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Structures and thermal properties of fatty acid/expanded perlite composites as form-stable phase change materials

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ABSTRACT

Capric acid/expanded perlite (CA/EP) and capric-stearic acid/expanded perlite (CA-SA/EP) composites were prepared. The composite phase change materials (PCMs) were characterized by scanning electron microscopy (SEM) and Fourier transformation infrared spectroscopy (FT-IR). The thermal properties and thermal reliability of the composites were determined by differential scanning calorimetry (DSC), melting-freezing test, polarization microscope equipped with hot stage. Results show that the form-stable composite PCM has an optimal mass ratio of 50% fatty acid. The fatty acid is impregnated into EP by physical attraction. The measured latent heat values of CA/EP composites are 87.3 J/g for the melting process and 89.0 J/g for the freezing process. The corresponding values of the CA-SA/EP are 82.1 J/g and 82.6 J/g, respectively. The DSC, FTIR, and thermal cycling test results show that the thermal reliability of the composite PCMs imperceptibly changes. All of the conclusions indicate that the composites have good thermal and chemical stability.

1. Introduction

Amongst various heat storage techniques, latent heat storage has drawn considerable attention, because it presents advantages such as high energy storage density and narrow operating temperature range [1,2]. The technique is extensively applied in fields that include solar energy storing, smart air-conditioning buildings and temperature-regulating textiles [3–5]. PCMs can be classified into four groups according to phase change states: solid–solid phase change materials, solid–liquid PCMs, solid–gas PCMs and liquid–gas PCMs [6,7]. Of these types, solid–solid PCMs have undergone rapid development.

As one of the most promising solid–liquid PCMs, fatty acids exhibit many desirable characteristics, such as high energy storage density, mild corrosive, non-toxicity, non-flammability, no or less subcooling and good thermal reliability [8,9]. Nevertheless, its widespread application is restricted by major drawbacks, including leakage and low thermal conductivity. To overcome these problems, researchers have introduced various methods, for instance, encapsulating PCMs into polymer pellets, grafting PCMs with polymers or impregnating PCMs into porous materials. Numerous form-stable composites with high latent heat energy capacity have been successfully prepared by impregnation given that this method is cost-efficiency and easy to handle [10–12].

Recently, scientists have exerted significant efforts in improving the performance of fatty acids as form-stable PCMs. Two methods have been proposed: (1) encapsulating fatty acids in polymer pellets, and (2) simply immersing fatty acids into porous substances [12,13]. Obviously, the second method is simple and cheaper for fabrication. Expanded perlite (EP) is a promising porous substance, which is a glassy amorphous volcanic rock with low density, relatively low cost and good thermal reliability. Its high porosity and large specific surface area makes it an excellent matrix in which to incorporate a substantial amount of fatty acids. However, EP is not widely used as a carrier in latent heat storage applications, therefore, the research on fatty acid/EP as a form-stable phase change material is very meaningful and prospective.

In this study, capric acid/expanded perlite (CA/EP) and capric-stearic acid/expanded perlite (CA-SA/EP) composite PCMs were prepared. Their thermal properties and reliability were analyzed by differential scanning calorimetry (DSC), polarization microscope (POM), accelerated thermal cycle test, and melting-freezing performance test. Their morphologies and structures were investigated by scanning electronic microscope (SEM) and Fourier transformation infrared spectroscope (FTIR). Results show that the

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Table 1
Chemical constituents of EP.

Constituent	SiO_2	Al_2O_3	MgO	Fe_2O_3	K_2O	CaO	Na_2O	Other
Ratio %	74.6	13.6	0.3	0.9	6.2	2.8	1.1	0.5

composite with a mass ratio of 50% performs well as a form-stable phase change material.

2. Experimental

2.1. Materials

Capric acid (CA, CP) and stearic acid (SA, AR) were obtained from Shanghai Linfeng Chemical Reagent Corporation, and used without further purification. Expanded perlite (EP), its porosity up to 90%, was obtained from Lingshou Bochuan Mineral Processing Plant. The mean volume diameter of EP is 29.1 μm measured by a Sepctrex laser particle counter (MS-2000, Malvern) and its specific surface area is 4.12 m^2/g determined by an automatic specific surface area analyzer (ASTP 2020-M, Micromeritics). The composition of EP was determined by X-ray fluorescence (XRF-1800, Shimadzu) (Table 1).

2.2. Preparation of CA/EP and CA-SA/EP composites

Firstly, CA-SA eutectic mixture was prepared with a mass ratio of 90%. CA and SA were weighed within ±1 mg, melted, and then stirred for 2 h in a water bath at 80 °C. After that the mixture cooled to room temperature.

Secondly, EP was washed with ethanol and then dried at 105 °C for 24 h.

Thirdly, the CA-SA eutectic mixture, expanded perlite and absolute ethyl alcohol were placed in a round bottom flask, and stirred for 2 h at 60 °C. The mixture was then dried in an oven at approximately 35 °C. CA-SA was impregnated with the EP of different mass fractions, 50, 60, 70 and 80 wt%. The proportion of composite PCMs powders retained 70% without leakage at room temperature; this composition was therefore defined as reflective of form stability. In the same method, CA/EP composites were obtained with mass ratios of 50%, 60% and 70%.

2.3. Characteristics of form-stable composite PCMs

Phase change properties [13], such as melting temperature, freezing temperature and latent heat, were determined by differential scanning calorimetry (DSC-200PC, Netzsch) at a heating/cooling rate of 5 °C/min from −20 °C to 80 °C in a purified nitrogen atmosphere. To verify the compatibility between the fatty acids and EP, infrared spectra were recorded by FTIR (Magna-IR 550, Nicolet) with KBr pellets in the range of 4000–400 cm^{-1}. CA/EP, CA-SA/EP and EP were imaged and analyzed by SEM (JSM-6360LV, JEOL).

2.4. Thermal performance and thermal stability test for form-stable PCMs

To confirm the thermal performance of the composite PCMs in practical application, the melting and freezing processes were investigated [14]. Glass jars were separately with 5 g of fatty acid, EP and fatty acid/EP. A thermocouple was placed in the center of the jar. The water bath for the melting process was set at a constant temperature of 50 °C. After this process, the samples were immediately placed in an ice bath for crystallization. Transient temperature values were recorded in a PC via a data logger at time intervals of 15 s.

The thermal reliability of the composite PCMs was determined by accelerated thermal cycle test and POM test to investigate the effects of cycle times and temperatures on composite phase changes. The morphologies of the composite PCMs were observed

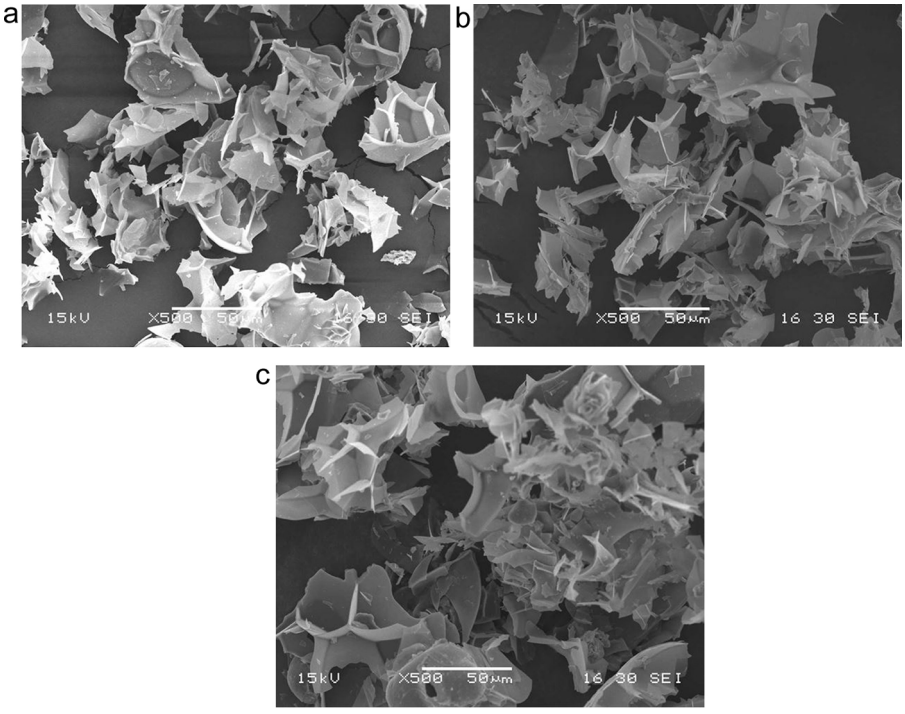

Fig. 1. SEM micrographs of (a) EP, (b) CA/EP 50 wt%, and (c) CA-SA/EP 50 wt%.