



Technical note

Electrospun polyethylene glycol/cellulose acetate phase change fibers with core–sheath structure for thermal energy storage



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ABSTRACT

The ultrafine phase change fibers (PCFs) with core–sheath structure based on polyethylene glycol/cellulose acetate (PEG/CA) blends were fabricated successfully via coaxial electrospinning for thermal energy storage. SEM and TEM images show that cylindrical and smooth phase change fibers are obtained and PEG as a phase change ingredient is encapsulated completely by CA sheath. The morphology of the composite fibers before and after thermal treatment indicates that the prepared fibers are form stable phase change materials (PCMs). The results from DSC demonstrate that the composite fibers impart balanced and reversible phase change behaviors, and phase transition enthalpies of the composite fibers increase with the increasing of PEG content in the fibers, while the phase transition temperatures of the fibers are similar with those of pure PEG. The stress–strain curves show that the ultimate strength and ultimate strain of the composite fibers are lower than those of CA fibers, and they decrease with the increase of PEG content. The PEG/CA composite fibers have extensive applications as a smart material for thermal energy storage and temperature regulation.

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1. Introduction

Phase change fibers (PCFs) are one type of phase change materials (PCMs), and they have attracted extensive interest [1–10] for thermal energy storage and temperature regulation as high performance smart nonwoven fabrics and coatings. Generally, phase change fibers are capable of thermal energy storing and releasing through heat exchanges between PCMs in the fibers and the external environment during the phase change process as the ambient temperature alters.

As renewable and clean energy storage materials, phase change fibers have been researched and applied for several decades [1–6]. Since 1980s, several preparation methods of phase change fibers have been reported in the literature such as coating [2], filling [1], wet spinning [4], melting spinning [5], and microencapsulation [3]. However, there are some shortcomings and limitations for the above methods; for example, lower enthalpies and complicated preparation technology. Therefore, a new method, namely electrospinning [11,12], has been introduced recently to fabricate ultrafine phase change composite fibers [7–10,13,14] because

electrospun fibers have unique advantages such as ultrafine size, huge surface-to-volume ratio and excellent thermal performances. In the electrospun phase change fibers, the given polymer acts as the fiber template/matrix and the common solid–liquid PCMs act as the phase change ingredient, which could be served as form stable PCMs [13,14].

In this work, in order to enhance encapsulation efficiency of the phase change materials in the phase change fibers, coaxial electrospinning is used to fabricate ultrafine polyethylene glycol/cellulose acetate (PEG/CA) phase change fibers in which PEG as a phase change ingredient acts as a core and CA acts as a sheath. The morphology, phase change properties and tensile properties of the composite fibers were investigated by field emission scanning electron microscopy (FE-SEM), transmission electron microscopy (TEM), differential scanning calorimetry (DSC) and a tensile tester, respectively.

2. Experimental part

2.1. Materials

CA ($M_n = 29,000$ g/mol, purchased from Aldrich), PEG ($M_n = 10,000$ g/mol), acetone and N,N-dimethylacetamide (DMAC) (purchased from Guangzhou Chemical Agent Company, China) were used as received without further purification.

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2.2. Electrospinning

15 wt% CA solutions in acetone/DMAc (2:1, w/w) were prepared as the sheath spinneret solution, and the core spinneret solution is PEG solution in the same solvent system. The core/sheath spinneret was a stainless-steel needle with inner diameters of 0.6/0.9 mm, respectively. The core/sheath solution was placed in a 5 ml syringes and fed by a syringe pump (LSP02-1B, Baoding Longer Precision Pump Co. Ltd., China) at a rate of 3–5 ml/h. Electrospinning was performed at 25 °C in air. The needle was connected a high voltage supply (BPS-20, Beijing Electrostatic Facility Ltd., China) with a fixed voltage at 15 kV. An aluminum flat sheet or a rotating drum with a speed of 2000 rpm was earthed and used as the collector. The distance between the needle and the collector was fixed at 15 cm. PEG content in the phase change fibers was regulated by the concentration of core spinneret solution. In order to determine the PEG content in the composite fibers, the PEG/CA composite fibers were immersing in deionized water for 24 h to remove PEG, and then the wet fibers were dried at 40 °C under vacuum for 24 h. And PEG content is calculated by the following formula:

$$\text{PEG wt\%} = (W_0 - W_1)/W_0 \quad (1)$$

where W_0 and W_1 are the weight of PEG/CA composite fibers before and after water immersion, respectively.

According to formula (1), we have obtained two types of PEG/CA phase change fibers with PEG content of 37.0 wt% (labeled as PCF-1) and 43.2 wt% (labeled as PCF-2), respectively.

2.3. Thermal cycles test

A test of 100 heating-cooling thermal cycles was performed to monitor the variations in morphology and thermal properties of

the samples. The sample was placed into the empty aluminum pan and then placed onto a hot stage (STC200, Instec, USA). A saw-tooth shaped thermal cycle consisted of heating process and the cooling process (in the temperature interval 20–80 °C). The heating and cooling process times were maintained at approximately 15 min and 25 min, respectively until 100 complete thermal cycles had been undertaken.

2.4. Measurements

The morphology of electrospun fibers was observed with a Field-emission scanning electron microscope (FE-SEM, JSM-6700F, JEOL, Japan) at acceleration voltage of 20 kV under low vacuum and a transmission electron microscope (TEM, JEOL-100CX/II, NEC, Japan) operating at 100 kV, respectively. The fibers were gold-coated prior to SEM measurement. The average fiber diameter (AFD) of the electrospun fibers was obtained by using an UTHSCSA Image Tool Program to measure from at least five FE-SEM images for each sample. The thermal properties of the samples were determined using a differential scanning calorimeter (DSC, PE DSC-100, USA) with nitrogen as purge gas. The DSC was calibrated using the melting point of high-purity indium. First, samples were heated from 0 °C to 100 °C at the heating rate of 10 °C/min, and subsequently cooled to 0 °C at the cooling rate of 10 °C/min. FTIR spectra of pristine PEG, CA and the phase change composite fibers were taken in NICOLET-760 (Nicolet co. USA) Infrared Spectrophotometer in the wavenumber range of 4000–500 cm^{-1} . The samples were mixed with KBr and then pressed into a pellet. The thermal stability of pure PEG, CA and PEG/CA composite fibers was characterized by TG analysis using TA Instruments Co. thermal analysis system (TGA2050, USA). About 10 mg of the dried sample was weighed into an alumina crucible and the profiles were recorded from room temperature to 700 °C under a nitrogen atmosphere at a

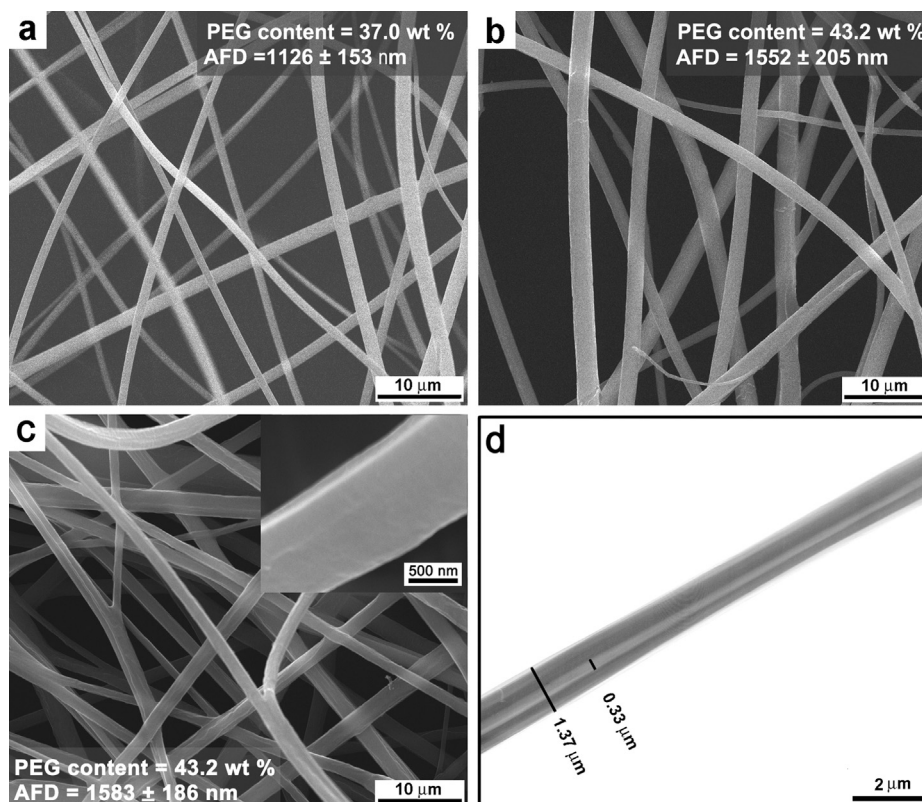


Fig. 1. SEM images of a) PCF-1; b) PCF-2; c) PCF-2 after thermal treatment (the inset shows higher magnification image); and d) TEM image of PCF-2 after washing.

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