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Thermal conductivity enhancement of polyethylene glycol/expanded perlite with carbon layer for heat storage application

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ABSTRACT

In this study, polyethylene glycol/expanded perlite composite with carbon layer phase-change materials were prepared. EP was impregnated with a sucrose solution, followed by carbonation in situ by the carbon-bed method, for obtaining EPC composite, thus providing an important method for enhancing the thermal conductivity of composite PCMs. Scanning electron microscopy images showed that the EPC composite with a highly porous structure composed of rough micro-pores could act as a good supporting material for absorbing molten PEG. The results obtained from differential scanning calorimeter analysis indicated that the values for the latent heat and temperature of PEPC composite during melting were 134.93 J/g and 55.19 °C, respectively, while, these values were 129.27 J/g and 46.71 °C during freezing, respectively. The thermal conductivity of PEPC composite was 0.479 W/(mK), which was 2.975 times that of PEP composite. The results obtained from Fourier transform infrared spectroscopy and thermo-gravimetric analysis showed that PEPC composite exhibited good chemical stability and thermal stability, respectively. Furthermore, thermal cycling tests indicated that PEPC composite exhibited good thermal reliability after 200 melting/freezing cycles. In conclusion, PEPC composite with excellent thermal properties, ideal thermal conductivity, good thermal reliability and chemical stability could act as the promising building filler materials for the sustainable development of energy-efficient buildings.

1. Introduction

Phase-change materials have many advantages such as exhibit renewability, high energy storage density, and constant temperature during phase change [1–4]; therefore, they have attracted much attention and have been applied in building energy conservation, thermal insulation, smart textiles, heat pumps, waste heat recovery, air-conditioning systems, and solar heating system, etc. [1,4–7]. PCMs satisfy the demand in terms of time and space, solve severe environmental and energy shortage, and thus achieve significant economic benefit, indicating great potential for the sustainable development of energy-efficient buildings [6,8,9].

PCMs can be mainly divided into organic PCMs such as lauric acids, PEG, and their eutectic systems, and inorganic PCMs such as salt hydrates and their mixtures. [10]. Compared to inorganic PCMs, organic PCMs have been extensively studied owing to low cost, wide melting temperatures, chemical and thermal stabilities, and moderate phase change enthalpies [4,11]. Among various organic PCMs, PEG is an ideal choice because of its suitable phase change temperature and high latent heat storage capacity; they can be simply tuned by changing the molecular weight of PEG [12,13]. However, the main drawbacks of PEG, such as phase instability in the melting state, and low thermal conductivity, limit its further applications [11,13]. To overcome these problems, a new type of composite PCMs has been developed; it is prepared by absorbing PEG into porous materials, such as expanded vermiculite [14–16], EP [9,17–20], diatomite [21,22], and halloysite nanotube [23,24], to fabricate form-stable composite PCMs by vacuum

Abbreviations: PEG, polyethylene glycol; EP, expanded perlite; PCMs, phase-change materials; EPC, expanded perlite/carbon; PEP, polyethylene glycol/expanded perlite; PEPC, polyethylene glycol/expanded perlite/carbon; XRF, X-ray fluorescence spectroscopy; SEM, scanning electron microscopy; FT-IR, Fourier transform infrared spectroscopy; DSC, differential scanning calorimeter; TGA, thermo-gravimetric analysis.

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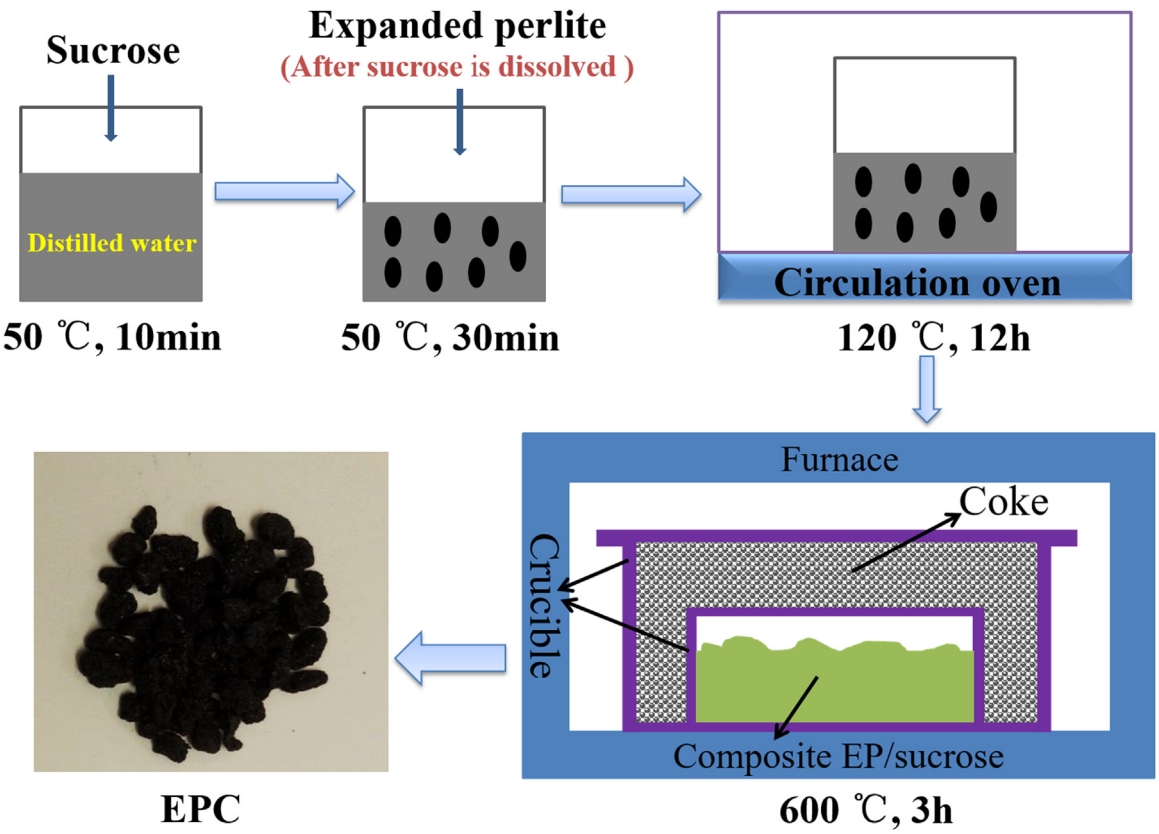

Fig. 1. Schematic for the preparation of EPC composite.

impregnation [9,15,16]. Among these porous materials, EP has been widely used because of its lightweight, abundance and low cost [9,18,20]. PEG does not easily leak from EP with a highly porous structure composed of rough micro-pores during solid-liquid phase transition, because of the combined action of capillary force, and physical adsorption [15,18].

To solve the low thermal conductivity of PEG, many methods have been developed. Particularly, the addition of a material with a high thermal conductivity into porous materials was the most promising method [15,17,23]. Several studies have been conducted to improve the thermal conductivity of composite PCMs. Carbon-based nanostructures (nanofibers, nanoplatelets and graphene flakes), metallic (Ag, Al, and Cu), metal oxides (Al_2O_3, CuO, MgO, and TiO_2), and metallic (Ag, Al, and Cu) nanowires have been investigated as thermal conductivity promoters [15–19,25–29]. Deng [16] prepared expanded vermiculite-Ag nanowire/PEG composite PCMs, the thermal conductivity of the composite PCMs reached 0.68 W m^{-1} K^{-1}, 11.3 times higher than that of pure PEG. Sun [19] prepared EP/paraffin/graphite composite PCMs with a thermal conductivity of 0.459 W m^{-1} K^{-1}.

In this study, the form-stable PEPC composite was obtained with enhanced thermal properties. The resulting PEPC composite is a potential candidate for applications in the cooling/heating of buildings, such as PCMs walls and wallboards, Trombe walls, shutters, tiles, building blocks, and air-based heating systems [1,30–35], whose temperature is often as high as 40–60 °C.

2. Experimental

2.1. Materials

EP was purchased from Lingshou county, Hebei province, and the particle size of EP was about 2–3 mm. PEG with an average molecular weight of 6000, sucrose (AR), distilled water, and ethanol absolute were analytically pure and supplied by Sinopharm Chemical Reagent Co., Ltd.

2.2. Characterization

XRF (ARL ADVANT XP+) was employed to test the chemical composition of EP. The morphology of EP, EPC and PEPC was observed by SEM (Hitachi S4800). FT-IR (SHIMADZU FTIR 8400) were used to characterize the chemical compatibilities in the composite PCMs. The thermal property of composite PCMs were determined by DSC (Q2000) calibrated with an indium standard and using a temperature program of 0–100–0 °C at 10 °C/min heating/cooling rate. The variation in quality with temperature was determined by TGA (Q50) in the range from room temperature to 600 °C with a scanning rate of 10 °C/min under nitrogen atmosphere. The transient plane source method was employed to measure thermal conductivity of samples at room temperature by using the laser thermal conductivity analyzer (LFA-427).

2.3. Preparation of EPC

Fig. 1 shows the schematic for the preparation of EPC composite. As shown in Fig. 1, 5 g sucrose was dissolved in 40 mL of distilled water, affording a transparent sucrose solution after stirring for 10 min at 50 °C in a water bath. Second, 2 g EP, which was dried at 120 °C for 4 h before use, was added into the sucrose solution prepared in the first step, and stirring was continued for 30 min at 50 °C in a water bath, followed by drying for 12 h at 120 °C for releasing redundant distilled water. The EP/sucrose composites was carbonated in situ by the carbon-bed method in a furnace at 600 °C for 3 h. After cooling to room temperature, the EPC composite was carried out.