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Study on Straw Micron Pores Encapsulating Paraffin and Performance of Its Shape-Stabilized Phase Change Materials†

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Paraffin was first encapsulated in straw by impregnation method and then the shape-stabilized straw-paraffin phase change material (SPCM) was prepared by molded method with pure acrylic emulsion as binder. The influence of impregnation temperature on the loading ratio as well as the leakage ratio of straw-paraffin phase change material under thermal cycling was investigated. The micron structure and thermal properties of straw-paraffin phase change material were analyzed by scanning electron microscopy (SEM) and differential scanning calorimeter (DSC), respectively and then influence of straw micron pores on encapsulating effectiveness were discussed. The results indicated that the loading ratios of paraffin in wheat straw at 60 and 120 °C were 319.8 % and 443.6 %, respectively. The leakage ratio of paraffin in straw-paraffin phase change material was 0.83 % at 30 phase change cycles. It was pointed that the additional pressure from capillarity on liquid in micron pores of straw can inhibit the leaking of liquid, suggesting that the micron materials were good encapsulating materials for phase change materials.

Keywords: Phase change materials, Straw, Paraffin, Encapsulation.

INTRODUCTION

Generally, phase change material (PCM) was used to store, release and regulate energy demanding since it can adsorb or release heat at phase change temperature[1]. Therefore, it had a widespread application prospect in energy-efficient buildings and waste heat recycle, *etc.*[2]. The shape-stabilized phase change material was obtained by encapsulating phase change material in support materials. There were many methods to encapsulate, which mainly were mixing method, soaking method, polymer cross linking method, micro-encapsulated method and nano-materials composite method[3-7], *etc*. The support materials were mainly gypsum, polyolefins, epoxy resins, polymer capsule wall materials, expanded graphite, expanded perlite and kaolin and so on. In this field, one of the research hot topics was how to inhabit the leak of phase change material phase change liquid[8-10]. Straw was a kind of agricultural waste, which could be a potential support material because it contained lots of micron pores therein. In this study, we chose straw as encapsulation material and studied the performance of straw-paraffin phase change material and its shape-stabilized phase change material.

EXPERIMENTAL

Crop straw (wheat straw and rice straw, chopped into 5 mm by chaff-cutter, Yancheng Jiangsu province); hybrid paraffin (industrial grade, Haizhou chemical materials co., LTD, Dongtai); S-800 pure acrylic emulsion (the copolymer of acrylic acid, methacrylic acid, methyl methacrylate and acrylic, Shengda chemical co., LTD, Nantong).

The thermal properties were performed on DSC200 F3 differential scanning calorimeter (DSC), N_2 atmosphere, heating rate: 5 K/min; Microscopy images were taken with a QUANTA2000 scanning electron microscope (SEM).

The straw (W_0) was dried in an oven at 120 °C for 24 h, then immersed into liquid paraffin for 24 h at designed temperature and finally removed the fluids and weighted (W_1). The mass ratio of loading (r) was calculated according to the following equation:

$$r\ (\%) = \frac{(W_1 - W_0)}{W_0} \times 100 \quad (1)$$

The resulting sample was denoted as straw-paraffin phase change material.

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Spray evenly pure acrylic emulsion on the surface of straw-paraffin with the mass ratio of pure acrylic emulsion and straw-paraffin at 1:6 and then the resulting sample was molded into 360 mm × 240 mm × 30 mm at 1 MPa for 2 h. The resulting sample was denoted as shape-stabilized straw-paraffin phase change material (SPCM).

Place a certain mass of straw-paraffin phase change material and straw-paraffin phase change material on filter paper, respectively and then treated them in a cold-thermal cycling (20 °C and 70 °C, 2°C/min). To guarantee the experimental accuracy, these samples were all kept at hot and cold spot temperatures for 1 h during every cycle. The leakage ratios of paraffin were calculated according to the qualitative change during 5, 10, 15, 20, 25 and 30 cycles.

RESULTS AND DISCUSSION

Influence of preparation temperature on loading ratio: Fig. 1 showed the loading ratio curves of rice straw and wheat straw under different preparation temperatures. As shown in a range of temperature (60-160 °C), the loading ratio increased with the preparation temperature increasing and the optimum temperatures for rice straw and wheat straw were 140 and 120 °C, respectively. The loading ratios of paraffin in rice straw at 60 and 140 °C were 248.8 and 366.7 %, respectively, that was, the high temperature had positive effect on the loading of paraffin which may be due to the low viscosity of paraffin at high temperatures. When the temperature increase over the optimum value, the micron pores structure of straw was destroyed because of carbonization, as a result, the loading ratio decreased. It was worth mentioning that the loading ratio of wheat straw was higher than that of rice straw. This was because that compared with rice straw, wheat straw had higher porosity and more developed spatial reticular structure. Therefore, wheat straw was chosen for the following research.

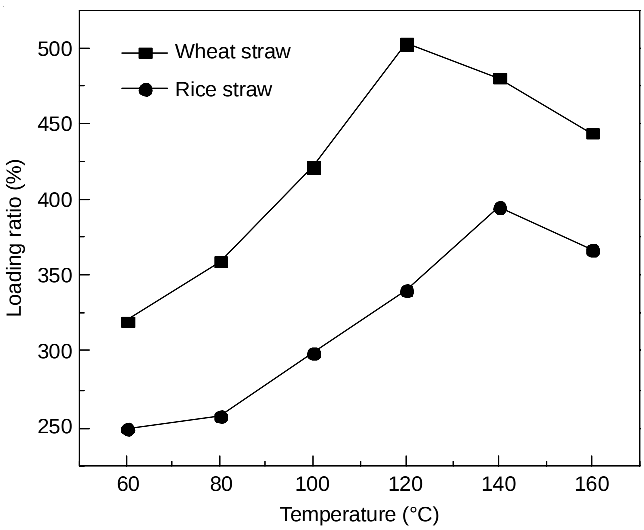

Fig. 1. Loading ratio of paraffin in straw

Fig. 2 showed the SEM image of wheat straw-paraffin phase change material. The continuous phase was the wall of straw. Paraffin adsorbed in the inner wall of micron pores and was spherical with 2-10 μm in diameter because of the effect of interfacial tension. As shown in the figure, the paraffin spherical distributed evenly in the inner wall of straw and the fill ratio was relatively high.

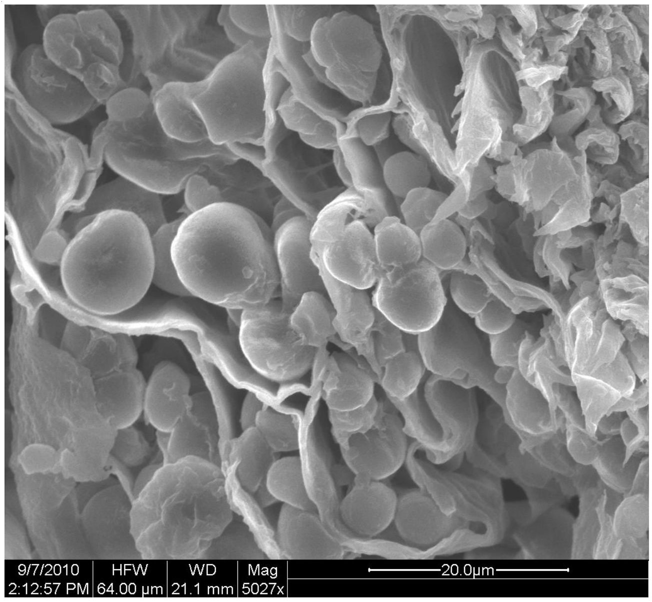

Fig. 2. Morphology of paraffin in the straw

Heat storing performance of wheat straw-paraffin phase change material: Fig. 3 gave the TG-DSC curves of pure paraffin and wheat straw-paraffin phase change material. According to the endothermic peak area, we calculated the latent heat of pure paraffin and wheat straw-paraffin phase change material were about 214.1 and 178.7 J/g, respectively. It was obvious that the latent heat of wheat straw-paraffin phase change material was slightly smaller than that of the pure paraffin, which indicated that straw had no significant influence on the phase change temperature of paraffin. In addition, the highest load ratio of paraffin in straw was 502 %, that was, the mass ratio of paraffin in wheat straw-paraffin phase change material was 83.3 %, the same as that of the latent heat ratio of wheat straw-paraffin phase change material and pure paraffin. This was evident that the latent heat of phase change material was only related with the mass ratio of paraffin.

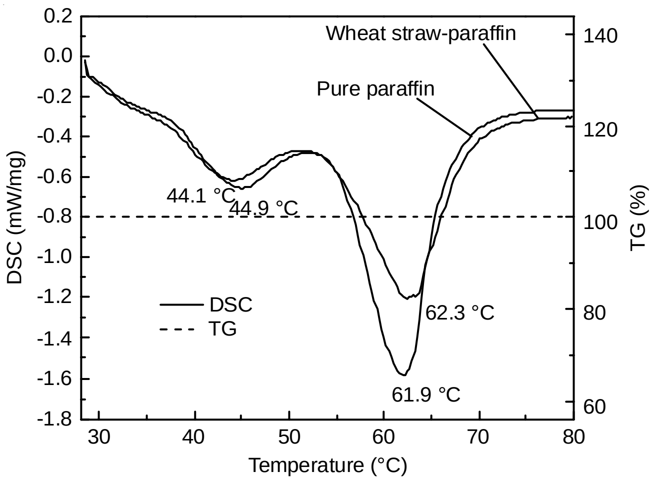

Fig. 3. TG-DSC curve of paraffin and wheat straw-paraffin

Leakage ratios of straw-paraffin phase change material and straw-paraffin phase change material: Fig. 4 presented

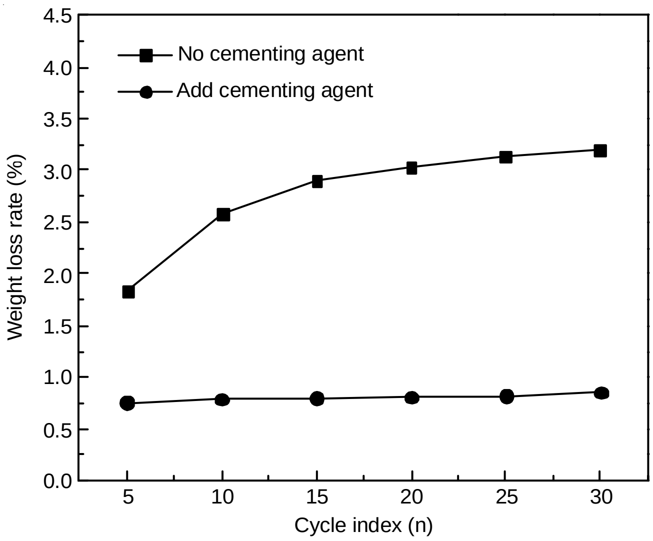

Fig. 4. Leakage ratios of straw-paraffin phase change material

the leakage ratio curves of wheat straw-paraffin and straw-paraffin phase change material. The ratio of wheat straw-paraffin increased slightly with the number of cold-thermal cycling times increasing, starting out at 1.83 % at 5 loops and going up to about 3.20 % at 30 loops. It reflected that the straw had good encapsulating effectiveness for phase change materials. The leakage ratios of straw-paraffin phase change material were merely 0.77 and 0.83 % after 5 and 30 loops, respectively, it reflects pure acrylic emulsion can further inhibit the leakage of paraffin.

In addition, there were much disconnected closed micron pores in wheat straw. Therefore, a certain pressure formed due to the capillarity, which can prevent leaking to a certain extent. Previous research had shown that the diameter of micron pores in wheat straw was about 20-50 μm and the surface tension (γ) of paraffin at 60 °C was 26.2 mN/m, so the additional pressure (P_S) of paraffin in straw-paraffin phase change material was about 0.262-1.048 kPa, which was calculated by the equation 2. The additional pressure was big enough to fix the liquid paraffin in wheat straw-paraffin phase change material.

$$\text{Additional pressure } (P_S) = \frac{2\gamma}{R} \qquad (2)$$

where, R: curvature radius.

Conclusion

The straw can load large amount of phase change material, loading ratios of paraffin in wheat straw at 60 and 120 °C were 319.8 and 443.6 %, respectively. The leakage ratios of paraffin in straw-paraffin phase change material was 0.83 % at 30 phase change cycles. It was pointed that the additional pressure from capillarity on liquid in micron pores of straw can inhibit the leaking of liquid. Our study developed a new way to encapsulating phase change material by the straw with micron pores structure.

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