Applied Clay Science 146 (2017) 14–22

Contents lists available at ScienceDirect

Applied Clay Science

journal homepage: www.elsevier.com/locate/clay

Research paper

Lauric acid/modified sepiolite composite as a form-stable phase change material for thermal energy storage

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ARTICLE INFO

Keywords:
Sepiolite
Composite phase change materials
Lauric acid
Modification
Thermal energy storage

ABSTRACT

A series of novel composite phase change materials (PCMs) were prepared by impregnating lauric acid (LA) into the chemically modified sepiolite (SEP) via a vacuum impregnation method. Modification strategy was developed to improve the adsorption capacity of SEP, and the effects of thermal and chemical modification on the physical and chemical properties of SEP were investigated. The loading of LA inside the acid treated SEP could reach up to 60 wt%, which was 50% higher than that of pristine SEP. The corresponding latent heats of the composite PCMs exhibited 125.2 J/g at the melting temperatures of 42.5 °C and 113.9 J/g at the freezing temperatures of 41.3 °C, respectively. The increased latent heat could be attributed to the better microstructure of the modified SEP. The thermal conductivity (0.59 W/(m·k)) of the composite PCMs was higher than that of LA. The composite PCMs presented chemical and thermal reliability after 200 thermal cycling tests. The form-stable composite PCMs could be the promising candidate material for thermal energy storage.

1. Introduction

Developments in renewable and sustainable energy have been of prime significance after the oil crisis in the 1970s. Thermal energy storage (TES) has proved to be a low-cost and promising technique for energy saving efficiency improvement (Ding et al., 2016a,b; Li and Wu, 2012; Niu et al., 2016a,b), which also in turn mitigates the energy consumption. For the latent heat of TES, phase change material (PCM) has become an attractive option due to its repeatable utilization property, constant heat source temperature, high heat recovery, and high energy storage density (Rathod and Banerjee, 2013; Shu et al., 2017; Yan et al., 2017). PCM also has been widely used in many fields such as insulation clothing, building energy conservation, air condition systems, solar energy storage, and waste heat recovery (Hou et al., 2017; Kuznik et al., 2011; Peng et al., 2016a,b).

In recent years, many PCMs have been widely researched for application in energy conservation buildings (Jin et al., 2017; Peng et al., 2017a, 2017b; Sharma et al., 2013). Building materials including PCMs allow the TES, thus achieving spatial and temporal transfer of energy (Pielichowska and Pielichowski, 2014). During the development of building materials including PCMs, the leakage of PCMs and the thermal transfer between the ambient environment and PCMs are the main difficulties (Chen et al., 2015; He et al., 2016; Ouyang et al., 2016). So the form-stable PCMs have been greatly investigated in these years. The form-stable PCM could be prepared via impregnating PCM into the supports like bentonite, expanded perlite, diatomite, vermiculite, and clay mineral (Fu et al., 2017a,b; Karaipekli and Sarı, 2016; Liu and Yang, 2015; Lv et al., 2017; Memon et al., 2013; Sarı et al., 2014; Song et al., 2014a).

Despite the innovations made in the previous investigations, most of researchers have continued to use paraffin as PCM in energy storage systems (Shen et al., 2016; Tang et al., 2015). Other PCMs suitable for application in low-temperature heat storage systems (40–75 °C) require further research before practical use. Among the phase transformation matrix for PCMs, lauric acid (LA) possesses a melting point in the desired operating temperature range of application in building field (melting/freezing at 41–45 °C), and exhibits little supercooling during the freezing process and large latent heat with respect to thermal cycling for thermal energy storage in the long term. Additionally, LA has reliable chemical stability with small volume changes during phase transition. So, LA has been considered as a desirable candidate for thermal energy storage systems (Liu and Yang, 2016; Liu et al., 2017; Wen et al., 2016). On the other hand, porous supports have been used in the building field in recent years. Sepiolite (SEP) is considered to be special mineral with its fibrous structure (Konuklu and Ersoy, 2016; Ma and Zhang, 2016; Yang et al., 2016). This unique crystal structure is

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http://dx.doi.org/10.1016/j.clay.2017.05.035
Received 14 April 2017; Received in revised form 21 May 2017; Accepted 24 May 2017
0169-1317/

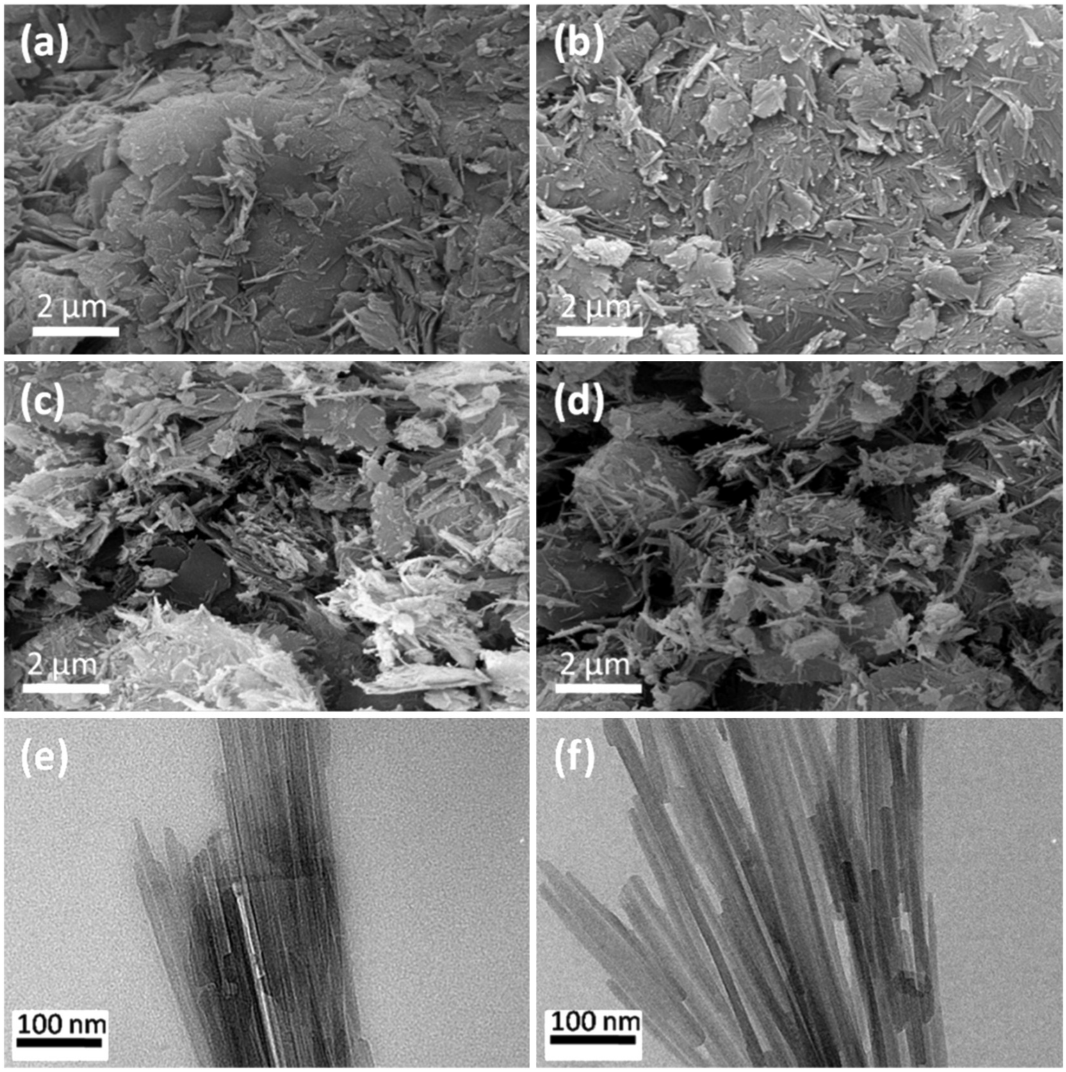

Fig. 1. SEM images of (a) SEP, (b) CSEP, (c) NSEP and (d) HSEP. TEM images of (e) SEP and (f) HSEP.

responsible for its important characteristic related to adsorption active centres, dehydration, porosite, and surface area. SEP has good physical properties like non-toxicity, porous structure and fire resistance. And it has great chemical compatibility with organic PCM (Li et al., 2016; Ying and Zhang, 2016). However, SEP has its shortcoming that the pores of natural clay mineral are commonly blocked by impurities. Hence, raw SEP needs to be modified before commercial utilization.

Recently, clay minerals could be functionalized upon proper modification, which increased the compatibility with matrix (Zhang et al., 2016a,b,c, 2017; Zhou et al., 2016). Currently, modified SEP supported PCMs for thermal energy storage have been little documented. In this paper, SEP was first treated by calcination, alkali leaching and hydrochloric acid treatment. Then, LA was absorbed in raw and modified SEP by the vacuum impregnation method. Finally, the characterization and properties of the composites were determined. The results indicated that the form-stable composite will be a potential candidate for thermal storage application.

2. Experimental

2.1. Materials

Lauric acid (LA, $C_{12}H_{24}O_2$) was analytically pure and supplied by Tianjin Kemiou Chemical Reagent Co., Ltd., China. Natural sepiolite (SEP) was collected from mineral deposit located in Hunan Province in China. Before the composite PCMs preparation, SEP was thermally treated at 400 °C for 2 h to obtain CSEP. SEP was immersed in sufficient amount of 10 wt% sodium solution at 30 °C for 2 h to obtain NSEP. SEP was acid-leached in 10 wt% HCl solution at 30 °C for 2 h to form HSEP.

2.2. Preparation of the form-stable composite PCMs

The composite PCMs were prepared by vacuum impregnation method. Firstly, LA was placed in a conical flask with HSEP, the conical flask was heated at 80 °C and the vacuum was evacuated to − 0.1 MPa for 40 min. Then, the vacuum pump and air entry was closed to force LA to penetrate into HSEP, with ultrasonic heating at 80 °C for 5 min. To remove excess LA by thermal filtration, the composite PCMs were maintained at 80 °C for 48 h as the mass did not decrease longer. After cooling, the mixture was ground to obtain the composite PCMs. LA with different mass ratio (30%, 40%, 50%, and 60%) is dispersed in HSEP, and the composites were denoted as HS-LA1, HS-LA2, HS-LA3 and HS-LA4, respectively.

2.3. Characterization

The SEM images of the samples were obtained using a JEOL JSM-6360LV SEM. The TEM images were collected with a JEOL JEM-2100F TEM. FTIR (Nicolet 5700) spectra of the samples were investigated in the range of 450–4000 cm^{-1}. The XRD (RigakuD/max 2550) experi-