



A Phase Change Storage Material that May Be Used in the Fire Resistance of Building Structure

Peng Wang, Na Li, Cheng-shou Zhao*, Liu-yan Wu, Guo-bin Han

Southwest Jiaotong University, 111, 1st Section, Northern 2nd Ring Road, Chengdu 610031, China

Abstract

This study prepared polyethylene glycol/silicon dioxide composite, a kind of form-stable phase change material. The composites can be made into mortar which is able to adhere to the surface of building structure and absorb the fire heat. This paper aims to study the effect of the composites on the fire resistance of building structure. Scanning electronic microscope and differential scanning calorimeter were adopted to investigate the structural and thermal properties of the composites. It was found that the polyethylene glycol was well dispersed into the network of solid SiO₂. And the latent heat of PEG/ SiO₂ increased with the decrease of SiO₂ content. The required weight percentage of SiO₂ was found to be 15% at least if the composites remain solid without leakage. It was also found that a phase change of pure PEG6000 happened with an enthalpy of 158 J/g while the 80 wt% PEG composite is 133 J/g. In conclusion, the phase change storage material may be used for fire resistance of building structure.

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Nomenclature

T_t	melting point (°C)
T_m	melting temperature (°C)
ΔH	melting enthalpy (J/g)
$\Delta H'$	theoretical value (J/g)

1. Introduction

Composed by supporting materials and working substances[1], the form-stable phase change materials(PCMs) have received more and more attention today. As they always can remain in solid state even when the working materials change from solid to liquid[2], shape-stabilized PCMs can be used in various fields. Even in a fire, lots of heat would be absorbed by the phase change of the working materials and there would be a reduction of the heating rate of the building structure.

Polyethylene glycol (PEG), owing to its considerable latent heat of fusion, congruent melting behavior, resistance to corrosion and suitable melting point range, shows better thermal energy storage properties[3-7]. Particularly PEG with wide molecular weight distribution could be used for thermal energy storage and temperature-control extensively. Feng[8] prepared polyethylene glycol (PEG)/ active carbon (AC) composites as form-stable phase change materials by a blending and impregnating method.

* Corresponding author. Tel.: +86-028-87601741; fax: +86-028-87601545.
E-mail address: chengshou-zhao@163.com

They showed the effects of PEG with different molecular weight and the weight percentages on the structural and thermal properties of the composites. The maximum mass percentage of PEG dispersed into the prepared form-stable PCMs was determined less than 70%. As the sorption capacities of AC totally depend on the effect of capillary, the PEG content in the PEG/AC composites is limited. Grandi[9] used TEOS to synthesize SiO₂-PEG hybrid materials both of class I and II by sol-gel method, needing catalyst. The PEG molecule in hybrid of class II showed an enhanced thermal stability up to 350°C. However, the preparation technologies were complicated[10], showed poor reproducibilities.

In this paper, we prepared the form-stable polyethylene glycol (PEG)/silicon dioxide (SiO₂) composite PCMs with PEG and silicon tetrachloride (STC). STC is a toxic corrosive liquid, extremely harmful to the environment and human security. With the popularity of solar power, more and more polysilicon produced, comes with a large amount of STC by-product. Although the high-purity STC react easily with water, generated silicon dioxide. In this new material, the polyethylene glycol acts the latent heat storage material and silicon dioxide serves as the supporting material, which provides structural strength to prevent the leakage of the melted polyethylene glycol. We investigated the maximum content of PEG in the composite PCMs. Also the structural and thermal properties of the composites were measured by various techniques.

2. Experiments

2.1. Materials

Chemically pure polyethylene glycol (PEG) with an average molecular weight of 6000, was purchased from Chengdu Chemical Agent Company (Chengdu, China). Silicon tetrachloride (SiCl₄) was obtained from a silicon polycrystal factory in Leshan (Leshan, China). Sodium hydroxide (NaOH) was purchased from Chengdu Chemical Agent Company (Chengdu, China).

2.2. Preparation of PEG/SiO₂ PCMs

PEG/SiO₂ PCMs were prepared using sol-gel methods. First, PEG was dissolved in water with a magnetic stirrer at room temperature. Then with a constant pressure funnel the silicon tetrachloride was added to the PEG solution at a certain rate while stirring until the hydrolysis and polycondensation reactions were complete. By-product hydrogen chloride (HCl) could be absorbed by Sodium hydroxide solution prepare in advance. After this, the mixture was dried at 60°C for 72 h, so that the residual hydrochloride would evaporate and the form-stable PEG/SiO₂ PCMs composites were obtained.

When the weight percentage of PEG in the composites was higher than 85 wt%, the gel mixture couldn't be formed. So the PEG contain in the PEG/SiO₂ PCMs was varied from 30 to 85. Also it was found that there was no leakage of the liquid phase when the composite PCMs were kept at 80°C (above the melting point of PEG). Thus, in this paper we mainly discuss the composites with different weight percentages of PEG.

2.3. Performance analysis

The morphology and microstructure of the form-stable PEG/SiO₂ composite PCM was observed using a scanning electronic microscope (SEM, JSM-5900). The thermal properties of the PCMs were obtained using a differential scanning calorimeter (NETZSCH DSC 404 C) at 10°C/min under a constant stream of nitrogen at a flow rate of 20 ml/min in the range from 20°C to 100°C.

3. Results and discussion

3.1. Structure analysis of the form-stable composite PCMs

Fig.1 shows SEM photographs of the microstructures of the form-stable PEG-6000/SiO₂ composite PCM and SiO₂. As seen in Fig. 1a, the SiO₂ has a rough surface. Fig. 1b shows the polyethylene glycol is well dispersed into the network of solid SiO₂ used as supporting material. The multiple porous structure of SiO₂ provided a mechanical strength to the whole compound due to the effect of capillary and surface tension forces between the PEG and the porous network of the SiO₂. Thus, the composite maintained its shape in the solid state without seepage of the melted PEG.

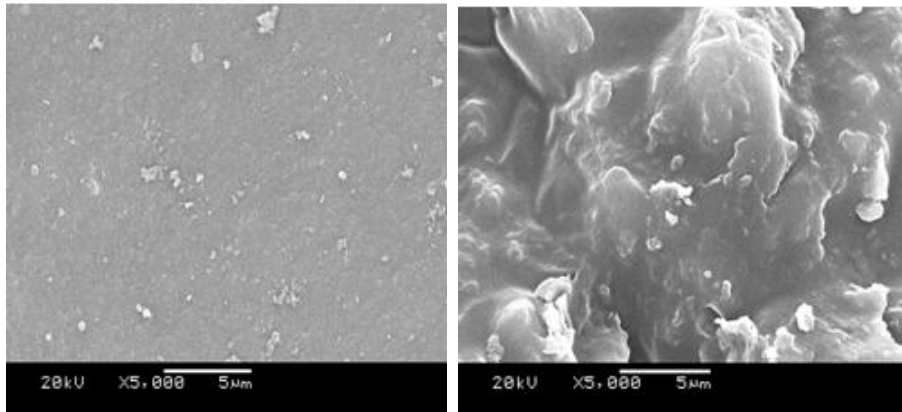


Fig. 1. SEM images of SiO₂ and the PEG-6000/ SiO₂ PCMs: (a) SiO₂, (b) the composite with 80 wt% PEG .

The maximum mass percentage of PEG dispersed into the composites was found to be 85%. There was no leakage of PEG from the composites up to this mass ratio even when it melts.

3.2. Thermal properties of the form-stable composite PCMs

The DSC results of PEG, PEG-80% composite and PEG-60% composite are presented in Fig. 2 and Table 1. As shown in Fig. 2, a phase change of pure PEG6000 happened at 64.6 °C with an enthalpy of 158 J/g while the 80 wt% PEG composite is 133 J/g at 65.6 °C. Table 1 indicates the melting point of the PEG6000/SiO₂ PCMs is lower than that of pure PEG6000, and the melting enthalpy reduced with the decrease in PEG weight percentage. However, the thermal characteristics of the composites are still very close to those of pure PEG, which proved that there is no chemical reaction between PEG6000 and SiO₂.

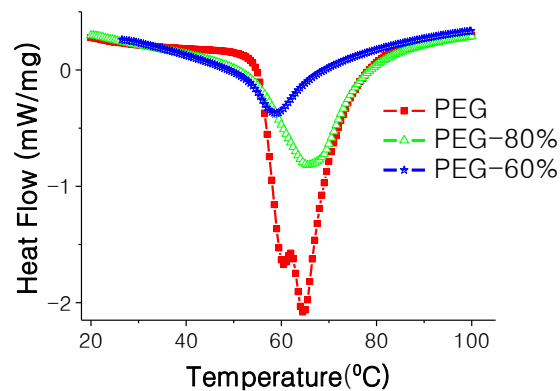


Fig. 2. DSC curves of PEG-6000 and the composites with different weight percentages of PEG .

From Fig.2 it can be seen that there are twin peaks during the phase change process of pure PEG6000 while the composites only has one. This is due to the flaws existence in PEG crystal and in the composites SiO₂ overcomes the differences between the crystals and plays a role in crystal nucleation, which can be also reflected on the latent heat values. Theoretically the PEG-80% composite has 80 wt% PEG, and the latent heat should be 126.4 J/g (133.4 J/g in fact), which prove the crystal nucleation role of SiO₂. However, from Table 1 we know the latent heat of PEG-60% composite is less than the theoretical value. In the compositions silica may help PEG overcome the flaws and crystal nucleation, but also can be the space obstacle to the crystal nucleation of PEG. When the amount of silica is not large, it shows the role of helping crystal nucleation. Otherwise it shows the role of space obstacle.

If the composites were made into mortar which is able to adhere to the surface of building structure, the working materials will absorb the heat released by the burning of the fire. And there will be a decrease in the heating rate of the building structure. More heat was absorbed by the phase change storage materials, more safe the building structure was.

Table 1. DSC data of PEG composites.

Samples	T_i (°C)	T_m (°C)	ΔH (J/g)	$\Delta H'$ (J/g)
PEG-6000	55.4	54.9/64.6	158	158
PEG-80%	53.9	65.6	133.4	126.4
PEG-60%	52.0	58.9	79.43	94.8

4. Conclusions

In summary, a new shape-stabilized PCM was simply prepared by sol-gel methods. By varying the weight percentage of PEG, the structural and thermal properties of the as-prepared PEG6000/ SiO₂ composites were investigated. It was found that the polyethylene glycol was well dispersed into the network of solid SiO₂ due to the effect of capillary and surface tension forces. There was no leakage of PEG from the composites up to this mass ratio even when it melts. And the latent heat of PEG/ SiO₂ can be used to decrease the heating rate of the building structure. So the composite can be made into mortar and adhere to the surface of building structure. In that way, the building structure can be protected by the phase change storage materials.

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