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Preparation of continuous nanofiber core-spun yarn by a novel covering method

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ABSTRACT

A novel covering method to fabricate nanofiber core-spun yarn has been developed. Effects of span distance and rotation speed of disks on morphology, covering effect, abrasion resistance, wicking property, and mechanical property were mainly discussed in this investigation. Results showed that span distance had a significant effect on covering effect, and nanofiber core-spun yarn with a perfect covering effect could be prepared at the span distance of 2 cm with covering rate and abrasion growth rate of 30% and 142.3%, respectively. Alignment direction of nanofibers on the surface of nanofiber core-spun yarn was affected by rotation speed of disks, and would lead to the changes of wicking property and mechanical property. When the rotation speed of disks was 200 rpm, wicking property of nanofiber core-spun yarn was relatively better with the wicking effect of 7.6 cm. Breaking strength was decreased first and then increased with the increase of rotation speed.

1. Introduction

Electrospinning is a simple and efficient method for fabrication of nanofibers, which possess a huge specific surface area, nano-sized diameter and high porosity [1,2]. Therefore, they have great application value in filters, wound dressings, composites, tissue engineering scaffolds, protective clothing, electronics, sensors, and drug delivery materials [3–6]. Generally, repulsion between charges makes polymer jets unstable under high-voltage electric field, resulting in deposition of nanofibers on the collector in a random state. However, the randomly oriented non-woven mat has relatively low mechanical strength, which has limited its applications in some fields [7,8]. In order to solve this problem, it can be considered to use a traditional yarn as the core covered by nanofibers to prepare the nanofiber core-spun yarn, which will have a enough strength to be woven into a functional fabric.

Approaches to cover nanofibers on the traditional yarn surface by using rotary disk or funnel were commonly used. Scardino [9] prepared the continuous nanofiber core-spun yarn by using helical-vortex air current to apply nanofibers on the core yarn surface randomly. Zhou [10] electrospun nanofibers on the surface of parallel monofilaments with the diameter of 50 μm, and a number of nanofiber-covered monofilaments were then twisted into a composite nanofiber yarn by a conventional nozzle-type electrospinning setup. Dabirian [11] used two charged oppositely-placed needles and a neutral plate to produce the nanofiber core-spun yarn. He [12] produced the nanofiber core-spun yarn by covering nanofibers on the surface of a core yarn through a multi-nozzle air jet electrospinning set-up and a rotating funnel, which were further used to prepare four kinds of carbon nanofiber yarns through thermal stabilization and carbonization [13]. Liu [14] prepared the nanofiber core-spun yarn by adoption of the blown bubble spinning, and nanofiber bundles could be formed and twisted in one step. Najafi [15] produced core-sheath yarn by using an aluminum drum as the temporary collector, in the surface of which there was a hole for core yarn entering the collecting area, where nanofibers were formed from two opposite spinnerets. However, above existing methods to prepare the nanofiber core-spun yarn through electrospinning were either complicated or failed to consider the alignment of nanofibers covering on the core yarn.

Based on the method to prepare aligned electrospun nanofibers through parallel electrode method proposed by Teo [16] and Zhao [17], a novel covering method was designed to prepare the nanofiber core-spun yarn through electrospinning. A conventional yarn was placed between two parallel aluminum flakes to twist aligned nanofibers on the surface of core yarn, and then a novel nanofiber core-spun yarn is formed. Effects of span distance (distance between two parallel

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aluminum flakes) and rotation speed of disks on covering effect, abrasion resistance, wicking property, and mechanical property of the resultant yarn were investigated.

2. Experimental

2.1. Materials

Poly acrylonitrile (PAN) (M_w = 70,000 g/mol) (Hangzhou Bay Acrylic Fiber Co., Ltd., China) solution with the concentration of 12 wt% was prepared by dissolving it in *N*,*N*-dimethylformamide (DMF) (Tianjin Kermel Chemical Reagents Co., Ltd., China). PAN and DMF were used without further purification.

2.2. Electrospinning process

Collecting distance (distance between spinneret tip and upper edges of two parallel aluminum flakes), applied voltage and flow rate were set at13cm, 17 kV and 0.8 mL/h, respectively. Rotation speed of rollers (30 rpm) was constant during every electrospinning process. In order to explore the effect of span distance on covering effect of the resultant nanofiber core-spun yarn, different span distances including 2 cm, 3 cm, 4 cm, 5 cm, and 6 cm were selected. Effect of rotation speed of disks on alignment of nanofibers on the surface of core yarn, wicking property, and mechanical property of nanofiber core-spun yarn was studied. Rotation speeds of disks were selected as 200 rpm, 350 rpm, 500 rpm and 700 rpm, respectively. All the experiments were carried out at 20 ± 2 °C and 65 ± 5 RH%.

2.3. Measurement

2.3.1. Characterization of morphology of resultant nanofiber core-spun yarn

Morphology of the nanofiber core-spun yarn was characterized by a field emission scanning electron microscope (FESEM) (Quanta-450-FEG, FEI, England). Optical images and videos of electrospinning process were recorded by a digital camera (HDR-SR11E, SONY, Japan).

2.4. Measurement of performance of resultant nanofiber core-spun yarn

Covering effect: The obtained nanofiber core-spun yarn was cut into 10 sections with the equivalent length of 2 m, which were weighed by an electronic balance(Sartorius CP 225D, Germany, with the precision of 0.00001 g) to calculate the covering rate (R_c) of the resultant nanofiber core-spun yarn.

$$Rc = \frac{W_1 - W_0}{W0} \times 100\% \tag{1}$$

where R_c is covering rate, %; W_0 is the weight of core yarn, g; W_1 is the weight of nanofiber core-spun yarn, g.

Abrasion resistance: All the obtained core-spun yarn with the length of 2 m were then used to obtain the abrasion resistance of nanofiber core-spun yarn by a abrasion tester (Y731D, China). Abrasion resistance can be characterized with abrasion growth rate (R_a) expressed as follows:

$$Ra = \frac{N1 - N0}{N0} \times 100\% \tag{2}$$

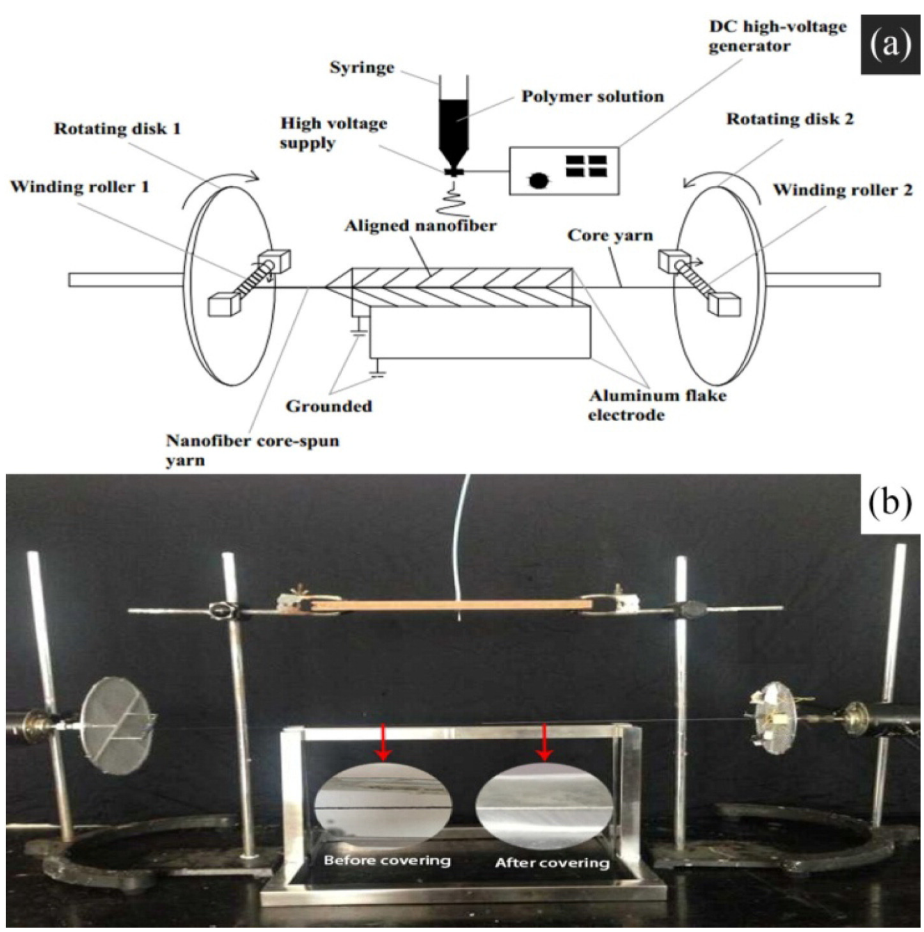

Fig. 1. (a) Schematic of the set-up used to prepare nanofiber core-spun yarn; (b) image of the self-designed setup.