologies of the newly manufactured GM-MPCM examined by stereomicroscope (XTL-3000 °C, Shanghai Caikon Optical Instrument Co., Ltd., P.C. China) and environmental scanning electron microscopy (ESEM; Quanta 250 FEG, FEI Company, USA) are shown in Fig. 3(a) and (b), respectively. From Fig. 3, it can be known that GM-MPCM maintained its spherical shape without leakage during the observation; therefore, the paraffin is well encapsulated. The black spots in Fig. 3(a) are flake graphite. Fig. 4 shows morphology of shell of GM-MPCM. Fig. 4(a) shows a broken GM-MPCM. From it, we can know thickness of GM-MPCM shell is uniform. According to Fig. 4(b), the thickness of the GM-MPCM shell was measured to be 7.74 μm.

2.2. Preparation of mortar with GM-MPCM

2.2.1. Materials

The cement used was P.II 42.5R Portland cement which complied with GB 175-2007 (China National Standard: Common Cement Paste), and the China ISO standard sand was used. Polycarboxylate superplasticiser and the defoaming agent were used as additives.

2.2.2. Mix proportion

Cement mortar with good mechanical and function of thermal energy storage was produced by incorporating GM-MPCM into cement mortar. The mass percentages of GM-MPCM in the GM-MPCM cement mortar (GM-MPCM-CM) specimens were 0%, 5%, 10%, 15%, and 20% with respect to weight of cement. The ratio