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Lauric–palmitic–stearic acid/expanded perlite composite as form-stable phase change material: Preparation and thermal properties

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ABSTRACT

Based on theoretical calculation, lauric–palmitic–stearic acid ternary eutectic mixture (LA–PA–SA) with a suitable phase change temperature was prepared firstly. Then LA–PA–SA was incorporated with expanded perlite (EP) by vacuum impregnation method. The maximum mass ratio of LA–PA–SA retained in EP was found as 55 wt%. The microstructure and chemical characterization of LA–PA–SA/EP form-stable phase change material (PCM) was characterized by scanning electron microscope and Fourier transformation infrared spectroscope, and the results showed that LA–PA–SA was uniformly dispersed into the pores of EP by physical interaction. The melting and freezing temperatures and latent heats of LA–PA–SA/EP were measured by a differential scanning calorimeter as 31.8 °C, 30.3 °C and 81.5 J/g, 81.3 J/g respectively. The result of thermogravimetry analysis revealed that the form-stable PCM had a good thermal stability. Thermal cycling test showed that there was no significant change of the thermal property of LA–PA–SA/EP after 1000 thermal cycling. Moreover, the thermal conductivity of LA–PA–SA/EP was increased by 95% by adding 2 wt% expanded graphite, and the thermal energy storage/release rates were also increased. All results indicated that the prepared LA–PA–SA/EP form-stable PCM can be considered as a potential material for building energy conservation due to satisfactory thermal properties, high thermal conductivity, good thermal reliability and stability.

1. Introduction

Latent heat thermal energy storage (LHTES) has attracted much attention in many engineering application by using phase change material (PCM) to store/release thermal energy during its melting/freezing process. Featuring a high energy storage density and small temperature variation during storage/retrieval processes [1,2], PCMs have been widely used in waste heat recovery, solar energy storage and building energy conservation, etc. [3–6]. In order to decrease the indoor temperature fluctuations, the design of building envelopes focuses on thermal insulation which is always realized by light porous building materials. However, the low thermal capacity of the building material is a problem. In recent years, the use of PCMs to enhance the thermal capacity of the building material is becoming an effective way in the application of building energy conservation [7,8].

Among the investigated PCMs, fatty acids and their eutectic mixtures are considered as desirable candidates for application in LHTES systems due to the advantages of good thermal and chemical stability, no or little supercooling, high heat capacity and wide phase change temperature range [9,10]. Sarı [11] studied the thermal reliability of stearic acid (SA), palmitic acid (PA), myristic acid (MA) and lauric acid (LA) as latent heat energy storage materials with respect to various numbers of thermal cycling. The experimental results showed that the investigated fatty acids had a good thermal reliability in view of melting temperature and latent heat with respect to thermal cycling for thermal energy storage applications in the long term. Lv et al. [12] prepared a kind of PCM wallboard by incorporating CA–LA mixture as PCM into gypsum, and a PCM wallboard room was constructed by attaching PCM wallboards to the surface of an ordinary wall. Compared with an ordinary room, the PCM wallboard room could greatly reduce the energy cost of HVAC systems and transfer electric power peak load to valley. Yang et al. [13] prepared a MA–PA–SA ternary eutectic mixture by the method of combining theoretical calculation and experimental procedure. In order to enhance the thermal conductivity and prevent the leakage of the PCM, expanded graphite (EG)

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with high thermal conductivity and porous structure was added in MA–PA–SA to prepare composite PCM. The optimum mass ratio of the composite PCM was determined. All investigated results indicated the prepared MA–PA–SA/EG composite PCM had good thermal properties, high thermal conductivity, and good thermal reliability for thermal energy storage in solar heating, waste heating recovery systems and other potential applications.

Expanded perlite (EP) is a kind of building material with porous structures, lightweight, odorless, nontoxic, soundproof and inexpensive, and therefore it becomes an environment-friendly candidate building material for incorporating PCM for energy storage in buildings [14,15]. Li et al. [16] prepared a paraffin/EP shape-stabilized PCM by absorbing paraffin into the pores of EP by the vacuum adsorption method. Gypsum-based heat storage and preservation material was prepared by mixing the prepared paraffin/EP shape-stabilized PCM with gypsum. And the research results showed that the prepared gypsum-based heat storage and preservation material can be used to make heat storage boards in buildings. Karaipekli et al. [17] prepared a novel form-stable PCM through the incorporation of eutectic mixture of CA–MA with EP for LHTES in buildings.

This paper aims to prepare a novel form-stable PCM used in some summer burning hot area. The ambient temperature of the hot area in summer is always higher than the human comfort temperature even in the night. In order to ensure the thermal energy stored in day can be released, the phase change temperature of PCMs should be higher than the environment temperature in night. So, lauric–palmitic–stearic acid ternary eutectic mixture (LA–PA–SA) as a novel PCM with the phase change temperature of about 30 °C was prepared firstly. And the form-stable composite PCM of LA–PA–SA/EP was prepared by using the vacuum impregnation method. The microstructure and thermophysical properties of the LA–PA–SA/EP were characterized by scanning electron microscope (SEM), Fourier transformation infrared spectroscope (FT-IR), differential scanning calorimeter (DSC) and thermogravimetry analyzer (TG). Thermal reliability of LA–PA–SA/EP was tested by accelerate thermal cycling and DSC.

2. Experimental

2.1. Materials

Lauric acid (LA, 98% pure), palmitic acid (PA, AR) and stearic acid (SA, 98% pure) were purchased from Aladdin Industrial Corporation, Shanghai, China. Expanded perlite (EP) was used as the supporting material to prepare form-stable PCM. The EP was sieved by 100–200 meshes sieve with the specific surface area of 1.294 m^2/g. Expansible graphite was sieved by an 80 meshes sieve with the carbon content of 99%. Expanded graphite (EG) was obtained by microwave treatment of expansible graphite using a microwave oven at a microwave irradiation power 700 W for 30 s, and it was used as the additive to improve the thermal conductivity.

2.2. Preparation of form-stable PCM

LA–PA–SA was prepared according to the method provided by Reference [18]. The mass ratios of LA, PA and SA in the eutectic mixture were determined as 62.2 wt%, 24.6 wt% and 13.2 wt% respectively.

The LA–PA–SA/EP composite PCMs were prepared by the vacuum impregnation method using the experiment setup shown in Fig. 1. EP was placed in the three-necked flask, and LA–PA–SA was dissolved in 50 ml absolute ethyl alcohol. Then the solution was dropped slowly into the three-necked flask under the vacuum environment. The absolute ethyl alcohol was evaporated after vacuum impregnation for 1 h. When the absolute ethyl alcohol was evaporated, the LA–PA–SA/EP composite PCMs were dried for 3 h at 40 °C, and then the LA–PA–SA/EP composite PCMs were obtained. In order to determine the maximum absorption ratio in which no melted LA–PA–SA leakage was observed, a series of LA–PA–SA/EP composite PCMs with mass ratios of 40 wt%, 45 wt%, 50 wt%, 55 wt%, 60 wt% and 65 wt% (LA–PA–SA) were prepared. It was found that the maximum mass fraction of LA–PA–SA was 55 wt%. In order to determine the leakage of the LA–PA–SA/EP with the maximum mass ratio, the samples were heated at 50 °C for 2 h. Fig. 2(a) shows the

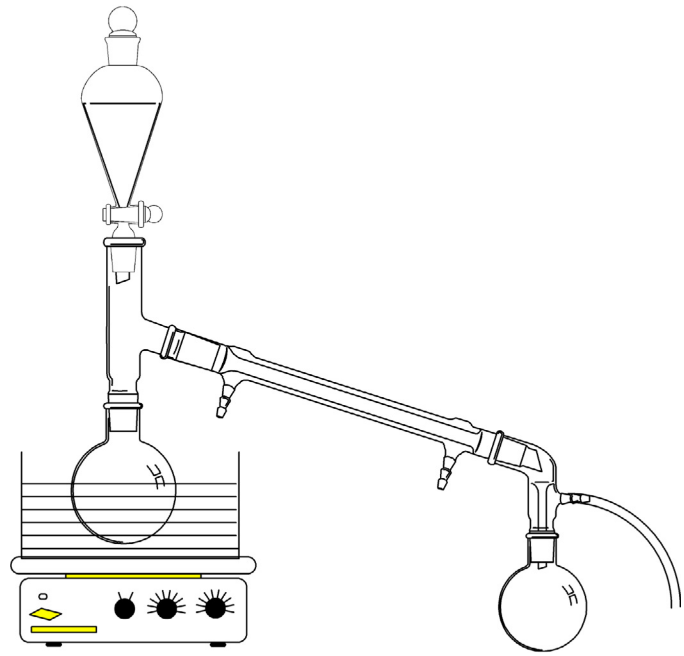

Fig. 1. Experiment setup for preparation of LA–PA–SA/EP composite PCM.

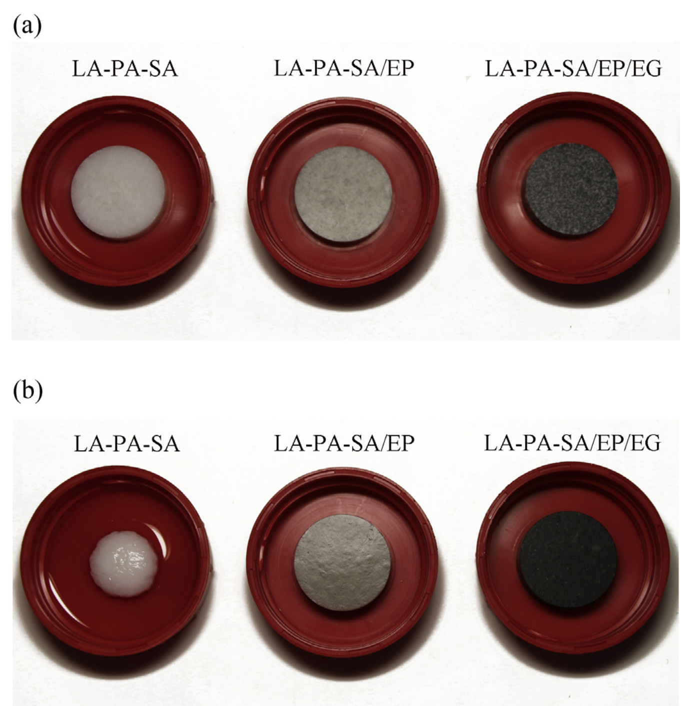

Fig. 2. Photographs of LA–PA–SA, LA–PA–SA/EP and LA–PA–SA/EP/EG before (a) and after (b) heat treatment.