A new photothermal conversion and thermo-regulated fibres

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Photothermal conversion and thermo-regulated fibres (PCTFs) have been prepared using the fibre-forming polymer containing photothermal conversion ceramic as sheath and the fibre-forming polymer containing microPCMs as core. The structures and properties of the PCT fibres, such as mechanical property, photothermal conversion ability, and temperature-regulating ability, have been studied using DSC, IR lamp, temperature sensors and SEM. It is observed that the photothermal conversion and thermo-regulated fibres have better photothermal conversion and temperature-regulating abilities when compared with the control. The maximum heat absorbing and heat releasing temperature differences are found to be 4.5°C and 6.5°C respectively when the PCTF nonwoven is compared with PP nonwoven.

Keywords: Microencapsulated phase change material, Photothermal conversion ceramic, Polypropylene, Thermo-regulated fibre

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1 Introduction

The technology for applying phase change material (PCM) to textile fibres or fabrics to improve their thermal performance was developed in 1980s under the NASA research project. The PCM possesses the ability to store and release a large amount of latent heat when they go through solid-liquid transitions. By selecting the materials that change phase around skin temperature, the textiles containing PCM can create a thermo-regulating effect, responding to temperature changes between the human body and the outside environment. Therefore, the study of heat-storage and thermo-regulated textiles has attracted more and more attention in recent years. The wet-spun polyacrylonitrile (PAN) fibre that contains microPCMs has been developed during 1997 (ref.4). However, the content of microPCMs in the wet-spun PAN fibre was only 6-7% (w/w). Later, the polypropylene (PP) and poly(butylene terephthalate)(PBT) fibres containing 3%(w/w) microPCMs were melt-spun in laboratory. However, the 3%(w/w) amount of microPCMs was too low to push the fibre into the market. The study on the use of photothermal conversion ceramic as sheath and the microencapsulated phase change material as core for manufacturing heat storage and thermo-regulated composite fibres has not been reported so far. The effect of microPCMs content on the properties of heat-storage and thermo-regulated fibres has also not been reported. The present work was, therefore, aimed at preparing the photothermal conversion and thermo-regulated fibres (PCTFs) using fibre-forming polymer containing photothermal conversion ceramic as sheath and the fibre-forming polymer containing microPCMs as core. The properties, such as mechanical property, latent heat, heat storage, temperature regulation ability and photothermal conversion ability, of the fibre and the nonwoven made out of it have also been studied.

2 Materials and Methods

2.1 Materials

2.1.1 Chips

The phase change material was selected from the hydrocarbons with predetermined melting and crystallizing temperatures (Table 1). In this work, octadecane was selected as phase change material. The microcapsules containing the phase change materials were synthesized using certain thermoplastic resin as container by in-situ polymerization in the laboratory and the diameter range of microcapsule was between 1μm and 10μm. The microPCMs powders and polyethylene were mixed, melt extruded into water, cut into the chips...
and then used as core components. The 4% (w/w) of photothermal conversion ceramic (ZrC) and the polypropylene were melt extruded into water, cut into the chips and then used as sheath components.

2.1.2 Fibre
The polyethylene polymer containing microencapsulated phase change material was used as core component and the polypropylene containing 4% (w/w) photothermal conversion ceramic was used as sheath component. In a weight ratio of 6/4 (core/sheath), the photothermal conversion and thermo-regulated sheath/core composite fibres (PCTFs) were melt spun. The PCT fibres were curled, cut and then used for manufacturing nonwoven (weight, 400g/m²). For the study, three different samples of PCTFs, namely HT1, HT2 and HT3, having 6%, 9% and 12% of PCMs respectively were prepared.

2.2 Methods

2.2.1 SEM Study
Scanning electron photomicrographs of PCTFs were taken by KYKY-2800 (20kV) instrument produced by Beijing Zhongke Keyi Technology Development Ltd. The specimens were coated with silver in ion sputtering device under vacuum for 5 min.

2.2.2 Differential Scanning Calorimetric (DSC) Analysis
DSC analysis was conducted using a Perkin-Elmer DSC-7 instrument. The 6-8 mg specimen was put in aluminum holder. Thermographs for both PCTF powders (HT1, HT2 and HT3) and chips (samples S₁, S₂ and S₃) were recorded under the protection of ultra pure dry nitrogen. The temperature of rising and cooling rate was 10°C/min.

2.2.3 Measurement of Temperature Regulation Ability
To test the temperature regulation ability of the PCTF nonwoven, the microencapsulated phase change material must change from liquid to solid and vice versa. The effect can be studied when fabrics go through a temperature change. Therefore, the test was conducted in both warm and cold conditions. The inner temperature of PCTF nonwoven and polypropylene nonwoven was measured using thermographs when the atmospheric temperature changes from 0°C to 50°C and from 50°C to 0°C. The inner temperature of sample and the measurement time recorded are given below:

\[ T_s \quad \text{inner temperature of PCTF sample} \]
\[ T_p \quad \text{inner temperature of PP sample (control)} \]
\[ \Delta T_d (T_s - T_p) \quad \text{maximum difference in temperature of PCTF and PP nonwoven during temperature rising process.} \]
\[ \Delta T_g (T_s - T_p) \quad \text{maximum difference in temperature of PCTF and PP nonwoven during temperature decreasing process.} \]

2.2.4 Measurement of Photothermal Conversion Ability
It was reported that the carbides of IV group metals have the ability of absorbing the energy of wavelength less than 2 μm and thoroughly reflecting the ray of wavelength longer than 2 μm in the solar radiation spectrum. To test this photothermal conversion ability, the experiment was conducted under IR lamp (250W, 1-2.5 μm spectrum) irradiation. The test results of the PCTF nonwoven and the polypropylene nonwoven were recorded after every 2 min and compared.

3 Results and Discussion

3.1 Composition and Phase Change Properties of Chips
The phase change properties of chips containing microencapsulated phase change material are shown in the Table 2.

The heat capacity or enthalpy of the chips depends on the content of PCMs. Obviously, the measured capacity or enthalpy of the chips is lower than the calculated value of the chips. This is probably due to the lower heat conductivity of the chips containing microcapsule; the heat enthalpy of the microcapsule decreases. In general, the chips show a higher enthalpy or heat capacity with the increase in microencapsulated phase change material content.

3.2 Structure and Properties of PCTF
The scanning electron photomicrographs of the cross-section of melt-spun PCT fibre is shown in Fig. 1. The sheath component was able to surround the core component containing microPCMs (Fig. 1a).
Table 2—Composition and phase change properties of chips

<table>
<thead>
<tr>
<th>Sample</th>
<th>Content of microPCMs, %w</th>
<th>Tm, °C</th>
<th>ΔHm, J/g</th>
<th>Tc, °C</th>
<th>ΔHc, J/g</th>
<th>ΔH, J/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>10</td>
<td>30.83</td>
<td>3.93</td>
<td>13.48</td>
<td>6.43</td>
<td>15.69</td>
</tr>
<tr>
<td>S2</td>
<td>15</td>
<td>30.75</td>
<td>17.93</td>
<td>11.08</td>
<td>19.7</td>
<td>23.53</td>
</tr>
<tr>
<td>S3</td>
<td>20</td>
<td>32.32</td>
<td>33.78</td>
<td>11.33</td>
<td>27.7</td>
<td>31.37</td>
</tr>
</tbody>
</table>

Tm—Melting point, Tc—Crystallization point, ΔHm—Heat of melting, ΔHc—Heat of crystallization, ΔH—Heat enthalpy calculated from microPCMs.

The cross-section of the PCT fibre has some holes that are possibly due to the thermal degradation of microcapsule wall and release of microcapsule core material (Fig. 1b). The reasons still need to be further studied.

The composition and mechanical properties of PCTF are shown in Table 3. The microPCMs content of the PCTF is in the range of 6-12% which is higher than that of the melt-spun PP or PBT fibre containing 3% (w/w) microPCMs. The factors that affect the tenacity and elongation of PCT fibre are content of microPCMs, polymer type and sheath/core ratio.

3.3 Temperature Regulation Ability

Using the same mass per unit area, the temperature regulation ability was measured between the PCTF nonwoven samples and the PP nonwoven (control). It is observed that all the PCTF samples show temperature regulation ability as compared to control (Table 4). The higher the microPCMs content, the higher is the heat storage and thermo-regulated ability of textile. The microcapsule incorporated into fibre
melts and absorbs heat energy with increasing temperature. The temperature of PCTF nonwovens was lower than that of PP control and the superheating phenomenon did not occur. During the process of melting and heat absorbing, the nonwovens containing microPCMs can show thermo-regulating effect (Fig. 2). On the contrary, the temperature of PCTF nonwovens was higher than that of PP control due to the PCM crystallization and heat releasing. The nonwovens containing microPCMs show heat-retaining effect but do not show supercooling phenomenon (Fig. 3). However, to enhance thermal performance of textile, the microPCMs incorporated into fibre should be as high as possible.

3.4 Photothermal Conversion Ability
Using the same mass per unit area, the photothermal conversion ability was measured between the PCTF nonwoven and the PP nonwoven (control). The sample containing 4% (w/w) zirconium carbide and 9% microPCMs (HT2) was selected to study the photothermal conversion ability. Compared to the polypropylene nonwoven, the HT2 nonwoven has better heat storage and heat insulation properties. The maximum difference in temperature of two types of nonwoven is 5.7°C when exposed to near infrared ray. The minimum difference in temperature between PCTF sample and PP sample is 2.2°C when the IR ray is cut off (Fig. 4). The results show that the PCT fibre has better light absorbing property in the near infrared ray and visible light. The PCT fibre can convert the near infrared and visible light into heat energy much easier than PP.

4 Conclusions
4.1 The photothermal conversion and thermo-regulated sheath/core composite fibre has been, for the first time, successfully melt spun with the chips using polyethylene mixed with microencapsulated phase change material as core and polypropylene containing photothermal conversion ceramic as sheath.
4.2 The content of microPCMs in the PCT fibre can be varied up to 12% (w/w), which is higher than that of the PAN or PBT fibre. Further work should be focused on how much amount of microencapsulated phase change material can be incorporated into the spinning of chemical fibre and on the study of the relationship between the amount of microPCMs in
textile and the comfortable performance of the human body.

4.3 The maximum heat absorbing temperature difference is 4.5°C and the maximum heat releasing temperature difference is 6.5°C when the PCTF nonwoven is compared with PP nonwoven.

4.4 When exposed to the near infrared ray, the temperature rising rate of PCTF nonwoven is evidently faster than that of polypropylene nonwoven. The maximum difference in temperature of two types of nonwoven is 5.7°C when exposed to near infrared ray. The minimum difference in temperature between photothermal conversion fibre nonwoven and PP sample is 2.2°C when the IR ray is cut off. The results show that the PCT fibre is able to not only convert the near infrared ray to heat energy, but also to regulate the inner temperature.

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References


