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Research Paper

Experimental exploration of incorporating form-stable hydrate salt phase change materials into cement mortar for thermal energy storage

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HIGHLIGHTS

- Cement-based composite with form-stable hydrate salt is prepared for the first time.
- Cement-based composite exhibits good thermal performance and acceptable strength.
- Thermal performance is decided both by energy storage and thermal conductivity.
- Strength and thermal conductivity are associated with microscopic pore structure.

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ABSTRACT

In this study, the thermal energy storage cement-based composites were fabricated by integrating cement mortar with the form-stable hydrate salt PCMs based on binary eutectic hydrate salt/expanded graphite oxide (EHS/EGO) and EHS/poly (acrylamide-co-acrylic acid) copolymer (EHS/P(AA-AA)). The form-stable hydrate salt PCMs were incorporated in cement-based composites at 5%, 10%, 15% and 20%, by weight of sand. It is found that the mechanical strengths of the thermal energy storage cement-based composites decrease with the increasing form-stable hydrate salt PCMs content, however, they can still be able to use as building envelope materials. Furthermore, Scanning Electron Microscopy (SEM) was used to investigate the compatibilities of EHS/EGO and EHS/P(AA-AA) with cement mortar. The pore size distribution collected from mercury intrusion porosimeter (MIP) results also has been analyzed, which is associated with mechanical strength and thermal conductivity. Besides, thermal performance test demonstrates that the cement mortars containing the form-stable hydrate salt PCMs have good endothermic and exothermic characteristics and play a role in adjusting the peak value of indoor temperature.

1. Introduction

The increasing building energy consumption and serious global warming have become a large challenge in recent years. In order to solve these problems, phase change materials (PCMs) are incorporated into building materials to prepare the thermal energy storage building materials [1–4]. By means of characteristics of PCMs absorbing and releasing thermal energy, the energy efficiency in buildings could be improved by using PCMs to adjust the temperature fluctuation of environment. Therefore, the use of PCMs in buildings will achieve the dual purpose of ensuring building thermal comfort and reducing building energy consumption [5,6].

The interior wall building materials can be classified as cement and concrete materials, gypsum, brick materials, etc. In recent years, researchers have made a lot of attempts in the field of thermal energy storage building materials. Zhang et al. [7] fabricated thermal energy storage cement-based materials with good thermal properties by incorporating a novel polymer-inorganic hybrid shell form-stable organic PCM. Cunha et al. [8] investigated the effects of the addition of non-encapsulated organic PCMs on physical and mechanical properties of cement mortar. Cabeza et al. [9] added a kind of commercially available form-stable organic PCM into concrete to produce phase change concrete composite. Thereafter, an experimental room was established to evaluate the thermal performance using this composite. The results indicated that the phase change concrete possessed good energy storage and release performance. Zhang et al. [10] produced a foam gypsum

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board PCM which showed a good heat capacity due to its applied temperature range lower than that of ordinary gypsum board. Such foam gypsum board PCM could be used as thermal insulation lightweight wall materials. Sun et al. [11] prepared a cement mortar with paraffin/expanded perlite material and investigated the influence of form-stable phase change materials on mechanical properties of cement mortar. The results showed that the strength of cement mortar decreased with paraffin/expanded perlite materials content increasing.

Viewed from above research status, most of researches have only been focused on the application of organic PCMs in building materials. Unfortunately, due to the disadvantages of lower latent heat and higher cost, the further application of organic PCMs in building materials has been severely limited. Moreover, the toxicity and flammability of organic PCMs leads to health and fire risks when applied in building materials [4,12]. The inorganic hydrate salts PCMs used for thermal energy storage have gained research popularity due to their low cost, high latent heat, nontoxicity and nonflammable compared with organic PCMs [13,14]. Obviously, the inorganic PCMs have a promising application when incorporated into cement-based materials. However, to date, few reports took the use of inorganic hydrate salt PCMs in building materials into consideration. The reason lies in the leakage of liquid-state, phase separation and supercooling of the inorganic hydrate salts to limit their applications [15]. A method to prevent leakage is to use form-stable PCMs which consisted of hydrate salt PCMs as core materials of energy storage and shell materials as the support network [16,17]. Moreover, the phase separation and supercooling can be mitigated effectively by impregnating hydrate salts into various shell materials through pore confinement effect [18–20]. Benefiting from the above advantages of form-stable hydrate salt PCMs, it has become possible to apply the inorganic hydrate salts PCMs into the building materials.

In this work, the thermal energy storage cement-based composites were fabricated by integrating cement mortar with two kinds of form-stable hydrate salt PCMs based on binary eutectic hydrate salt (EHS)/expanded graphite oxide (EHS/EG) and EHS/poly (acrylamide-co-acrylic acid) copolymer (EHS/P(AA-AA)). Subsequently, the mechanical properties including compressive strength and flexural strength, microstructure, pore size distribution, thermal conductivity and thermal energy storage performance of cement mortars with EHS/EGO and EHS/P(AA-AA) were investigated. This work will provide a new insight for the preparation of high-performance energy-storage cement-based composites with low cost.

2. Materials and methods

2.1. Materials

According to the preparation methods described by our previous work [21,22], the $Na_2CO_3{\cdot}10H_2O$-$Na_2HPO_4{\cdot}12H_2O$ eutectic hydrate salt/expanded graphite oxide composite form-stable phase change materials (EHS/EGO) and $Na_2CO_3{\cdot}10H_2O$-$Na_2HPO_4{\cdot}12H_2O$ eutectic hydrate salt/poly (acrylamide-co-acrylic acid) copolymer form-stable phase change materials (EHS/P(AA-AA)) are prepared. The mean particle size of the form-stable PCMs used is close to that of the standard sand (≦2 mm). The P·O 42.5 ordinary Portland cement was purchased from Yatai Co. Ltd (Tianepai Cement, China, Harbin) with 183 min of the initial setting time and the final setting time 235 min in accordance with Chinese standard GB/T21236-2007. The standard sand was purchased from Sinoma Co. Ltd (China, Xiamen).

Fig. 1 presents the DSC curves of EHS/EGO and EHS/P(AA-AA), showing the thermal properties of form-stable hydrate salt PCMs. From Fig. 1, the melting temperatures of EHS/EGO and EHS/P(AA-AA) are 26.0 °C and 24.6 °C, and the freezing temperatures of EHS/EGO and EHS/P(AA-AA) are 17.1 °C and 11.6 °C, respectively. Thus, the subcooling degrees of EHS/EGO and EHS/P(AA-AA) are 8.9 °C and 13.0 °C, respectively. Moreover, the latent heats of EHS/EGO and EHS/P(AA-AA) are 195.0 J/g and 189.1 J/g, respectively. The accelerated thermal-cycling tests have been carried out to evaluate the stability and thermal long-term recycling ability of EHS/EGO and EHS/P(AA-AA). As shown in Fig. 2, the latent heat of EHS/EGO has only a decline of 8.1% from 1 cycles to 200 cycles, and there is no obvious change in the latent heat of EHS/P(AA-AA) before and after 300 thermal-cycling tests. This suggests that the EHS/EGO and EHS/P(AA-AA) have good thermal stabilities.

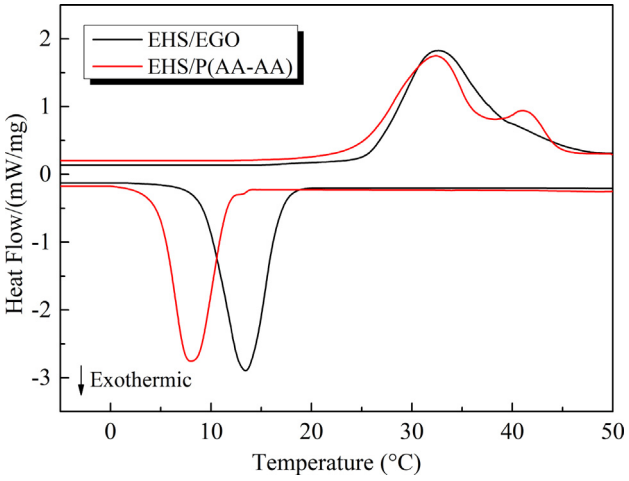

Fig. 1. The DSC curves of EHS/EGO and EHS/P(AA-AA) form-stable hydrate salt phase change materials.

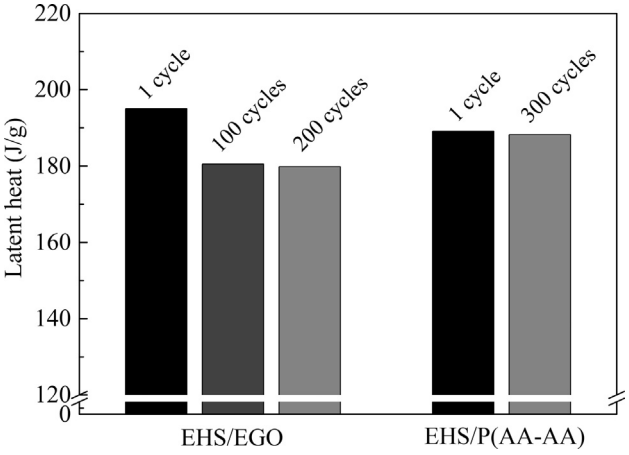

Fig. 2. Changes in the latent heat of the EHS/EGO composite and EHS/EG composite with thermal cycling.

2.2. Preparation and characterization of form-stable hydrate salt thermal energy storage cement-based composites

The form-stable EHS/EGO composite was prepared by a physical blending and the impregnation method. Prior to the impregnation process, the solid supports, Expanded graphite oxide (EGO) was treated through removing its fine granules by use of 25 μm (600 mesh) sieves. In the general procedure, the EGO (1.0 g) was added into $Na_2CO_3{\cdot}10H_2O$-$Na_2HPO_4{\cdot}12H_2O$ eutectic hydrate salt (EHS) solution (25.0 g) and the resulting mixtures were stirred vigorously for 6 h at 55 °C. Finally, the EHS/EGO composite was collected by suction filtration using the Buchner funnel equipped with 25 μm (600 mesh) filter membrane; The fabrication process of form-stable EHS/P(AA-AA) was as follows: the melted EHS (10.0 g) was placed into the small beaker and kept at 55 °C in thermostat water bath. Under the condition of rapid and continuous stirring, 5 wt% P(AA-AA) was slowly added to the EHS solution. When the bubbles no longer escaped, the stirrer was stopped