



Fabrication and thermal characterization of kaolin-based composite phase change materials for latent heat storage in buildings



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ABSTRACT

Three kinds of kaolin-based composite phase change materials (Kb-CPCMs) including capric acid (CA), PEG600, and heptadecane (HD) as organic PCMs were fabricated using vacuum impregnation method for latent heat storage (LHS) application in buildings. The surface morphology, compatibility, maximum ratio for impregnated PCM, LHS properties, thermal endurance, thermal conductivity and its effect on the melting times of prepared Kb-CPCMs were investigated by using microscopy, spectroscopy, calorimetry and thermal methods. The seepage test indicated that CA, PEG600 and HD were impregnated maximally into the kaolin as 17.5, 21 and 16.5 wt%, respectively. The fabricated three composites, K/CA, K/PEG600, and K/HD, have a phase change temperature of 30.71, 5.16 and 22.08 °C and a latent heat of 27.23, 32.80 and 34.63 J/g, respectively. The thermal cycling test exposed that the thermal reliability of the Kb-CPCMs slightly changed after repeated 1000 heating-cooling cycling. The heat storage rates of the Kb-CPCMs were increased considerably by adding expanded graphite (EG) in mass fraction of 5%. All the prepared Kb-CPCMs have good thermal energy storage (TES) function for heating, ventilating and air conditioning (HVAC) in building envelopes because of their suitable LHS properties, high reusability performance and enhanced thermal conductivity.

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1. Introduction

The primary energy consumers in the world are building and industrial sectors and about one-third of total energy consumption is originated from these sectors [1,2]. Therefore, enhancing the energy efficiency of buildings diminishes the fossil sourced-energy consumption and the hazardous gas emissions. In this sense, thermal energy storage (TES) has an important function in the improvement of the energy efficiency of building envelopes and reduces the environmental damages caused by the fossil-based energy use. [3,4]. Amongst various TES techniques, latent heat storage (LHS) using phase change material (PCM) has drawn substantial interest since it makes possible to storage and release high energy at narrow servicing temperature range [5–7]. This method has been extensively used for heating, ventilating, and air conditioning (HVAC) purposes in buildings to achieve thermal comfort and acceptable indoor air quality by flattening the fluctuations at indoor temperature [8,9].

The organic solid–liquid PCMs have high latent heat of fusion and suitable phase change temperature for passive solar heating and cooling applications. They are generally non-corrosive,

non-toxic, chemically stable and do not show no or a little supercooling (except PCMs in PEG group) behavior [10–14]. However, the low thermal conductivity (0.15–0.20 W/mK) can cause disinhibitory effect on the rate of thermal energy storage and release during the heating and cooling periods of PCMs. To resolve this problem, some high conductive materials such as expanded graphite [15,16] and β -aluminum nitride [17] have been introduced into the composite PCMs. On the other hand, to get rid of the leakage problem encountered during the solid–liquid phase change processes of organic PCMs, many researchers have strived about the encapsulation of PCMs using the different methods such as confining into a polymeric network, grafting with polymeric materials and impregnating with porous building materials. Among these methods, the combination of porous materials with PCM is simple, cost-effective and thus relatively proficient way to fabricate form-stable lightweight constructive materials with high LHS capacity [18–20]. In addition to gypsum [21–25] and cement [26–31], natural clays as porous building materials, such as montmorillonite [32–35], perlite [36–39], attapulgite [40,41], vermiculite [42–44], bentonite [45–47], silica-fume [48,49] and diatomite [50–56] have been evaluated in the incorporation of several organic PCMs. Moreover, these materials have been used to fabricate PCM wallboards, plasters, concrete blocks, hollow bricks and wall covering materials for passive solar buildings [57–63].

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As well as the above-mentioned clay materials, kaolin is one of the most common industrial clays and has a chemical composition of $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$. Kaolin is a layered silicate mineral, with one tetrahedral sheet linked through oxygen atoms to one octahedral sheet of alumina octahedral [64]. It is generally used in ceramics, toothpaste, light bulbs, cosmetics, water and wastewater treatment, etc. Especially, metakaolin is a supplementary cementitious material (SCM) acting as pozzolan. Additionally, some advantageous properties of this clay such as low cost (e.g., its wholesale price is about 0.25 \$/kg in Turkish markets), large surface area, porous structure, abundantly availability, easy handling, direct usability without extra encapsulation and good compatibility with mortar and concrete make it a potential matrix for the fabrication of building composites with organic PCMs. Therefore, successful integration of kaolin with organic PCMs for the TES purposes in buildings can expand its industrial usage areas. However, the number of the studies about the usability of the kaolin as supporting matrix to encapsulate organic PCMs is limited with only a few [65–68]. So, many works to enlarge the varieties of novel composite PCMs with high LHS efficiency are still needed.

On the other hand, capric acid (CA), polyethylene glycol 600 (PEG600) and heptadecane (HD) are fitting organic PCMs for the incorporation with kaolin clay because they have suitable phase change temperature range (10–31 °C) and high latent heat capacity in the range of 136–216 J/g for passive solar TES applications in building envelopes. As far as the authors are aware, there is no investigation reported in the literature on the fabrication, chemical-morphological characterization and determination of LHS properties of newly developed K/CA, K/PEG600, and K/HD composites. The morphological and chemical characterization of fabricated three types of kaolin based-building composite PCMs (Kb-CPCMs) were made using scanning electronic microscope (SEM) and Fourier transformation infrared spectroscopy (FTIR) techniques. The LHS properties and thermal reliability of the Kb-CPCMs were analyzed by differential scanning calorimetry (DSC). The thermal degradation temperatures of the Kb-CPCMs were measured using thermogravimetric analysis (TGA) method. Furthermore, the thermal conductivities of the Kb-CPCMs were increased by addition of expanded graphite (EG) and the obtained results were confirmed by comparing the melting times of the samples with and without EG additive.

2. Materials and methods

2.1. Materials

Kaolin clay used in this work is originated with of Balıkesir city of Turkey. It was kept at 105 °C in an oven to remove its humidity and

then sieved from 200 mesh. The dried sample is mainly consisted of SiO_2 (48 wt%), Al_2O_3 (36.6 wt%), K_2O (2 wt%) and other metal oxides [69,70]. The selected organic PCMs, capric acid (CA), PEG600 and heptadecanol (HD) were supplied from Sigma–Aldrich company.

2.2. Methods

K/CA, K/PEG600, and K/HD composites were fabricated using vacuum impregnation method and the same vacuum conditions reported in our previous studies [71,72] were used here. By following that procedure, the dried kaolin sample in specified weight amount were incorporated with CA, PEG600 and HD, separately in mass fractions varied from 10% to 30%, respectively. The highest mass portion of the PCM retained by kaolin was determined by performing the leakage test. With this aim, each composite sample was subjected to a heating process above the melting temperature of the confined PCM and then cooling process to room temperature. The test results exposed that the maximum fraction of CA, PEG600 and HD in the composite samples, which did not show any PCM loss was determined as 17.5, 21 and 16.5 wt%, respectively. The photograph images of kaolin clay, the selected organic PCMs and fabricated Kb-CPCMs are shown in Fig. 1.

The morphologies of kaolin and the produced three kinds of Kb-CPCMs were investigated by using a SEM instrument (LEO 440 model). The compatibility among the components of the composites was characterized chemically using a FT-IR spectrophotometer (JASCO 430 model). The analysis procedures performed for the SEM and FT-IR analysis were the same as in our previous studies [42,43,46]. The LHS properties of the prepared Kb-CPCMs were measured under atmospheric nitrogen and at a heating rate of 5 °C min⁻¹ using by a Perkin Elmer JADE model DSC instrument. For each sample, the DSC measurement was repeated for three times and the mean deviations in the phase change temperature and latent heat values were calculated as ±0.14 °C and ±1.24 J/g, respectively. Thermal durability of the Kb-CPCMs was determined by comparing the measured thermal degradation temperatures of pure organic PCMs and the fabricated Kb-CPCMs using a TGA analyzer (Perkin–Elmer TGA7 model). The analyses were applied at heating rate of 10 °C min⁻¹ between 50 °C and 500 °C.

The thermal reliability of the Kb-CPCMs was evaluated in terms of probable changes to be occurred in their LHS properties after the following heating-cooling cycles repeated for 1000 times. The cycling process was realized by using a thermal cycler instrument (BIOER TC-25/H model). In order to reach a decision about the thermal reliability and chemical stability of Kb-CPCMs, their DSC and FT-IR data obtained after and before the cycling process were compared. Furthermore, the thermal conductivities of the prepared



Fig. 1. Photograph images of pure kaolin, pure CA, pure PEG600, pure HD and the fabricated K/CA, K/PEG600 and K/HD composite PCMs.

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