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Study on the Application of Polymer Thermal Energy Storage Materials in Building Energy Conservation System

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The application of polymer thermal energy storage materials in buildings can realize such functions as building temperature regulation, residual heat storage, auxiliary heat storage, and solar energy storage and utilization, which is an effective method for building energy conservation. With the polymer thermal energy storage materials as the form-stable matrix and phase change materials for thermal energy storage as research object, this paper conducts an in-depth study on heat storage mechanism and application of polymer thermal energy storage materials. The results show that the thermal conductivity and phase change energy storage rate determine the performance and efficiency of thermal storage materials, and the thermal conductivity of polymer thermal energy storage material depends mainly on lattice vibration. The latent heat value of the larger thermal energy storage board has a more pronounced adjustment effect on the indoor air temperature, thus can improve the living comfort of the building. The surface temperature increases gradually with the increase of the thickness of the thermal energy storage board, and the total amount of sensible thermal energy and latent thermal energy increase. The greater the thickness of the thermal energy storage board, the higher the indoor temperature at the same time. This study provides a theoretical basis for the application of polymer thermal energy storage material in building energy-saving systems.

1. Introduction

With the rapid development of the construction industry and the improvement of people’s quality of life, the energy consumption of buildings has exceeded 32% of the total energy consumption of the society, and has continued to increase (Feczkó et al., 2016). With the socio-economic development in the next decades or even longer-term, the rapid development of urbanization and infrastructure will promote the sustainable development of the construction industry (Tang et al., 2017). It is estimated that by 2030, energy consumption of the construction industry will surpass that of industry to become the world's largest energy consumer (Nilsson et al., 2016; Gotsmann et al., 2010). At present, the approaches for building energy conservation in China mainly include architectural design (reasonable design and layout of building structure), selection of building materials (wall, roof, door and window, etc.), and rational utilization of clean energy such as solar energy (Duangruedee et al., 2012). With the increasing building energy-saving requirements, a single building energy-saving mode has been unable to meet the requirements. Therefore, composite thermal insulation walls, composite energy-saving wall materials, thermal insulation materials, and polymer thermal energy storage materials have emerged (Goudarzi et al., 2017).

Thermal energy storage modes of thermal energy storage materials in a building include sensible thermal energy storage, latent energy storage and chemical reaction thermal energy storage (Maccarini et al., 2017). Latent thermal energy storage is referred to as phase change thermal energy storage, which utilizes the absorption or release of phase change by polymer materials to achieve the purpose of thermal energy storage. The thermal, kinetic and chemical properties are prerequisite conditions (Ghahramani et al., 2016; Liu et al., 2010). The thermal energy storage medium and the matrix material can compose thermal energy storage functional composite materials, in which PCM thermal energy storage wallboard, interior wall thermal energy regulation wallpaper, PCM cement and gypsum wallboard, PCM independent thermal energy storage unit and other thermal energy storage materials are widely used in the building energy conservation design (Petcharat et al., 2012). At present, the research on the insulation building materials starts earlier and has a

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large number. There are few researches on polymer thermal energy storage materials, thus the researches on their work efficiency and energy conservation effect are urgently needed (Wang et al., 2015). With the polymer fatty acid phase change materials and composite thermal energy storage materials as research objects, this study discusses their thermal energy storage mechanism and application in building energy conservation.

2. Study on Thermal Energy Storage Properties of Fatty Acids and Their Eutectic

The polymer fatty acid material is a natural, non-toxic and widely-sourced natural thermal energy storage material (Gunner et al., 2014). As a phase change energy storage material, it has the advantages of low price, environmental protection and renewability, as well as long-term stability, which can achieve complete reversibility of the melting and solidification process. Two or more fatty acids can be blended to form lower melting eutectic crystals (Assadi et al., 2011; Saidur, 2009). The thermophysical properties of polymer fatty acid materials include phase change temperature, latent heat of phase change, heat capacity and thermal conductivity. Figure 1 is a differential scanning calorimeter curve of the binary eutectic of capric acid and stearic acid, with a melting point of 19.79°C and a heat of fusion of 154.16 kJ/kg. Its phase change temperature is close to the comfort temperature of the human body, which is favorable for the application of energy conservation in buildings. Table 1 shows the swelling volume change rate of capric acid and stearic acid and its eutectic, from where it can be seen that there is no significant difference in the swelling volume change rate between capric acid and stearic acid with their eutectic, which thus does not affect the volume swelling of fatty acids. Figure 2 shows the thermal conductivity values of capric acid, stearic acid and eutectic fatty acids obtained from three tests, which are 0.175, 0.1747 and 0.1747 $W \cdot m^{-1} \cdot K^{-1}$, respectively, and their thermal conductivity is low.

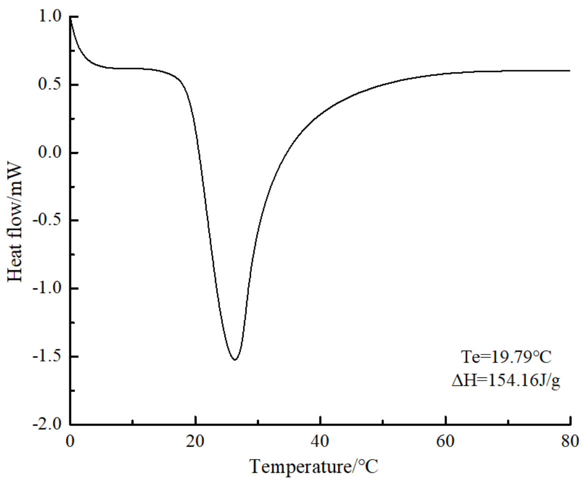


Figure 1: Differential scanning calorimeter curves of the fatty acid binary eutectics (Capric acid-Stearic acid)

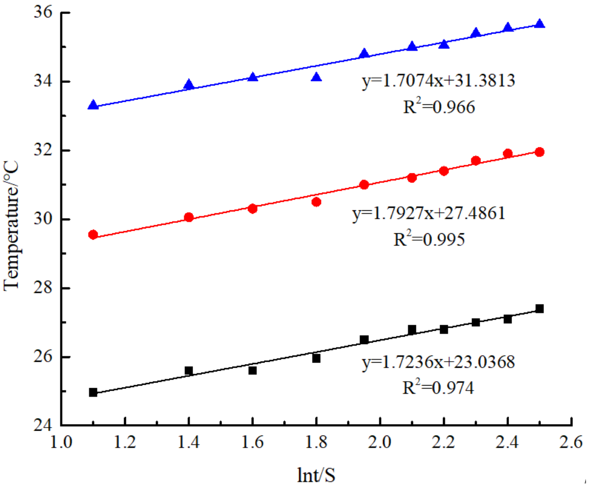


Figure 2: Temperature variation versus ln (t) for thermal conductivity measurement of capric acid-stearic acid

Table 1: Volume variation rate of the capric acid, stearic acid and their eutectics

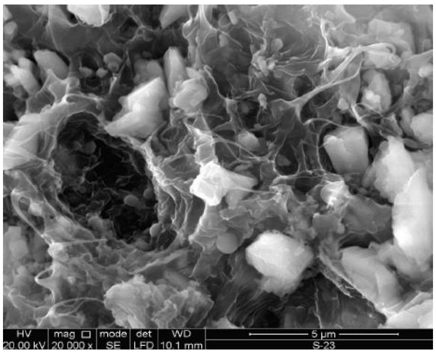
Fatty acid type	Capric acid	Stearic acid	Capric acid-Stearic acid
Swelling volume change rate	12.45	12.09	12.21

3. Study on Thermal Energy Storage Properties of Polymer Fatty Qualitative Acid Phase-Change Materials

3.1 Thermal energy storage and temperature regulation properties of fatty acid-polymethyl methacrylate materials

The polymer materials have the best encapsulating effect on the phase change materials, thus can be used as form-stable matrix, such as polymer polyurethane, acrylic resin, polyolefin, etc. In this experiment, three groups of form-stable phase change material components are designed, including capric acid 50wt%+polymethyl methacrylate 50wt% (PCM1), stearic acid 50wt%+polymethyl methacrylate 50wt% (PCM2), capric acid 38.5wt%+stearic acid 11.5wt %+polymethyl methacrylate 50wt%(PCM3). By controlling the type of fatty acid, the phase transition temperature of the composite phase change material can be adjusted. Figure 3 shows the cross-sectional morphology of capric acid-polymethyl methacrylate and stearic acid-polymethyl methacrylate shaped phase change materials, from where it can be seen that the two fatty acids fuse well with the cross-section of the phase change material, and the structure of the capric acid is more compact. Table 2 shows the latent heat change of phase change of three kinds of polymer thermal energy storage phase change materials. The calculated latent heat of phase change is greater than the measured value of latent heat of phase change, but the rate of change is not large, and both are less than 5%. Table 3 shows the compressive strength values of three types of polymer thermal energy storage phase change materials, from where it can be seen that the polymethyl methacrylate form-stable phase change material mixed with stearic acid has the highest indoor temperature compressive strength, 80°C compressive strength and flexural strength.

In order to investigate the effect of fatty acid content on the polymer phase change materials for thermal energy storage, capric acid- stearic acid contents of 30%, 50%, 60%, 70%, 80% and 100% are selected for experiments. Figure 4 shows the relationship between capric acid- stearic acid content and latent heat of phase change in qualitative phase change materials for polymer thermal energy storage, from where it can be seen that the latent heat of the polymer composite phase change materials for thermal energy storage increases with the increase of the capric acid-stearic acid content, and there is a nearly positive linear relationship between the two. Figure 5 shows the relationship between capric acid- stearic acid content and compressive strength in qualitative phase change materials for polymer thermal energy storage, from where it can be seen that the compressive strength decreases with increasing capric acid-stearic acid content, it is necessary to encapsulate the phase change material by the polymer composite materials and the specific application requires to coordinate the ratio between the two.


(a) PCM1

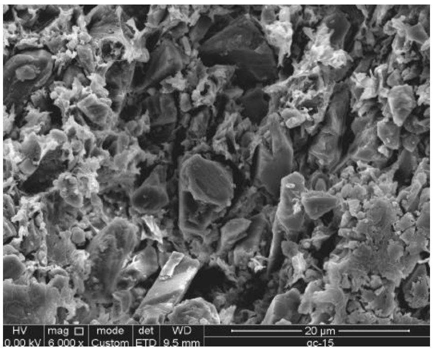

(b) PCM2

Figure 3: Cross section morphology of the citric acid- polymethyl methacrylate, stearic acid- polymethyl methacrylate

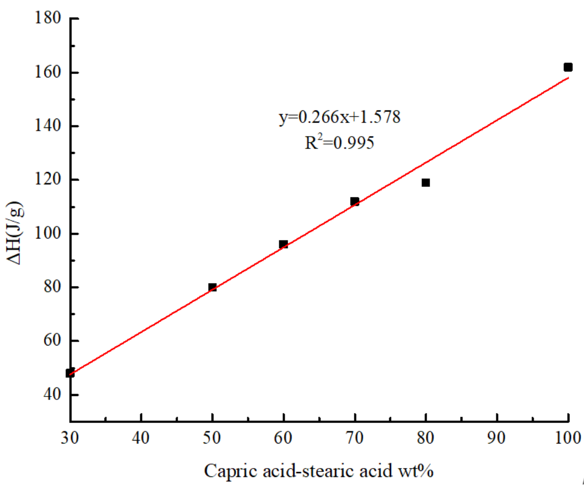


Figure 4: Relationship between capric acid-stearic acid mass fraction and latent heat of the PCM composites

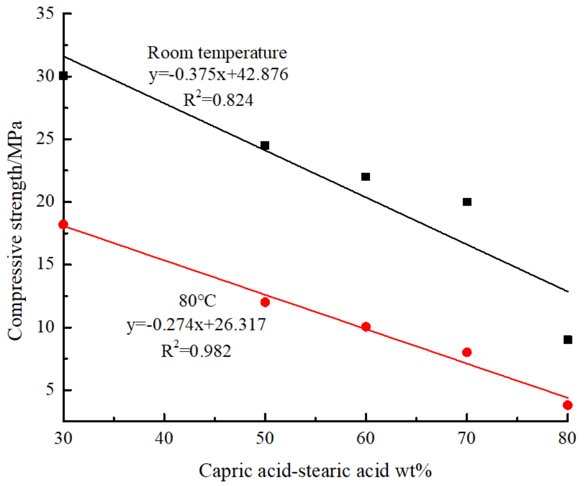


Figure 5: Mechanical properties of the PCM composites

Table 2: Latent heat variation of the form-stable PAMs J/g

Material No.	Latent heat of phase change measurement	Latent heat of phase change calculated value	Change amount	Change rate
PCM1	81.16	84.28	-3.12	3.7%
PCM2	86.24	90.17	-3.93	4.3%
PCM3	59.18	61.18	-2	3.3%

Table 3: Compressive strength of the form stable PCMs MPa

Material No.	PCM1	PCM2	PCM3
Indoor temperature compressive strength	24.87	28.34	27.56
80℃compressive strength	11.03	14.46	13.47
Bending strength	9.84	10.05	9.70

3.2 Analysis of thermal conduction mechanism of composite thermal energy storage materials

The thermal conduction of the composite thermal energy storage material is the process of energy transmission inside the material, and the conduction capability is related to the microstructure of the material and the acting particles. The thermal energy storage material maintains the ambient temperature through the internal thermal conduction. There are two types of thermal conduction: free electron flow and lattice atom thermal vibration. There is no free electron in the polymer. Therefore, the thermal conduction of the polymer thermal energy storage material mainly depends on the lattice vibration. Due to the relatively large molecular weight, disperse distribution, uneven molecular size and irregular molecular chain of the high molecular polymer, it is difficult for it to form a complete crystal lattice, making its thermal conductivity small. Considering the particle shape and the type and orientation of the particles in the system, the thermal conductivity can be calculated as follows: $\lambda=(1+ABV)/(1-B_{\psi}V)$, $B=(\lambda_2/\lambda_1-1)/(\lambda_2/\lambda_1+A)$
In the formula, λ is the thermal conductivity of polymer thermal energy storage material, and the A and V_m markings represent constants related to particle size and traits.

4. Application of Polymer Phase Change Materials for Thermal Energy Storage in Building Energy Conservation

4.1 4.1 Evaluation index of polymer thermal energy storage material for building energy conservation

Polymer thermal energy storage phase change material is a new type of building energy conservation product that has been applied in thermal energy storage of buildings. It can be directly applied to building materials, or prepared as board, strips or blocks which are combined with building materials to constitute energy storage structures. In areas where the temperature varies greatly with the seasons, as the thermal energy storage material system is a composite, the combined phase change material can effectively reduce the irreversible heat loss in the heat transfer process, thus can improve the thermal efficiency. According to the evaluation criteria for building energy conservation insulation enclosure structure, the evaluation index of energy conservation materials includes dry density, thermal conductivity, specific heat capacity, thermal energy storage coefficient, total heat transfer coefficient and thermal inertia index, etc., wherein the thermal conductivity and phase change energy storage rate determine the heat transfer rate inside the material, thus determine the thermal energy storage material’s performance and efficiency.

4.2 Establishment of phase change heat transfer model for building

The operation of the building environment control system is determined by the outdoor climate conditions, the thermal conditions of the indoor thermal energy storage materials, and the indoor and outdoor thermal bridge conditions. A heat transfer physical model is used to establish the floor heat transfer, wall heat transfer, and the simplified room model. A test is conducted by laying a thermal energy storage floor simulation box. Figure 6 shows the temperature variation curve of the thermal energy storage material in the experimental box, indicating that the initial temperature drops quickly in the box, then the speed slows down with the decreasing temperature difference with the room temperature. Finally, the temperature tends to be constant. The simulated temperature, measured temperature, and ambient temperature exhibit the same pattern of change. Figure 7 shows the effect of variation of the latent heat value of three types of thermal energy storage board on the surface temperature and room temperature of the PCM board. The ground surface temperature drops faster in the first 5 hours, after which the change in ground surface temperature tends to be slow. It can be seen from the change in room temperature that the larger latent heat value has a more pronounced adjustment effect on indoor air temperature, thus can improve the living comfort of buildings. Figure 8 shows the temperature and time variations under the effect of polymer phase change thermal energy storage board with different thicknesses. As can be seen in the figure, the surface temperature gradually increases as the thickness of the thermal energy storage plate increases, and both the total sensible heat and the latent heat increase. The greater the thickness of the thermal energy storage board, the higher the indoor temperature will be.

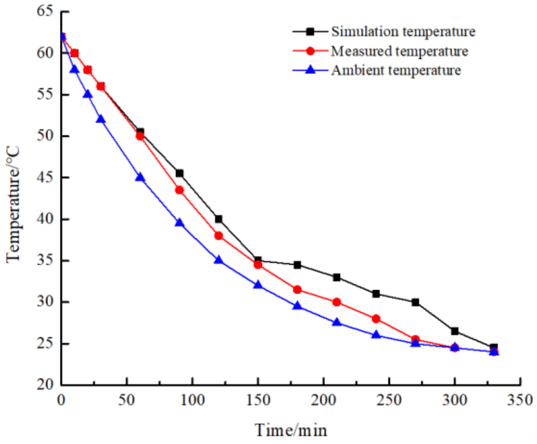


Figure 6: Experimental temperature variation with the form-stable PCM

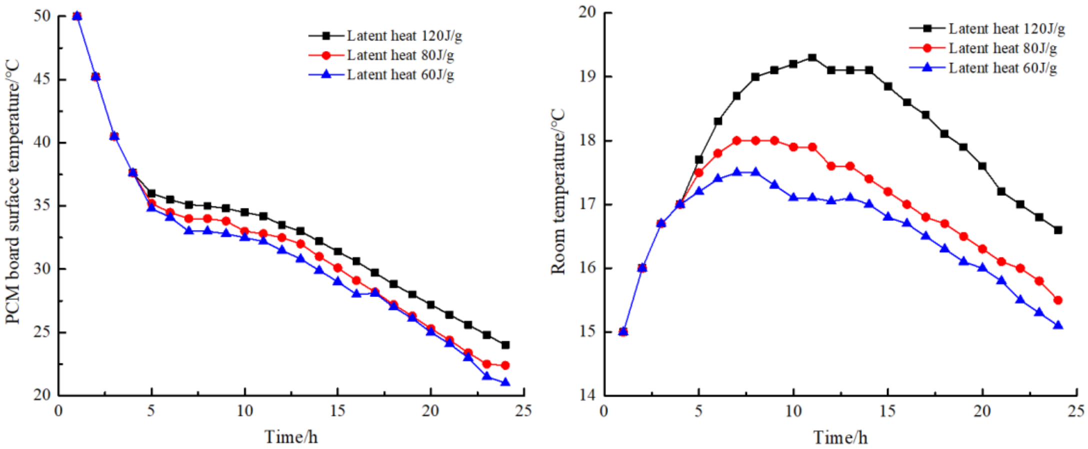


Figure 7: Temperature variation cures affected by the form-stable PCMs with different latent heat values

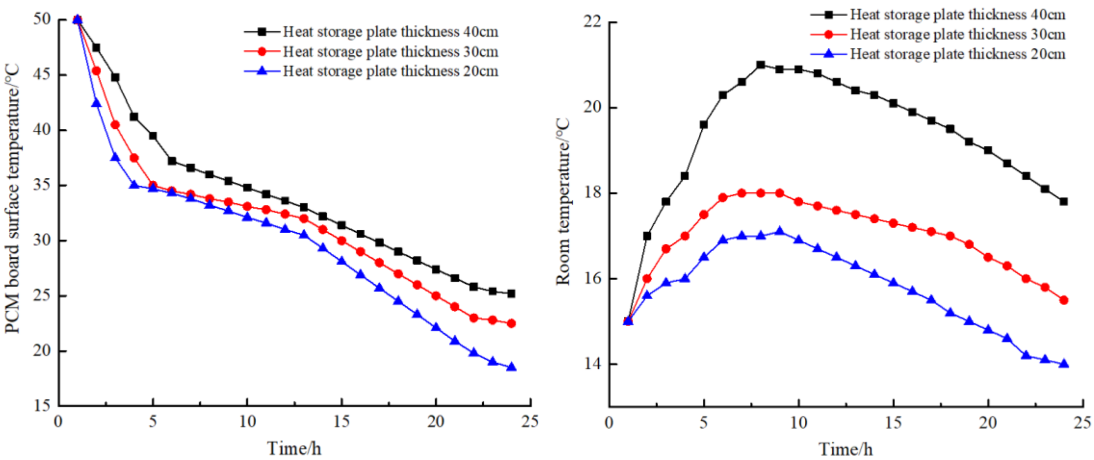


Figure 8: Temperature variation curves affected by the form-stable PCMs with different thicknesses

5. Conclusions

This study investigates the high molecular fatty acid phase change materials and composite thermal energy storage materials, and discusses the thermal energy storage mechanism and its application in building energy conservation in depth. The specific conclusions are as follows:

(1) The high molecular polymer material has the best encapsulating effect on the phase change material, thus can be used as form-stable matrix. The latent heat of the polymer composite phase change material for thermal energy storage increases with the increase of the capric acid-stearic acid content, and there is a nearly positive linear relationship between the two.

(2) The thermal conduction of the polymer thermal energy storage material mainly depends on the lattice vibration. Due to the relatively large molecular weight, disperse distribution, uneven molecular size and irregular molecular chain of the high molecular polymer, it is difficult for it to form a complete crystal lattice, making its thermal conductivity small.

(3) The latent heat value of the larger thermal energy storage board has a more pronounced adjustment effect on the indoor air temperature, thus can improve the living comfort of the building. In addition, the surface temperature increases gradually with the increase of the thickness of the thermal energy storage board, and the total sensible and latent heat increases. The greater the thickness of the thermal energy storage board, the higher the indoor temperature will be.

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