

Effect of carbon fiber on thermal properties of n-Docosane phase change materials

Li Min^{1,2} Wu Zhishen² Chen Zhenqian² Peng Changhai²

(¹Jiangsu Province Key Laboratory of Construction Materials, Southeast University, Nanjing 211189, China)

(²Low-Carbon Building Environment Equipment and System Energy-Saving Engineering Center of Ministry of Education, Southeast University, Nanjing 210096, China)

Abstract: The improvement of the heat transfer rate of phase change material (PCM) is studied by mixing with carbon fiber (CF) which is a good heat conductor. The composite PCM is prepared by blending CF and n-Docosane and its thermal performance is tested using the method of differential scanning calorimetry (DSC) analysis and thermogravimetric/differential thermal analysis (TG/DTA). In addition, the influence of the mixing amount and the length of CF on the thermal conductivity of n-Docosane are investigated. The results show that CF can significantly improve the heat transfer rate of n-Docosane, and the mixing amount and the length of CF are two influence factors. The heat storage and release rates increase with the increase in the mixing amount of CF. Moreover, the melting point of n-Docosane is increased from 40.2 to 50.8 °C after being mixed with CF. The heating time is decreased from 720 to 660 s by mixing with 6% of CF, and is decreased to 600 s by mixing with 10% of CF.

Key words: phase change material; carbon fiber; thermal conductivity; n-Docosane

The phase change material has a unique latent heat performance; i. e., the phase change process is almost isothermal. Therefore, it is beneficial to maintain the temperature variation on a small scale to make indoor people feel comfortable. Moreover, PCM can absorb and release a considerable amount of latent heat during phase change. Compared with sensible heat storage materials such as concrete and brick, latent heat storage materials can greatly reduce the occupied area of building materials. This kind of material is regarded as an environmentally-friendly energy-saving smart material, which has very wide application prospects^[1-3]. It can evidently improve building energy conservation and relieve the contradiction of energy shortages. More attention has been paid to the phase change materials.

In recent years, the International Energy Agency has developed a research proposal about PCM and its application in energy saving of buildings. Europe, America and Japan

participated in the research proposal. A working group studying the application of PCM in buildings and other fields was founded in Australia in December 2003. Recently, overseas scholars have studied thermal analysis and simulation of PCM application in buildings, and have established a thermal exchange theory model as well as the encapsulation technology of PCM. Sarier and Onder^[4] obtained the form-stable PCM by directly injecting two kinds of PCMs (n-octadecane and n-hexadecane) into the honeycomb structure of polyurethane foam. Athienitis et al.^[5] performed experimental and simulation studies of a full-scale outdoor room with PCM gypsum board wall lining with 25% of butyl stearate. They established a detailed finite element difference model to simulate a heat transfer process. The results show that the highest room temperature can drop by 4 °C in the daytime when the PCM gypsum board is used as wallboard, and the heat load can also be significantly decreased at night. On the basis of the finite element difference method, Stetiu and Feustel^[6] developed a heat storage simulation program of PCM wallboard. Krupa et al.^[7] studied the soft and hard paraffin blended with polypropylene. The results show that a polypropylene matrix can maintain the compact shape of PCM.

Different organic polymer bracing materials or capsule materials were used to prepare the form-stable PCM and their thermal performance was studied by scholars in China. Moreover, the experimental studies were carried out in concrete and gypsum board applications. Zheng et al.^[8] developed the technique of immersing a dry gypsum board into liquid paraffin to produce a composite phase change gypsum board. The results show that the phase change temperature drops by 3 °C as paraffin is infiltrated into the gypsum board. The paraffin/high density polyethylene and paraffin/styrene-butadiene-styrene phase change heat storage materials as well as their applications in wall and floor were developed in Tsinghua University^[9-10].

Although the performances and applications of PCMs have been investigated, a problem that PCM has a low conductivity is needed to be solved urgently. Low conductivity of PCM hinders the transfer of the latent heat of PCM. The problem is serious, especially for the form-stable PCM prepared by the encapsulation method, because the thermal resistance between the PCM and the external heat transfer medium is increased during the heat transfer. Some scholars tried to use the CF to improve the thermal conductivity of heat storage materials and prepared high performance composite phase change materials. Mesalhy et al.^[11] used carbon foam and paraffin to prepare paraffin/carbon foam composite phase change materials and studied the influence of

Received 2009-11-17.

Biography: Li Min (1974—), female, doctor, associate professor, limin.li@163.com.

Foundation items: The National Natural Science Foundation of China (No. 50808042), the National Key Technology R&D Program of China during the 11th Five-Year Plan Period (No. 2007BA000875-04), Six Projects Sponsoring Talent Summits of Jiangsu Province, Outstanding Young Teacher Funding Schemes of Southeast University, Open Fund of Key Laboratory of Inorganic and Composite Materials of Jiangsu Province (No. wjjqfxxcl200703), the Scientific Research Foundation for the Returned Overseas Chinese Scholars, State Education Ministry.

Citation: Li Min, Wu Zhishen, Chen Zhenqian, et al. Effect of carbon fiber on thermal properties of n-Docosane phase change materials[J]. Journal of Southeast University (English Edition), 2010, 26(2): 346–350.

the pore structure and the thermal conductivity of carbon foam on the performance of the composite phase change materials. The results show that the thermal conductivity of the carbon foam remarkably influences the heat storage and release rates of composite phase change materials.

The influence of the expanded graphite on the thermal conductivity of the paraffin/high density polyethylene composite phase change material was studied by Sari^[12]. The results show that the thermal conductivity of the composite phase change material rises by 14% and 24% when the mass fractions of the expanded graphite are 1% and 3%, respectively.

CF is an organic fibrous carbon compound which is carbonized in inert atmosphere at high temperature. The CF formed by asphalt and polymer fiber has been commercialized. The CF is a new carbon material with thermal conductivity as high as 1 000 W/(m·K). Moreover, the CF has the merits of low density and good chemical stability. The thermal conductivity and the performance of PCM can be improved noticeably by blending the CF. This study aims to prepare the composite PCM by blending the CF and n-Docosane and investigates the influences of the mixing amount and the length of the CF on the conductivity of n-Docosane.

1 Methodologies

1.1 Materials

PCM used in this study is n-Docosane. The melting point is 40 to 44 °C. The physical properties are listed in Tab. 1. The thermal conductivity of n-Docosane is 0.558 W/(m·K). The n-Docosane is supplied by Kanto Chemical Co., Ltd.

Tab. 1 The physical properties of n-Docosane

Melting point/°C	Flash point/°C	Ignition point/°C	Density/(kg·m ⁻³)	Solubility
40 to 44	149 to 232	260 to 371	900 (20 °C)	Soluble in some organic solvents

The CF is provided by Xingke Dalian CF Co., Ltd. The diameter of original wire is 7 μm, and the short cut length of the CF has three kinds of specifications: 4, 6, 10 mm; the density is 1 760 kg/m³.

1.2 Tests of thermal performance

1.2.1 Tests of the heat storage and release rates

The testing apparatus of the heat storage and release rates is shown in Fig. 1, which consists of the constant temperature water bath, the thermocouple, and the temperature acquisition instrument.

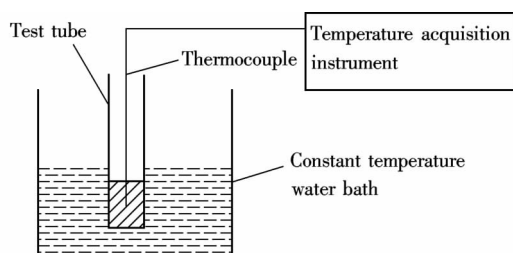


Fig. 1 Apparatus for the test of heat storage and release rates

A 5 g sample is put into a 10 mL test tube, and the thermocouple is inserted into the central position of the sample. The temperatures of the two constant temperature water flumes are set at 54 and 26 °C, respectively. First, the test tube with the sample is put in the constant temperature water flume of 26 °C. Then, the sample is put into the constant temperature water flume of 54 °C when the temperature of the sample reaches 26 °C, and the sample begins to absorb and store heat. Finally, the sample is put into the constant temperature water flume of 26 °C when the temperature of the sample increases to 54 °C, and the sample begins to release the stored heat and the temperature of the sample decreases to 26 °C. This is a storage and release heat process. The temperature-time curve is obtained with a temperature measurement instrument (RQ9008U, Ruiqin Electronic Co., Ltd. China) in the test.

1.2.2 Differential scanning calorimetry

The thermal analysis of n-Docosane is performed by a differential scanning calorimetry (DSC204, Netzsch Instrument Inc., Germany). The DSC measurement is carried out in a nitrogen atmosphere from 0 to 120 °C at a heating rate of 5 °C/min.

1.2.3 Scanning electron microscopy

The morphology of PCM and PCM mixed with the CF are observed with a SEM (JSM-6700F, JEOL, Japan) at an acceleration voltage of 20 kV under low vacuum.

1.2.4 Thermogravimetric/differential thermal analysis (TG/DTA)

The thermal analysis of n-Docosane mixed with the CF is performed by a thermogravimetric/differential thermal analysis (Diamond TG/DTA, Perkin-Elmer Co., Ltd. USA). The TG/DTA measurement is carried out in a nitrogen atmosphere from 0 to 900 °C at a heating rate of 10 °C/min.

2 Results and Discussion

The CF, with a thermal conductivity of 800 to 1200 W/(m·K), is a good heat conductor. Moreover, the CF is compatible with most heat storage materials because it has a strong ability to resist chemical corrosion. In this study, the CF with different lengths and different mixing amounts is mixed into n-Docosane, and the temperature variations of the composite PCM in the heat storage and release process are investigated. The effects of the CF on thermal conductivity of n-Docosane are investigated, and the influences of the length and the mixing amount of the CF on the thermal conductivity of n-Docosane are studied.

2.1 Microstructure of PCM mixed with CF

The SEM image of n-Docosane mixed with the CF is shown in Fig. 2. Fig. 2(b) shows that the CFs randomly disperse in the n-Docosane matrix. Moreover, Fig. 2(a) shows that the CFs combine with n-Docosane well, and some CFs are impregnated by n-Docosane. This is because the CF is compatible with n-Docosane, which leads to a good dispersion of the CF in the n-Docosane matrix.

2.2 Thermal property of PCM mixed with CF

The DSC thermogram of n-Docosane is shown in Fig. 3. The DTA/TG curve of n-Docosane mixed with CF is shown in Fig. 4. It can be seen from Fig. 3 that there are two peaks

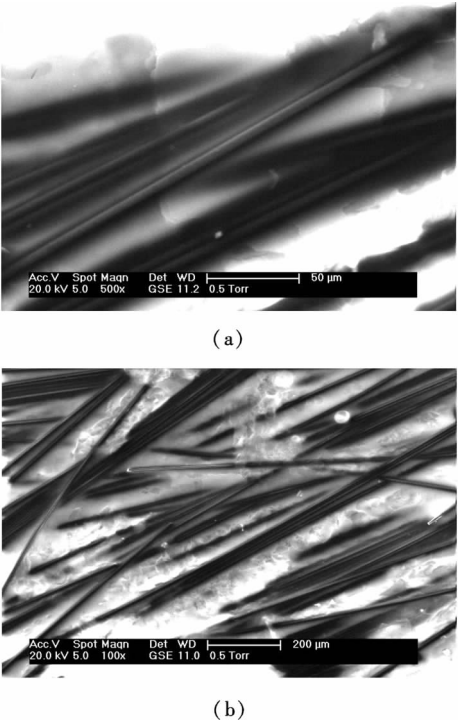


Fig. 2 SEM images of n-Docosane mixed with CF. (a) $\times 500$; (b) $\times 100$

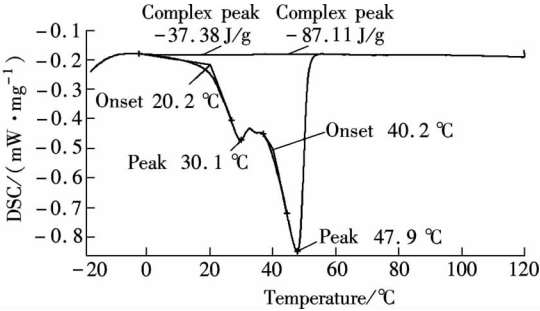


Fig. 3 DSC thermogram of n-Docosane

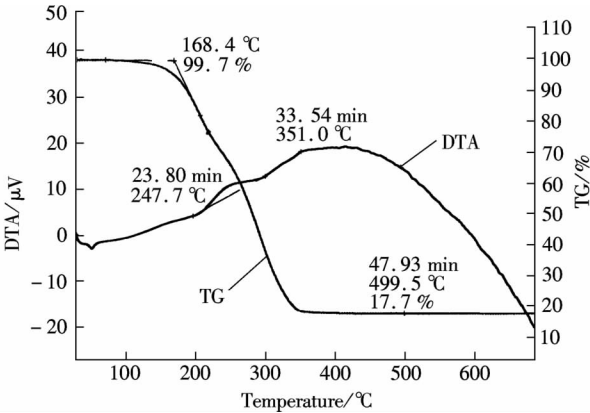


Fig. 4 DSC thermogram of n-Docosane mixed with CF

on the DSC curves. The main peak at the right side represents the solid-liquid phase change of n-Docosane, and the minor peak at the left side represents the solid-solid phase change of n-Docosane. Fig. 3 shows that the melting point of the n-Docosane is 40.2 °C and the phase change heat is 124.49 J/g. Fig. 4 shows that there is an endothermic peak

at 50.8 °C, and there is no thermogravimetric loss at this temperature. This suggests that the corresponding temperature to the endothermic peak is the melting point of the n-Docosane mixed with the CF, which is higher than that of the n-Docosane. Two exothermic peaks at 247.7 and 351.0 °C are due to the thermal decomposition process of n-Docosane, which agrees with the thermogravimetric loss from 100 to 351 °C in Fig. 4. And the thermogravimetric loss is as high as 17.7%.

2.3 Effect of mixing amount on thermal conductivity of n-Docosane

Figs. 5 and 6 show the temperature-time curves of PCM with and without the CF during the heat storage and release processes, respectively. The length of the mixed CF is 4 mm, and the mixing amounts are 6% and 10%. In Fig. 5, P100CF0 means that the mass fraction of n-Docosane and CF are 100% and 0%, respectively. The other legends in this paper have similar meaning.

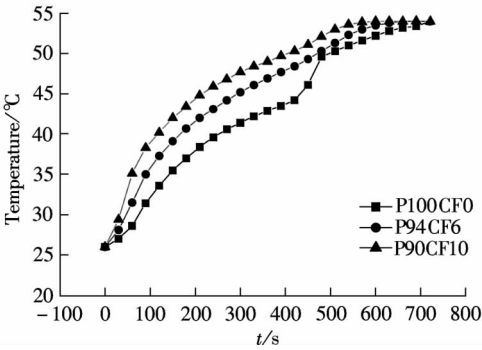


Fig. 5 Temperature-time curves of PCM with and without CF during heat storage process

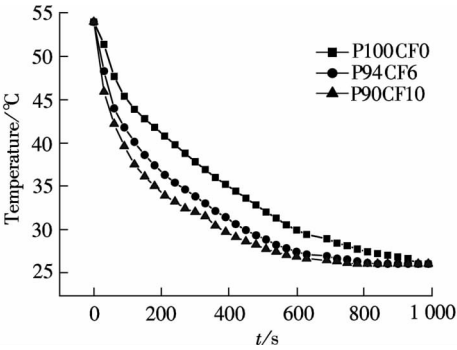


Fig. 6 Temperature-time curves of PCM with and without CF during heat release process

The heat storage and release rates are determined by heating time and cooling time in the same temperature range, respectively. Fig. 5 shows that the heating time is decreased from 720 to 660 s by mixing with 6% of the CF, and is decreased to 600 s by mixing with 10% of the CF. Fig. 6 shows that the cooling time is decreased from 960 to 840 s by mixing with 6% of the CF, and is decreased to 780 s by mixing with 10% of the CF. The decrease in the heat storage time and the reduction in the heat release time of composite PCM show the thermal conductivity improvement of n-Docosane. This is because the CFs with high heat conductivity not only can improve the thermal conduction diffusion

of n-Docosane in the liquid and solid states, but also can improve the thermal convection diffusion during the phase change of solid and liquid states of n-Docosane.

2.4 Effect of length of CF on thermal conductivity of n-Docosane

The CFs are distributed in a disordered form in n-Docosane and a network structure is formed by the CFs. The CFs with different lengths in n-Docosane have different stagger connecting manners when the mass fraction of the mixed CF is the same. So, they have different contributions to the improvement of the thermal conductivity of n-Docosane. Figs. 7 and 8 show the temperature-time curves of the composite PCM with 6% and 10% of the CF during the heat storage process, respectively. The lengths of the CF are 4, 6 and 10 mm, respectively.

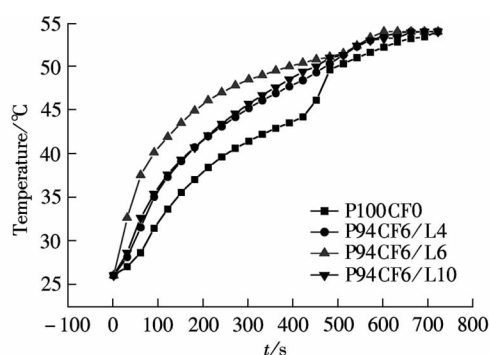


Fig. 7 Effect of length of CF with 6% of mixing amount on thermal conductivity of n-Docosane

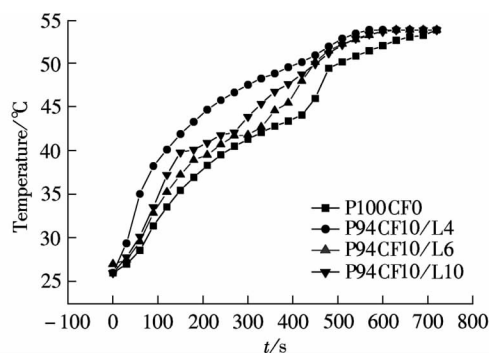


Fig. 8 Effect of length of CF with 10% of mixing amount on thermal conductivity of n-Docosane

The results show that the length of the CF has an influence on the improvement degree of the heat storage rate. The optimum length of the CF in improving the heat storage rate changes with different mixing amounts of the CFs. In the case of 6% of CF mixing amount, the endothermic rate is improved most by the CF with a length of 6 mm, and the melting time is 600 s. However, in the case of 10% of CF mixing amount, the CF with a length of 4 mm contributes most to the improvement of the endothermic rate of n-Docosane, and the melting time is 570 s. With the same mixing amount of the CFs, the shorter the CFs are, the more the number of single CFs is. The results can be explained by the fact that the optimum network structure in the n-Docosane matrix is formed by an appropriate number of single CFs.

3 Conclusion

A composite PCM is prepared by blending the CF and n-Docosane. The thermal properties such as heat storage and release rates are improved by blending the CF, and the CF can be considered as an effective additive to improve the thermal conductivity of n-Docosane.

The melting point of n-Docosane is increased from 40.2 to 50.8 °C after being mixed with the CFs. The heat storage and release rates increase with the increase in the mixing amount of the CF. The heating time is decreased from 720 to 660 s by mixing with 6% of the CF, and is decreased to 600 s by mixing with 10% of the CF. The length of the CF has an influence on the improvement degree of the heat storage rate. For 6% of the CF mixing amount, the endothermic rate is raised more by the CF with a length of 6 mm than by the CF with a length of 4 or 10 mm. However, for 10% of the CF mixing amount, the CF with a length of 4 mm is the best choice to improve the endothermic rate of n-Docosane.

References

- [1] Demirbas M F. Thermal energy storage and phase change materials: an overview[J]. *Energy Sources, Part B—Economics Planning and Policy*, 2006, **1**(1): 85–95.
- [2] Zalba B, Marin J M, Cabeza L F, et al. Review on thermal energy storage with phase change: materials, heat transfer analysis and applications[J]. *Applied Thermal Engineering*, 2003, **23**(3): 251–283.
- [3] Sharma A, Tyagi V V, Chen C R, et al. Review on thermal energy storage with phase change materials and applications [J]. *Renewable and Sustainable Energy Reviews*, 2009, **13** (2): 318–345.
- [4] Sarier N, Onder E. Thermal characteristics of polyurethane foams incorporated with phase change materials[J]. *Thermochimica Acta*, 2007, **454**(2): 90–98.
- [5] Athienitis A K, Liu C, Hawes D, et al. Investigation of the thermal performance of a passive solar test-room with wall latent heat storage[J]. *Building Environ*, 1997, **32**(5): 405–410.
- [6] Stetiu C, Feustel H E. Phase change wallboard as an alternative to compressor cooling in Californian residences [C]// *Proceedings of ACEE Summer Study for Energy Efficient Building*. Asilomar, CA, USA, 1996: 157–163.
- [7] Krupa I, Mikova G, Luyt A S. Phase change materials based on low-density polyethylene/paraffin wax blends[J]. *European Polymer Journal*, 2007, **43**(9): 4695–4705.
- [8] Zheng L H, Song G S, Wei Y L, et al. Preparation of figuration phase change material with gypsum as supporting material and its thermal characteristics[J]. *New Building Materials*, 2006, **33**(1): 49–50. (in Chinese)
- [9] Lin K P, Zhang Y P, Di H F, et al. Study of an electrical heating system with ductless air supply and shape-stabilized PCM for thermal storage[J]. *Energy Conversion and Management*, 2007, **48**(7): 2016–2024.
- [10] Zhang Y P, Lin K P, Yang R, et al. Preparation, thermal performance and application of shape-stabilized PCM in energy efficient buildings [J]. *Energy and Building*, 2006, **38** (10): 1262–1269.
- [11] Mesalhy O, Lafdi K, Elgafy A. Carbon foam matrices saturated with PCM for thermal protection purpose[J]. *Carbon*, 2006, **44**(10): 2080–2088.

[12] Sari A. Form-stable paraffin/high density polyethylene composites as solid-liquid phase change material for thermal energy storage: preparation and thermal properties[J]. *Energy Conversion and Management*, 2004, **45**(13): 2033 – 2042.

碳纤维对甘二烷相变材料热性能的影响

李 敏^{1,2} 吴智深² 陈振乾² 彭昌海²

(¹ 东南大学江苏省土木工程材料重点实验室, 南京 211189)
(² 东南大学低碳型建筑环境设备与系统节能教育部工程研究中心, 南京 210096)

摘要:对采用热的良导体——碳纤维改善相变材料的热传导速率开展了研究. 通过碳纤维与甘二烷的物理混合制备了相变复合材料. 采用示差扫描分析法、热重分析法和差示热分析法测试了此相变复合材料的热性能. 研究了碳纤维的掺量与长度对甘二烷热传导性能的影响. 研究表明, 碳纤维能有效地改善甘二烷的热传导速率, 碳纤维的掺量和长度是 2 个主要的影响因素. 随着碳纤维掺量的增加, 甘二烷的储热、放热速率增加. 掺入碳纤维后, 甘二烷的熔点从 40.2 ℃ 增加到 50.8 ℃. 当掺入 6% 的碳纤维后, 升温所需时间从 720 s 降至 660 s; 当掺入 10% 的碳纤维后, 升温所需时间从 720 s 降至 600 s.

关键词:相变材料; 碳纤维; 导热性; 甘二烷

中图分类号:TQ0