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Experimental investigation of thermal and mechanical properties of magnesium oxychloride cement with form-stable phase change material

Xiang Li [a,b,*], Yuan Zhou [a,b,*], Xinxing Zhang [a,b], Weixin Zheng [a,b], Chenggong Chang [a,b], Xiufeng Ren [a,b], Jinbo Zeng [a,b], Chunxi Hai [a,b], Yue Shen [a,b]

[a] Key Laboratory of Comprehensive and Highly Efficient Utilization of Salt Lake Resources, Qinghai Institute of Salt Lakes, Chinese Academy of Sciences, Xining 810008, China
[b] Key Laboratory of Salt Lake Resources Chemistry of Qinghai Province, Xining 810008, China

HIGHLIGHTS

- MOC/FSPCM composites show good mechanical properties and high heat storage efficiency.
- FSPCM absorbs heat, and reduce the hydration reaction temperature and hydration rate.
- MOC/FSPCM composites show excellent thermal regulation performance.

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ABSTRACT

To increase the heat storage efficiency of the building enclosure structure, form-stable phase change material (FSPCM) was implanted into the magnesium oxychloride cement (MOC) system to generate MOC/FSPCM composites with both high heat storage efficiency and considerable mechanical strength. The microstructure, mechanical properties, hydration process and thermal properties of MOC/FSPCM composites were investigated. The results indicated the structure of MOC was not destroyed and the hydration rate, hydration temperature and total hydration heat also dropped after adding FSPCM. The compressive strength and flexural strength of the MOC/FSPCM composites with 30 wt% FSPCM can still reach to 52.9 MPa and 5.9 MPa, respectively, and the melting and crystallizing enthalpy of MOC/FSPCM composites were 29.91 J/g and 26.52 J/g, respectively. Thermal performance tests indicated that thermal conductivity of MOC/FSPCM composites decreased with the increase in the mass percentage of FSPCM. Meanwhile, MOC/FSPCM composites show excellent performance of indoor temperature regulate, conserve energy and thermal comfort.

1. Introduction

Along with the development of the economy, the total energy consumption is increasing, the building energy consumption is one of the highest energy consuming sectors, accounting for about 30 per cent of total energy usage [1–4]. Huge building energy consumption has become enormous burden of economy. Building maintenance structure act as an escape route for the change of inside and outside buildings environment, and 1/3 heat consumption are attributed to the building maintenance structure [1]. Building maintenance structure materials includes concrete, block and other materials. However, traditional surrounding protection structure materials (concrete, block, stone, etc.) are not appropriate for today's architectural trends. It's because of that for their transportation and implementation would not be feasible due to their massiveness and higher volume, which leads to excessively costly [1]. Therefore, how to control the cost and select suitable building materials have become particularly important for building energy saving.

Currently, the construction materials with small heat transfer coefficient are being used to retard the heat transfer. Nevertheless, traditional construction materials have low heat capacity, which is violence against suppressing indoor temperature fluctuations, and makes it difficult to realize the effective use of energy [5–7]. Adding the phase change material (PCM) to the light building material (flooring, drywalls, concrete, ceilings, panels, gypsum boards, insulation panels, wallboards etc.) can form building envelope which high heat capacity, and the energy is stored in the form of phase

* Corresponding authors at: Qinghai Institute of Salt Lakes, Chinese Academy of Sciences, Xining 810008, China.
E-mail addresses: lixiang@isl.ac.cn (X. Li), zhouy@isl.ac.cn (Y. Zhou).

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change latent heat, which can increase the heat storage function of the enclosure structure, improve energy efficiency [8–10].

Various types of building materials and PCMs have been investigated to improve the thermal performances of buildings and help moderating the temperature variations such as gypsum plaster board with microencapsulated paraffin [11], pumice/organic PCM [12], eutectic mixture of octadecane and tetracosane [13] and polymeric-SiO_2-PCMs [14], porous plaster board with phase change capsules [4], mortar with micro-encapsulated phase change material [15], cement incorporated with flaky graphite-doped microencapsulated paraffin [16], concrete with shape stabilized phase change material [17] and microencapsulated PCM [18], wood with PCM [19,20], aluminous gusset plates with composites PCM [5], multi-layer drywall systems incorporating with phase change materials [21], brick masonry walls with PCM microcapsules etc. [22].

Comparing traditional building materials, magnesium oxychloride cement (MOC) building materials which features for high heat-insulating effect, heat preservation, lower thermal conductivity, strong adhesion and better durability, play an important role in application of building energy-saving technologies [23–26]. The incorporation of PCM into MOC can significantly improve the thermal energy storage capacity of building structures around the melting range of PCM but may reduce the mechanical performance of MOC [1]. As energy storing building materials, both efficiency of the thermal energy storage and the mechanical properties were very important. However, the thermal and mechanical properties of MOC containing PCM have not been rarely reported previously.

In the present study, form-stable phase change material (FSPCM) was implanted into the magnesium oxychloride cement (MOC) system to generate MOC/FSPCM composites with both high heat storage efficiency and considerable mechanical strength. Meanwhile, the microstructure, hydration process, mechanical properties, phase change properties and thermal properties were investigated in detailed. Experimental results are very helpful to optimize parameters of building energy saving.

2. Experimental section

2.1. Materials

Raw diatomite (Jilin Wanzhong Company, China), Calcium chloride anhydrous ($CaCl_2$, purity > 96%, Tianjin Damao Company, China), n-hexane (C_6H_{14}, purity > 95%, Tianjin Damao Company, China) and high melting-point paraffin (Lanzhou Wotu Company, China) were used to make FSPCM. The light-burnt magnesia with a content of reactive MgO 65.0 wt% (Haicheng Magnesium Cement Mining, China) and Magnesium chloride hexahydrate ($MgCl_2{\cdot}6H_2O$, purity > 98%, Jiayoumeiye, China) were adopted to fabricate the MOC.

2.2. Preparation

FSPCM was prepared by impregnating calcium chloride hexahydrate into diatomite and further coating with paraffin based on our previous work [27]. The melting and crystallizing enthalpy of the FSPCM are 108.2 and 98.5 J/g, respectively. The phase transition temperature was about 28 °C. After the 100 cycles, the melting and crystallizing enthalpy of FSPCM declined to 106.2 and 93.8 J/g.

The MOC/FSPCM composites were perpetrated by mixing light-burnt magnesia, FSPCM and $MgCl_2$ solution at room temperature according to the proportions listed in Table 1. The schematic illustration of the fabrication is described in Fig. 1.

Table 1
Composition of MOC/FSPCM composites.

Sample	FSPCM (*wt.* %)	Magnesia powder (g)	$MgCl_2$ solution (25%, g)	FSPCM (g)
MOC	0	30	25	0
MOC/FSPCM05	5	30	25	1.5
MOC/FSPCM10	10	30	25	3.0
MOC/FSPCM15	15	30	25	4.5
MOC/FSPCM20	20	30	25	6.0
MOC/FSPCM25	25	30	25	7.5
MOC/FSPCM30	30	30	25	9.0

2.3. Characterization

The crystalline phases of samples were got from an X-ray diffraction (X'PRO Pert). The morphologies of samples were observed by a scanning electron microscope (SEM, JSM-5610LV). The latent heat were measured by using a differential scanning calorimetry (TA Q20). The thermal conductivities were performed at laser thermal conductivity testing instrument (NETZSCH LFA-475).

The particle size distributions were detected by laser particle size analyzer (Mastersizer 2000). The porosity were investigated with mercury intrusion porosimetry (AutoPore IV 9500), and density were determined using solid densimeter (BEYONGTEST, BR-120N).

The hydration rate and total hydration heat of the MOC/FSPCM composites were measured on an 8-channel isothermal calorimeter (I-Cal 8000 HPC). Each sample was run for 3 days to analyze the effect of FSPCM on the hydration process of MOC/FSPCM composites.

The temperature-time of hydration reaction of MOC/FSPCM composites paste and surface temperature changes of MOC/FSPCM composites board versus time were recorded using a data logger (Jinailian Electrical Tech. Inc., Changzhou).

The 28 days mechanical property (compressive strength and flexural strength) were measurement by using a fully automatic cement-strength testing machine (HYE-300B). The pastes were mixed for 3 min, then cast into moulds 20 mm × 20 mm × 20 mm and 40 mm × 40 mm × 160 mm for the compressive strength and flexural strength tests after 28 days curing.

3. Results and discussion

3.1. Microstructure of MOC/FSPCM composites

Fig. 2 shows XRD patterns of FSPCM, MOC, and MOC/FSPCM composites. It is noticed that the sharp and intense diffraction peaks of FSPCM and MOC can be observed as the FSPCM content increased to 30% by weight. The result of X-ray diffraction test shows that the crystal structure of MOC was not destroyed and no other phase exist after addition of FSPCM which guarantee its mechanical property and meets the requirements of building material.

Fig. 3 shows SEM images of FSPCM, MOC, and MOC/FSPCM composites. As can be seen from the Fig. 3, with the increase of FSPCM contents, the porosity of MOC/FSPCM composites increased. The reason for this is that the particle size of FSPCM is bigger than the cavities size of MOC which prevent the FSPCM to fill the cavities of MOC and increase the entrap air of the surface, which lead to porosity increase of MOC/FSPCM composites. In addition, the morphologies of crystalline were change from needle rod-like crystal to gelatinous with poor crystallinity after adding FSPCM. The porosity increase and crystal pattern changes are harmful for the mechanical property of MOC/FSPCM composites.

Fig. 4 displays that the widest particle size distributions of FSPCM, and the particle size was about 27 μm or so, which further confirms the result of scanning electron microscopes.

3.2. Porosity, density and mechanical properties of the MOC/FSPCM composites

The total porosity and pore volume distribution of MOC/FSPCM composites tested by the mercury intrusion porosimetry (MIP) are tabulated in Table 2. It can be seen that the incorporation of FSPCM increase the total porosity. For instance, the total porosity increases by 45.82% when the addition amount of FSPCM was