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Research Paper

Preparation and analysis of lightweight wall material with expanded graphite (EG)/paraffin composites for solar energy storage

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HIGHLIGHTS

- The paper presents an experimental study on lightweight wall material (LWM).
- EG/paraffin composite is added into LWM with energy storage property.
- LWM possesses of certain enthalpy value and better thermal conductivity.
- EG/paraffin composite content affects thermal and mechanical properties of LWM.
- LWM has adequate stability on mechanical and thermal property.

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ABSTRACT

Lightweight wall material (LWM) composited with EG/paraffin composite was prepared by experimental procedures of foaming, slip casting and constant temperature curing. The EG/paraffin composites were synthesized via vacuum impregnation method. The scanning electron microscope (SEM) analysis indicated that paraffin was sufficiently absorbed into the EG porous network and depicted no leakage even in the molten state. The X-ray diffractometer (XRD) and Fourier transformation infrared spectroscope (FT-IR) results revealed that paraffin and EG in the composite didn't undergo chemical reactions but only physical combination. The compressive strength value of the sample reached 2.853 MPa, while bulk density reduced to 0.445 kg/m^3. The differential scanning calorimeter (DSC) results revealed that the sample melts at 47.78 °C with a latent heat of 16.26 J/g and solidifies at 43.81 °C with a latent heat of 15.98 J/g. The sample with 15% EG/paraffin composites had adequate stability by contrasting mechanical property and DSC profiles before and after 200 times thermal cycles. Furthermore, the thermal conductivity of the LWM increased to 0.76 W (m K) when 20% EG/paraffin was added into the composite. This indicates that the prepared sample has a good thermal property. Hence, the LWM containing EG/paraffin composite would be useful as thermal energy storage material.

1. Introduction

Nowadays, energy depletion has become a major crisis in the world as construction industry accounts for up to 40% of energy consumption and carbon dioxide for 24%. As a result, considerable efforts have been recently devoted to the study of novel materials with energy saving and storage properties [1]. In view of this, production of new wall materials with low-energy consumption is widely investigated and utilized [2,3]. LWMs not only possess considerable strength but also have reduced amounts of raw material consumption and self-weight. Examples of lightweight wall raw materials include fly ash, coal gangue, powder, slag, and charcoal, which have been investigated for their numerous interesting properties such as low-power, low-cost, light weight, and heat insulation [4–6]. On the other hand, LWMs using solar energy have also been investigated by many researchers and scholars. Solar energy could be utilized in daily life as in kitchens, bathrooms, etc. The process concerns burying a metal heat-conducting conduit containing a heat collector that after the phase change, the material absorbs solar energy and the heat collector absorbs the thermal energy that, in turn, can heat the metal conduit used to heat cold into hot water (Fig. 1). However, there still a lot to be done in terms of research in this field as the currently utilized materials have low energy efficiencies. The wall material containing phase change materials (PCMs) could improve the energy efficiencies.

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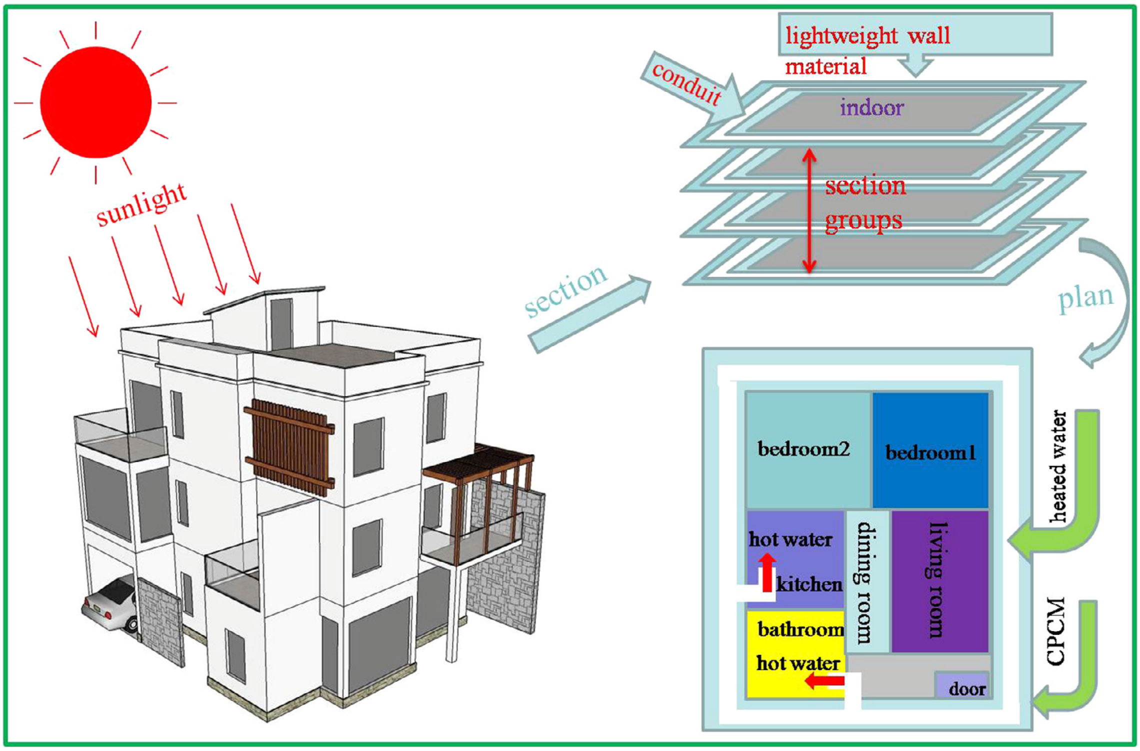

Fig. 1. Schematic diagram of the lightweight wall material with composite PCM (CPCM) for solar energy utilization.

PCMs [7–11] are a type of materials with thermal energy storage properties. The control of temperature that regulates the phase change in materials, i.e., heat absorption of the melting and solidification processes, can effectively improve the utilization and storage of the energy. Building materials with phase change and energy saving properties have been widely studied [12]. For example, Xu et al. [13] prepared a LMW containing paraffin/expanded vermiculite composites as aggregates for the development of lightweight thermal energy saving cement based-composites. Ramakrishnan [14] showed that incorporation of paraffin/expanded perlite (EP) composite into concrete significantly improved the thermal inertia and thermal energy saving through comparing paraffin/EP composites with paraffin/EP cement composites. Hassea et al. [15] filled a type of wallboard called hornet's nest with paraffin and found that the composite did not only prevent leakage of the PCM but improved the thermal conductivity as well as thermal energy storage properties. Sarı and Biçer [16] prepared fatty acid ester/building material composites as stable form of PCMs composite for thermal energy storage applications in buildings. Leea et al. [17] placed thin layers of PCM within building walls to evaluate reduction in both heat flux and heat transfer time delay. Guan et al. [18]proposed a three-layer wall with PCMs composed of: (i) an inner wall layer built with PCMs, (ii) an outer insulating layer, and (iii) a load-bearing wall layer built with heavyweight materials between the two layers. This strategy was designed to enhance heat storage and the thermal insulation properties of greenhouse walls, increase utilization rate of solar energy, improve the indoor thermal environment, and boost crop yield and quality. Lecompte et al. [19] showed that incorporated PCM in mineral matrices to produce building blocks could have a beneficial effect on walls thermal behavior and keeping consistent mechanical strength. However, these reported strategies suffer from some drawbacks such as low thermal conductivity and reduced utilization of heat energy.

This study firstly took the advantage of the interesting properties of EG as a supporting material loaded into paraffin to yield a composite with high thermal conductivity due to graphite, non-toxicity, and other fine performance such as large specific surface area and high adsorption properties. Then, fly ash was used as the main material to prepare light wall materials with the properties of phase change and energy storage through the addition of different contents of EG/paraffin composites. To investigate the microstructure, mechanical and thermal properties of the materials, appropriate measurements and characterizations were performed.

2. Materials and methods

2.1. Materials

The raw materials used to prepare the wall material are based on fly ash, expanded graphite, paraffin, alkali activator, and vesicant. Fly ash (taken from Beijing Shijingshan Thermal Power Plant) was used as the main raw material. EG (vermiform, obtained by rapid expansion and exfoliation of expandable graphite in a furnace controlled at constant 900 °C for 10 s) was utilized as supporting material. Paraffin (white solid plate material, purchased from Sinopharm Chemical Reagent limited corporation) was employed as thermal storage material. Alkali activator (water glass, MS = 1.6, complex alkali activator) is prepared by mixing water glass (MS = 2.4) with NaOH (1 mol/L) using certain ratios. The utilized vesicant was a ZC-41 thermal insulation block cement vesicant (the new composite cement foaming agent, latest developed by Beijing Zhong Ke Build Sincere Building Material Science and Technology, Ltd.).

2.2. Sample preparation

The preparation process of the wall materials is divided into two parts: the preparation of the EG/paraffin composites and foam concrete.