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Preparation and characterization of expanded perlite/paraffin composite as form-stable phase change material

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Abstract

In this study, a form-stable expanded perlite/paraffin (EP/PA) composite was prepared by absorbing paraffin into porous networks of expanded perlite. The form-stable composite was characterized by using Differential scanning calorimetry (DSC), Thermogravimetric analysis (TGA), Fourier transform infrared spectroscopy (FT-IR), Scanning electron microscope (SEM) techniques and leakage test. The melting temperature and latent heat of the form-stable EP/PA composite containing 60 wt.% paraffin were determined as 27.56 °C and 80.9 J/g, which showed good thermal energy storage property, thermal stability and thermal reliability. In addition, the FT-IR results revealed that there was no chemical interaction between the expanded perlite and the paraffin. By means of the direct impregnation method, the paraffin was distributed uniformly in the EP/PA composite without liquid leakage. All the results suggested that the form-stable EP/PA composite has great potential in building applications for thermal energy storage.

Keywords: Expanded perlite; Paraffin; Phase change materials; Thermal properties

1. Introduction

Phase change materials (PCMs) for latent heat thermal energy storage (LHTES) in buildings has been widely studied since the 1940s due to higher heat storage and constant temperature during endothermic and exothermic processes (Zhang et al., 2004; Nomura et al., 2009; Li et al., 2011; Karaman et al., 2011). Various inorganic and organic materials, and their mixtures have been studied as PCMs for LHTES systems (Sari and Bicer, 2012; Zhang et al., 2012; Xu and Li, 2013; Li et al., 2013). Among these PCMs, paraffin has been considered to have a potential as a PCM because of its high latent heat, chemical stability and non-toxicity (Feldman et al., 1995). However, the leakage problem of paraffin during the phase change process significantly has limited its application (Zhang et al., 2012). To overcome this problem, a new type of PCMs composite is come into being, which is prepared by absorbing PCMs into polymers or porous materials, such as expanded perlite, gypsum and diatomite, to fabricate form-stable PCMs composite by different impregnation methods. Xu and Li (2013) have demonstrated that paraffin can be dispersed uniformly into diatomite to form stable composite PCMs by direct impregnation method. Liu et al. (2014) also prepared a novel PCM of lauric–myristic–stearic acid/expanded graphite composite (LA–MA–SA/EG) by direct impregnation method, and the results indicated that LA–MA–SA uniformly distributed in the EG pore structure. Zhang et al. (2007) developed a vacuum impregnation method to make three kinds of porous materials (expanded perlite, expanded clay and expanded fly ash)

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and two kinds of PCMs (paraffin and capric acid) as form-stable phase change composites. Luz et al. (2010) fabricated PCMs composites by a suspension copolymerisation of styrene and methyl methacrylate by microencapsulation method. Among these methods, the direct incorporation method is the simplest and cheapest method because no extra equipment is further needed. It is the most convenient method to fabricate PCMs composites, especially for industrial production, in which liquid PCMs are directly added to porous materials. (Tyagi and Buddhi, 2007; Futane et al., 2011; Kuznik et al., 2011; Osterman et al., 2012; Zhou et al., 2012).The leakage problem could be resolved to some extent by the capillary and surface tension forces of the porous materials (Fang et al., 2010; Ehid et al., 2012; Jiao et al., 2012; Wang et al., 2014).

In this study, a series of EP/PA composites with different paraffin mass fractions (20%, 40%, 60% and 80%, named as P1–P4) were firstly prepared by absorbing paraffin into porous networks of expanded perlite. The thermal performances of the form-stable EP/PA composite were then characterized by DSC, TGA and leakage tests. The micro-morphology of the expanded perlite and the composite was observed by using SEM instrument, and the chemical compatibility of the composite was studied by FT-IR analysis. Finally, the thermal reliability of the form-stable EP/PA composite with a view of finding the optimum impregnation ratio was investigated by thermal cycling test.

2. Materials and experimental

2.1. Materials

In this study, paraffin was supplied by the Ke Qitai Chemical Company, Guangzhou, China. Expanded perlite was obtained from the Zhongde Perlite Factory, Liaoning, China.

2.2. Preparation of the form-stable EP/PA composite

In this study, the EP/PA composite was fabricated by using direct impregnation method because there is little latent heat difference between direct impregnation methods and vacuum impregnation (Feldman et al., 1991; Nomura et al., 2009; Xu and Li, 2013). Four mix proportions of EP/PA composites with different paraffin mass fractions (20%, 40%, 60% and 80%, named as P1–P4) were prepared in the following steps. Firstly, paraffin was melted at a temperature of 90 °C ± 5 °C for 1 h in an oven, and then immediately mixed with expanded perlite at ambient temperature and put back in the oven. The mixture was mixed in every hour until the paraffin was uniformly dispersed in the expanded perlite. Finally, the form-stable EP/PA composite was formed after cooling down at room temperature.

After fabrication, the leakage test was conducted to investigate exudation stability of the EP/PA composite (Ma et al., 2013; Li et al., 2014). The same amount of the prepared EP/PA composite, 15 g, was firstly put on the center of filter paper with the area of 50 mm × 50 mm (Fig. 1a and b). Then, the composite was transferred in a 90 °C oven for 2 h, and then observe the paraffin trace on the filter paper. The experimental results show that there was no paraffin trace observed on the surface of the filter paper for the composite P1, P2 and P3; however, very small amount of leakage was found within the circle area for composite P4. Fig. 1 shows the leakage phenomenon of the composites P3 and P4 before and after leakage test. It is clear to see that the filter paper is slightly darker for the composite P4 (Fig. 1d), which is caused by the paraffin leakage; however, there is no leakage phenomenon on the filter paper for the composite P3 (Fig. 1c). Therefore, the optimum and maximum mass fraction of paraffin contained in the composite without leakage is 60%.

2.3. Characterization of the form-stable EP/PA composite

The phase change temperature and latent heat of the form-stable EP/PA composite were measured using a DSC instrument (TAQ 1000) under a nitrogen atmosphere at 5 °C/min. Thermal stability of the composite was investigated by the TGA method (Perkin Elmer) at 10 °C/min under a nitrogen environment. Chemical compatibility between paraffin and expanded perlite was measured by using FT-IR analysis (Bio-Rad FTS 6000). Thermal cycling testing was carried out in a metal bath (CHB-T2-E, BIOER) with heating and cooling between 10 °C and 60 °C at 10 °C/min. Microstructures of the prepared form-stable composite were observed by using SEM (JEOL, JEM-6390).

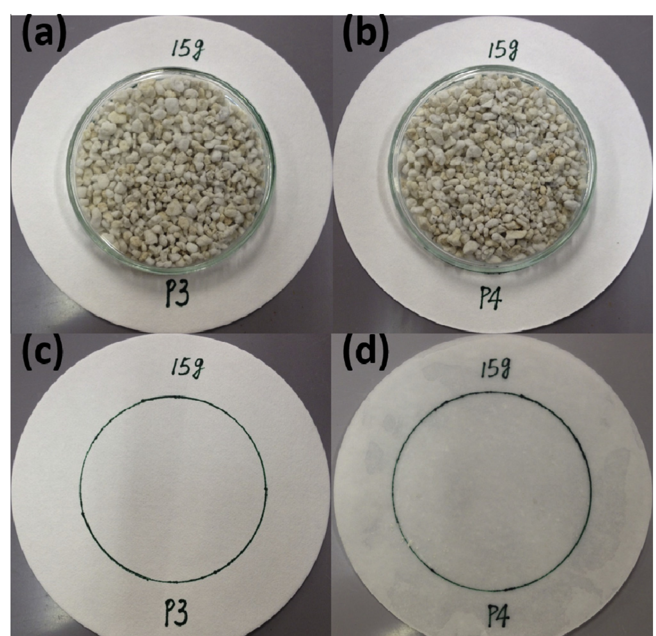

Fig. 1. Leakage test. (a) and (c): Filter paper of the composite P3 before and after leakage test; (b) and (d): Filter paper of the composite P4 before and after leakage test.