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Effects of the form-stable expanded perlite/paraffin composite on cement manufactured by extrusion technique

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A B S T R A C T

This paper presented the experimental results of MOC (magnesium oxychloride cement) with the EP/PA (expanded perlite/paraffin) composite manufactured by extrusion technique. The objective of this study was to improve the thermal insulation and thermal storage capacity of MOC cement with satisfied mechanical properties, which was expected to be used as structural materials with self-thermal insulation and storage in buildings. The DSC (differential scanning calorimetry) results revealed that the paraffin has melting temperature and latent heat of 26.7 °C and 138.0 J/g, respectively. The EP/PA composite can be obtained by absorbing the paraffin into the porous structures of expanded perlite, which showed good thermal storage and thermal stability properties. The incorporation of EP/PA composite caused not only 80% reduction in thermal conductivity, but also 14 min peak load shifting in thermal cycling test due to the improved thermal storage capacity. In addition, the extrusion technique contributed to the higher compressive and flexural strength of MOC cement due to the denser and better fiber alignment of the mixture, varied between 17–45 MPa and 6–8 MPa, respectively. In conclusion, the MOC cement with the EP/PA composite manufactured by extrusion technique has great potential for the sustainable development of energy efficient buildings.

1. Introduction

PCMs (phase change materials) for LHTES (latent heat thermal energy storage) in buildings have been widely studied due to the advantages of high heat energy storage, energy release temperature and constant temperature during phase change process [1–6]. PCMs mainly consist of inorganic PCMs such as melted salts, crystalline hydrated salts, etc., and organic PCMs such as paraffin, lauric acids and their eutectic system. Incorporating PCMs into building walls and ceilings can not only improves the thermal inertia of buildings, but also makes peak electrical load shifting and thus achieves significant economic benefit. Cabeza et al. [7] investigated the effects of PCMs on saving the heating and cooling energy, and the results revealed that the concrete cubicles with and without PCMs showed a temperature difference of 3 °C. Athienitis et al. [8] impregnated PCMs into a gypsum board to investigate the thermal performance in a passive solar building, which showed that the room temperature could be reduced by a maximum 4 °C during the daytime. Jin et al. [9] found that the peak heat flux of walls incorporated with PCMs can be reduced by more than 40%. Therefore, building materials incorporated with PCMs presented great potential for the sustainable development of energy efficient buildings.

Among the investigated PCMs, paraffin has been regarded as a promising candidate due to its higher latent heat energy, excellent thermals stability and low cost [10,11]. However, the leakage problem of paraffin during phase change process has greatly limited its application to some extent. In order to overcome this problem, the technology with encapsulation paraffin in a polymeric film or a container has been developed [12–17], but the high cost was the biggest concern for building applications. The other way is to combine paraffin into porous building materials, such as diatomite [18–20], expanded perlite [21] and metallic foam [22]. Among these porous materials, expanded perlite has been widely used because of its lightweight, abundance and low cost. Sun et al. [23] prepared the EP/PA composite by absorbing the paraffin into the pores of expanded perlite without any liquid leakage problems. Lu et al. [24] demonstrated that paraffin can be well dispersed in the

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expanded perlite until the mass fraction between paraffin and expanded perlite reached to 0.6. The leakage problem could be resolved to some extent by the capillary and surface tension forces of porous materials [25,26].

Although the incorporation of PCMs and porous materials can definitely enhance the thermal properties of cement, it has some negative effects on cement mechanical properties [27]. Meshgin [28] presented that the mechanical strength of cement can be reduced by addition of PCMs. Hunger et al. [29] reported that the porosity of cement was increased by incorporation of PCMs and the mechanical strength was decreased with increasing PCMs content. Ozkan [30] demonstrated that the compressive strength of cement containing 20 vol.% expanded perlite was approximately 40% lower than that of cement without the expanded perlite. Substantial reductions in the compressive strength were obtained for the higher expanded perlite content. In order to overcome this problem, in this study, the PVA (polyvinyl alcohol) fiber was firstly incorporated to improve the mechanical properties of MOC cement, and then the mixture was further manufactured by extrusion technique, which not only made better fiber alignment in the extrusion direction [31,32], but also densified the cement by the high shear and compressive forces during extrusion process. Therefore, the mechanical performances of MOC cement were significantly improved for compensating the strength loss with the EP/PA composite incorporation.

The objective of this paper was to improve the thermal insulation and thermal storage capacity of MOC cement with satisfied mechanical properties. Specifically, the form-stable EP/PA composite was firstly prepared by direct impregnation method and characterized by DSC (differential scanning calorimetry), TGA, SEM and leakage test. Then, effects of the EP/PA composite on thermal insulation property and thermal storage capacity of MOC cement were investigated by thermal cycling test and thermal conductivity test, respectively. Finally, the mechanical properties, including compressive strength, flexural strength and toughness, of the extruded EP/PA-modified MOC cement were also studied.

2. Materials and testing methods

2.1. Materials

Instead of Portland cement, MOC cement was used in this study due to its lower thermal conductivity and higher mechanical strength. The three starting materials of MOC cement were light-burned MgO (magnesium oxide), magnesium chloride ($MgCl_2{\bullet}6H_2O$) and water. The MgO was calcined magnesite powder with a purity of 96%. The $MgCl_2{\bullet}6H_2O$ was hygroscopic hexahydrate crystal with a purity of 98% from Israel. Paraffin was supplied by the Ke Qitai Chemical Company, Guangdong, China. Expanded perlite was purchased from the Zhong De Perlite Factory, Liaoning, China. The PVA fiber (KURALON K-II REC15) used was 39 μm in diameter and 12 mm in length. The chemical composition of the raw materials analyzed by X-ray fluorescence spectrometer (XRF, JSX-3201Z) are listed in Table 1.

2.2. Preparation of the form-stable EP/PA composite

In this study, the EP/PA composite was fabricated by direct impregnation method [21,33]. The paraffin particles were firstly weighted and then melted at a temperature of 50°C ± 5 °C for 1 h in an oven, and then mixed with the expanded perlite at ambient temperature immediately and put back in the oven. The mixture was mixed every hour until the paraffin was uniformly dispersed in the expanded perlite. Finally, the EP/PA composite were formed after cooling down at room temperature. Due to the combined action of capillary force, physical and chemical adsorption of the expanded perlite, the leakage problem of the paraffin above phase change temperature can be released to a certain degree [25,26].

2.3. Mix proportions and extrusion of the EP/PA-modified MOC cement

Table 2 lists the six mix proportions of the MOC cement with different EP/PA composite content. Firstly, the expanded perlite was incorporated as cement replacement at 20%, 30% and 40%, by volume of the MOC cement (named as MOC-E20P0, MOC-E30P0 and MOC-E40P0), to investigate the effect of expanded perlite on the thermal insulation property of the MOC cement. Based on the MOC-E40P0 which showed the best thermal insulation property, 5 vol.% and 10 vol.% paraffin were then added to study the effect of the paraffin on thermal energy storage capacity of the MOC cement (named as MOC-E40P5 and MOC-E40P10). For clear description, it should be noted that the abbreviation of the MOC-E40P10, for example, indicates the MOC cement with 40 vol.% EP and 10 vol.% PA; however, the 40 vol.% EP and 10 vol.% PA should be firstly pre-weight and pre-mixed together to form a composite and then incorporated into the MOC cement. Thus, the pre-prepared composite with 40 vol.% EP and 10 vol.% PA before incorporating into the MOC-E40P10 is abbreviated as composite E40P10. The mass fractions of the paraffin in the composite E40P5 and E40P10 are 0.25 and 0.40, respectively.

In order to prepare the fresh mixture with good workability and extrudability, the pre-prepared EP/PA composite was firstly mixed with one thirds of total water and then mixed with other dry powders. After dry mixing for 3 min, the left two thirds of water and pre-dissolved $MgCl_2$ solutions were gradually added for 2 min

Table 2
Mix proportions of the EP/PA-modified MOC cement.

No.	Binder		Aggregate (vol.%)		PVA (vol.%)
	MOC	FA	EP	PA	
MOC-E0P0	0.5	0.5	0	0	1.0
MOC-E20P0	0.5	0.5	20	0	1.0
MOC-E30P0	0.5	0.5	30	0	1.0
MOC-E40P0	0.5	0.5	40	0	1.0
MOC-E40P5	0.5	0.5	40	5	1.0
MOC-E40P10	0.5	0.5	40	10	1.0

Note: E and P are shorted for the expanded perlite and paraffin, and the number after E and P indicate the volume fraction of both materials in the MOC cement.

Table 1
Chemical composition of raw materials.

Materials	MgO	Al_2O_3	SiO_2	CaO	Fe_2O_3	Na_2O	$MgCl_2$	$CaCl_2$	NaCl	H_2O
MgO	92.80	–	4.40	1.91	–	–	–	–	–	
Fly ash	–	29.69	51.65	5.40	5.91	–	–	–	–	–
Expanded perlite	–	11.80	78.39	1.07	–	2.19	–	–	–	–
$MgCl_2{\cdot}6H_2O$	–	–	–	–	–	–	46.00	1.20	0.60	51.90