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Utilization of paraffin/expanded perlite materials to improve mechanical and thermal properties of cement mortar

Dan Sun *, Lijiu Wang

Faculty of Infrastructure Engineering, Dalian University of Technology, Dalian 116024, China

HIGHLIGHTS

- Paraffin has good compatibility with expanded perlite.
- The optimal cement of paraffin/expanded perlite materials in cement mortar is determined as 20 wt%.
- The heat storage/release curves of cement mortar with paraffin/expanded perlite materials changed slightly after 100 cycles.
- Cement mortar with 20 wt% paraffin/expanded perlite materials has good heat storage and thermal stability.

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ABSTRACT

In this study, cement mortar with paraffin/expanded perlite materials was prepared by direct mixing method. The effect of paraffin/expanded perlite material content on mechanical and thermal properties of cement mortar were investigated. The experimental results showed that the paraffin was confined in the porous structures of expanded perlite by capillary force. The average mass percentages of paraffin in paraffin/expanded perlite material reached as high as 65%. It was a physical interaction between paraffin and expanded perlite. Compressive strength and flexural strength of cement mortar decreased with increasing amount of paraffin/expanded perlite materials. Cement mortar with 20 wt% paraffin/expanded perlite materials had good heat storage property and thermal stability compared to ordinary cement mortar.

1. Introduction

Thermal energy storage is considered as one of the most important technologies for improving the energy utilization efficiency and reducing the energy consumption for buildings. Latent heat storage using phase change material (PCM) is particularly effective method [1–4]. PCM can not only save thermal energy to adjust indoor temperature fluctuation but also reduce the mismatch between energy supply and energy consumption [5–7]. The application of PCMs in building has been mainly focused on coating, concrete, gypsum board, plaster, mortar or other wall-covering material [8–12].

Three methods are proposed for combining PCMs into building structure. Direct immersion method is simple and low cost, but solid–liquid PCMs with low phase change temperature prone to leak after several heating–cooling cycles [13]. The preparation of microencapsulation PCMs is very complex and high cost [14], which limited its application in buildings. The third one is incorporation of form-stable PCMs into building materials, which form-stable PCMs are prepared by blending PCMs with porous materials. The commonly-used porous materials include diatomite [15], expanded perlite [16], expanded graphite [17], and so on. These porous materials provide good mechanical strength and prevent the leakage for PCMs during phase change process.

Among the investigated PCMs, paraffin as a promising PCM widely used in buildings because of high heat storage capacity, good chemical and thermal stability, little super cooling and low cost [18–20]. However, low thermal conductivity and liquid leakage during phase change process hinder its application in some fields. To overcome the low thermal conductivity problem of paraffin, graphite as excellent thermal conductivity promoter has been used [21–23]. Sari [24] studied the effect of graphite amount on thermal conductivity and they found that by taking into account the increase percent in thermal conductivity values and the decrease amount in latent heat capacity, the optimal mass ratio

* Corresponding author.
E-mail address: wlailovesd@126.com (D. Sun).

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of graphite additive was determined as 5 wt%. Expanded perlite as supporting material not only provides a good mechanical strength to the whole PCM, but also prevents the leakage of PCM [25]. However, solid–liquid PCM with expanded perlite as supporting material appeared leakage after long-term heating/cooling cycles. Epoxy resin was used in encapsulation due to its good mechanical resistance, strong adhesion, low shrinkage as well as good stability [26].

In this study, cement mortar with paraffin/expanded perlite materials was prepared by direct mixing method for thermal energy storage in building applications. The effect of paraffin/expanded perlite material content on mechanical and thermal properties of cement mortar were investigated by comparing with ordinary cement mortar.

2. Experimental

2.1. Materials

Paraffin mixture consisted of 46# paraffin (Shanghai, Yonghua) and liquid paraffin (Fushun, Shihua). The properties are shown in Table 1. Expanded perlite was supplied by Dalian Zhongde Perlite Factory and the properties are shown in Table 2. Graphite was purchased from Tianjing Damao Chemical Company. The thermal conductivity is 50.63 W m^{-1} K^{-1}.

Cement was ordinary Portland cement (P·O 32.5) that was supplied by Dalian Xiaoyetian Cement Company. Sand was purchased by Xiamen ISO standard sand Company. Epoxy resin and hardener were supplied by Wuxi Lanxing Resin Company and the proportion of epoxy resin to hardener is 1: 0.9.

2.2. Preparation of cement mortar with paraffin/expanded perlite materials

Graphite as additive was added into the melting paraffin at the beginning to improve the thermal conductivity of paraffin. The mass percentage of graphite was determined as 5 wt% in our previous work [27]. Then the expanded perlite was soaked into the melting paraffin at 60 °C for 5 h until the weight of paraffin in expanded perlite unchanged. The process was shown in Table 3. After that, paraffin/expanded perlite material was obtained (Fig. 1).

Cement mortar with paraffin/expanded perlite materials was prepared by direct mixing method. Cement, sand and water were mixed for additional minutes (90 s) using an electromotive mixer specified. After that, the paraffin/expanded perlite materials were mixed uniformly with epoxy resin and hardener, and then added into the ordinary cement mortar. The proportion of cement mortar with paraffin/expanded perlite materials is listed in Table 4.

2.3. Characterization

The morphology and microstructure of expanded perlite and paraffin/expanded perlite material were observed with SEM (JSM-5600LV) at 15 KV accelerating voltage. The chemical structures were analyzed with FT-IR (Nicolet 3600). The spectral data were recorded from wavenumber range of 500–4000 cm^{-1} with KBr pellet technique.

The mechanical properties of cement mortar with paraffin/expanded perlite materials were evaluated by measuring compressive strength and flexural strength. The specimen size is 40 mm × 40 mm × 160 mm. All the cubes were maintained under water at 20 ± 3 °C for 3 days and 28 days.

Leakage test was determined by using oven. The test was carried out at temperature 40 °C for 5 h. Heat storage property and thermal stability of cement mortar with paraffin/expanded perlite materials were tested with insulation can through recording the temperature change [28,29]. The test device is shown in Fig. 2. The insulation can is composed of six pieces of polystyrene boards with dimension of 300 mm × 300 mm × 300 mm. The depth of polystyrene boards is 30 mm. The inner surfaces of insulation can were made of ordinary cement mortar and cement mortar with paraffin/expanded perlite materials. Oven and fridge were used as heat and cold sources, respectively. The temperature in the center of insulation can was recorded by temperature data logger. Thermal conductivity was measured by using a hot disk thermal constant analyzer (Hot Disk: CD-DR3030A). The specimen size is 300 mm × 300 mm × 30 mm.

Table 1
Properties of paraffin.

	Melting	Latent heat
46# Paraffin	46–48 °C	122.05 J/g
Liquid paraffin	5–6 °C	–
Paraffin mixture (mass ratio of 1:1)	19.45 °C	128.46 J/g

Table 2
Properties of expanded perlite.

	Particle size (mm)	Density (kg/m^3)	Thermal conductivity (w/m k)
Expanded perlite	3–5	400	0.16

Table 3
The relation between paraffin carrying capacity and soaking time in expanded perlite.

Time (h)	Weigh after soaking (g)	Absorption of paraffin (g)
1	36.76	26.76
3	37.55	27.55
5	38.58	28.58
7	38.66	28.66
10	38.54	28.54
12	38.33	28.53

Fig. 1. Paraffin/expanded perlite material.

Table 4
Proportion of cement mortar with paraffin/expanded perlite material (mass ratio).

Mass ratio of cement and sand	Water cement ratio	Paraffin/expanded perlite material	Epoxy resin
1:2.5	0.6	20% of cement	33% of paraffin/expanded perlite material

3. Results and discussion

3.1. SEM of paraffin/expanded perlite material

Fig. 3 shows the SEM images of expanded perlite and paraffin/-expanded perlite material. It can be seen in Fig. 3(a) that expanded perlite have many rough and accidental porous structures. These porous structures not only provide a good mechanical strength to paraffin/expanded perlite material, but also prevent the leakage of paraffin during phase change process by capillary force and surface tension [25,30]. Fig. 3(b) shows that paraffin was dispersed into the porous structures of expanded perlite uniformly. The average mass fraction of paraffin confined into expanded perlite was determined as high as 65% in this study. Therefore, it can be concluded that there is a good compatibility between paraffin and expanded perlite.

3.2. FT-IR of paraffin/expanded perlite material

The FT-IR spectra of expanded perlite (a), paraffin (b), graphite (c) and paraffin/expanded perlite material (d) are presented in