



Development of granular expanded perlite/paraffin phase change material composites and prevention of leakage



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ABSTRACT

In this study, granular phase change material (PCM) composites were developed by absorbing paraffin into the pores of expanded perlite particles with two grades of particle size. Because of the different particle sizes and pore structures, the absorption mechanisms of the expanded perlite particles were found to differ. A significant amount of paraffin leakage was found when the PCM composites were applied directly into the cement mixture. To prevent such leakage, a new method by using hydrophobic silane was investigated as surface modification for the PCM composites. The method was then compared with nanosilica deposition method. Although both methods prevented leakage effectively, cement composites incorporating silane-modified PCM composites had lower compressive strength than those incorporating nanosilica modified PCM composites. Thermal performances of expanded perlite/paraffin composites were compared with that of microencapsulated PCM and the results showed expanded perlite/paraffin composites were superior under certain conditions.

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1. Introduction

Phase change materials (PCMs) have the ability to store a large amount of latent heat within the small temperature range associated with a phase change. Therefore, application of PCMs in building may help reduce indoor temperature oscillations. Over the past several decades, extensive research (Zhou et al., 2012) into the application of PCMs in buildings to achieve latent heat storage has been conducted. PCM-incorporated building components, such as wallboards (Kuznik and Virgone, 2009), floors (Entrop et al., 2011), and ceiling boards (Jaworski et al., 2014), have been experimentally proven to be successful because of their ability to reduce energy consumption by lowering space heating and cooling loads (peak reduction) and, more importantly, shifting HVAC (heating, ventilating, and air conditioning) loads from peak to off-peak periods (peak delay). Thus, incorporation of PCMs with suitable phase change temperature and large enthalpy in the building envelope could reduce not only total energy consumption but also peak energy demand by the storage and release of solar thermal energy.

As the most widely used building material, concrete has been extensively used for building components and is considered

suitable for incorporation of PCMs. PCMs can be directly incorporated into concrete by wet or dry mixing (Salzer and Griffen, 1986) and immersion (Hawes and Feldman, 1992). Direct incorporation methods are simple and easy to use, but the amount of PCM that they can incorporate is small and the PCM can leak from the matrix. PCMs can also be incorporated into concrete by using microencapsulated PCMs (Tyagi et al., 2011) and granular PCM composites (Zhang et al., 2005). Microencapsulated PCMs are produced by enclosing the PCM in a thin polymeric film with a high molecular weight. Granular PCM composites can be produced by incorporating PCMs into different types of porous aggregates by vacuum impregnation or blending. From the opposite point of view, the fabrication of granular PCMs is penetration of PCMs into pores of porous aggregates due to capillary actions. Although microencapsulated PCMs have demonstrated a positive impact on the thermal performance of concrete, some incompatibility problems (Hunger et al., 2009) with the cement matrix have occurred. Microencapsulated PCMs with broken polymer shells, as shown in Fig. 1 (Li, unpublished work), were found in the cement matrix because of collision/abrasion and the high pH environment of the cement hydration system. Granular PCM composites are preferred to microencapsulated PCMs because they are more economical, stable, and sustainable during the incorporation into the building materials.

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Fig. 1. Breakage of microencapsulated PCMs in cement composites (Li, unpublished work).

Over the past few decades, a series of granular PCM composites have been developed by incorporating PCMs into different types of porous materials. Among the wide range of PCMs, paraffin is believed to be the most promising PCM because it has high latent heat, low cost, and is stable, nontoxic, and non-corrosive (Rathod and Banerjee, 2013). In 1993, U.S. Patent titled “Dry powder mixes comprising phase change materials” awarded to Salyer (1993) disclosed a production method of a free flowing, powder-like mix of nanosilica particles and PCMs. The silica particles have a critical size of approximately 5–25 nm, and the amount of PCM added to the silica must be 75% or less. Zhang et al. (2005) developed a vacuum impregnation method to make granular PCM composites. In this investigation, expanded perlite, expanded clay and expanded fly ash granules were used. Sari et al. have developed a number of form-stable PCM composites by using a vacuum impregnation and blending method. In their investigations, materials such as clay (Sari, 2015), gypsum (Karaipekli and Sari, 2011), cement (Karaipekli and Sari, 2011), and diatomite (Sari and Karaipekli, 2012) were used to produce form-stable, granular PCM composites. Using a vacuum impregnation method, granular PCM composites have been formed from expanded perlite and paraffin with the melting point of 40 °C (Li and Li, 2007). Form-stable expanded perlite/paraffin composites have also been developed by a direct impregnation method (Lu et al., 2014; Sun et al., 2013). Porous carbon materials including expanded graphite, active carbon and ordered mesoporous carbon were used to developed form-stable PCM composites by Wang et al. (2012).

It should be noted that most granular PCM composites studies mainly focus on fabrications of the composites. There has been very few studies concerning the compatibility or leaking stability of granular PCM composites, especially when they are incorporated into concrete or other cementitious materials. The leaking stability was normally examined by conducting an exudation test (Ma et al., 2013), which determines the leakage qualitatively by observing PCM composites placed on filter paper under high temperatures. The method cannot reflect true situations when the PCM composites are introduced into cementitious materials, where the composites have to contact with water and high pH environment.

So, PCM leakage could still be a serious issue since granular PCM composites are not actually completely encapsulated. In recent work of Li et al. (2014), PCM leakage of form-stable PCM composites was observed when granular diatomite/paraffin composites were incorporated into cement paste. PX PCM powder from Rubitherm® is one of the commercially available, powder-like PCM composite in the market. However, significant leakage of paraffin was found when the authors (Li et al., 2014) attempted to mix the PX powder into a concrete mixture. In these two studies,

nanosilica particles were used as a surface modification for preventing the leakage. However, deposition of discrete nanosilica particles on surface of granular PCM composites is not completely reliable since it only relies on high surface energy of nano powders. More recently, Ramakrishnan et al. (2015) reported that no PCM leakage was observed if using a hydrophobic coated expanded perlite. However, the PCM composite was still not actually encapsulated since no protection was applied on the outside of PCM composites. Therefore, in terms of reliability, it would be better if a surface modification method can form a continuous layer onto surface of granular PCM composites.

In view of above discussions, there is still a need for in-depth study of the surface modification and leaking stability of granular PCM composites in order to successfully and reliably incorporate them into concrete. Also thermal performance comparisons between granular PCM composites and microencapsulated PCMs is of great interest from practical point of view.

This study is organized as follows. First, granular PCM composites were developed by blending two particle-size grades of expanded perlite particles and paraffin directly. Because of its high porosity and thermal resistance, expanded perlite is an attractive material that can absorb large amount of PCMs into its pores. However, it has large pore diameter (Zhang et al., 2005). One intent of this study is to examine leaking stability of expanded perlite/paraffin composites since perlite has relatively larger pore diameter which makes the penetration height lower during capillary actions. Then, the PCM composites were examined by microstructural observations and diffusion-oozing circle test (Ma et al., 2013; Li et al., 2014) in order to investigate the absorption mechanism and thermal stability, respectively. The PCM composites were also incorporated into cementitious mixture to investigate their leaking stability. It was demonstrated that without any prevention, the PCM composites leak significantly in cementitious mixture.

To address the leaking problem, the PCM composites were treated by a new surface modification method which used hydrophobic silane to modify the surface of PCM composites. It is believed that a continuous layer could be formed by using this new method. The leaking stability of the surface-modified PCM composites in the cementitious mixture were then investigated by mixing the composites with cement and water. The new surface modification method was also compared to nanosilica deposition method (Li et al., 2014) in term of its influence on compressive strength of cementitious composites. At last, another intent of this study was fulfilled by comparing thermal performances of the expanded perlite/paraffin composites with that of microencapsulated PCMs. The results demonstrated that expanded perlite/paraffin composites performed better than microencapsulated PCMs under certain conditions.

2. Materials

2.1. Expanded perlite

Expanded perlite with two grades of particle size, shown in Fig. 2, was provided by Australian Perlite Pty Ltd (New South Wales, Australia). In the following analysis, the expanded perlite particles are denoted as EP1 and EP2 according to particle size. EP2 with the smaller particle size is produced by milling larger expanded perlite particles of EP1. The chemical composition of the expanded perlite (EP1 and EP2) as determined by X-ray fluorescence is shown in Table 1. Fig. 1 shows that angle of repose of EP1 is smaller than that of EP2, indicating that EP2 is more cohesive than EP1, which is more free-flowing. The bulk densities of EP1 and EP2 are 200 kg/m³ and 140 kg/m³, respectively.

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