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A novel approach for preparation of aligned electrospun polyacrylonitrile nanofibers

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ABSTRACT

In this Letter, a new type of collector named 'rotating grid collector' was introduced and its capability in aligning the nanofibers was examined. The results showed that electrospinning using rotating grid collector could produce well aligned fibers with fiber alignment percent of 76%. It was found that in a constant solution flow rate increasing collector rotation speed and eccentric distance improved the fiber alignments. Having prepared the fiber textiles, we found that increasing the rotation speed improved the tensile strength of the fiber textile. This new collector is promising for future application in aligning nanofibers.

1. Introduction

Electrospinning is a relatively novel process that uses an electric field to produce polymeric fibers onto a target collector. In this process, fibers are formed when the applied electric field overcomes the surface tension of the droplet and a charged jet of polymer solution is ejected from the capillary tip. The jet extends towards the target attached to the ground and solidifies on it. Most of the produced nanofibers so far can only be utilized in applications such as filtration [1], tissue scaffolds [2] and wound dressing [3]. However, uniaxial fiber bundles can be unlimitedly used in various applications.

Up to now, several methods have been proposed to generate uniaxially aligned fibers. Application of a cylinder collector with high rotation speed is one of the solutions that have been used by Boland et al. [4], Matthews et al. [5], Fennessey and Farris [6] and Lee and Yoon [7]. Sundaray et al. [8] employed the same collector while using a thin stainless steel pin with sharp tip to align the fibers. A rotating disk collector was used by Theron et al. [9,10] to align individual nanofibers and modified by Yee et al. [11] by attaching parallel electrodes to it. Recently Khamforoush and Mahjob [12] generated highly aligned nanofibers by the application of a hollow metallic cylinder as collector. Two pieces of electrically conductive substrates [13,14], a rectangular frame structure [15] and two pieces of stainless steel plates [16] are the other devices employed as a collector to obtain aligned nanofibers. Also new techniques such as using a multiple field technique [17] and rapidly oscillating a grounded frame within the polymer jets [18] were used to straighten nanofibers.

Although, all the above mentioned methods can be employed to obtain aligned fibers, in most of them there are an essential need for high rotation speed in collector to provide appropriate linear fiber deposition speed onto the collector [4–12]. In the present Letter, a novel approach for aligning nanofibers by using a new type of rotating collector named 'Rotating grid collector' was developed. In this method, desired linear fiber deposition speed can be achieved by controlling the eccentric distance between needle and rotation axis. Also, no forced air flow is produced by rotating the collector because of its grid-like shape, whereas in most of the other rotating collectors such as rotating cylinder, there is an air flow near the collector surface that disarrange the fiber path.

The effects of the rotation speed of the collector and the eccentric distance on the alignment of collected fibers were investigated. Collected fibers have been used then to form fiber textiles and the effect of fiber alignment degree on tensile strength of the fiber textiles was examined.

2. Principles of rotating grid collector

Figure 1 shows the schematic setup used for electrospinning process in which the new rotating grid collector is used. The collector containing a round grid is rotating around an axis which is parallel to spinning axis. The grid can be built of circularly rounded rod which its center diameter determined by eccentric distance. The normal distance between the syringe axis and collector rotation axis is called eccentric distance (Figure 1). The radius of the rod must be small enough to affect the electrostatic field. The rotational speed of the grid is provided by a DC electric motor that can produce angular velocity of up to 1000 rpm or higher. The syringe and needle are installed eccentric to the grid rotation axis. In order to create an electrical potential difference between the solution and collector, the needle tip is connected to the positive voltage

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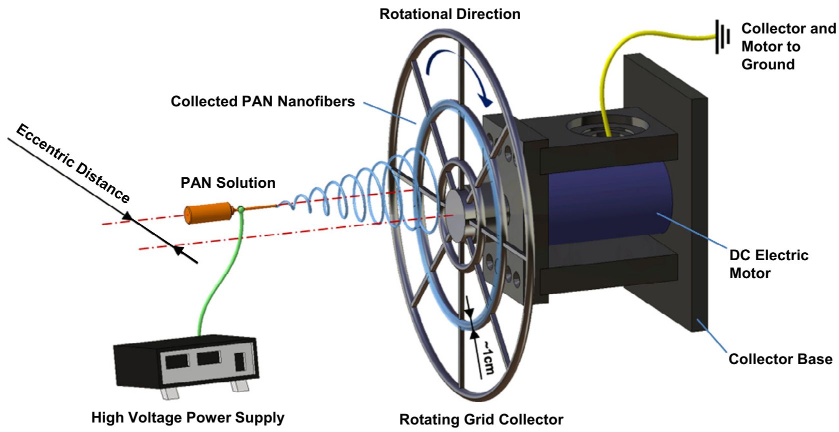

Figure 1. Rotating grid collector setup.

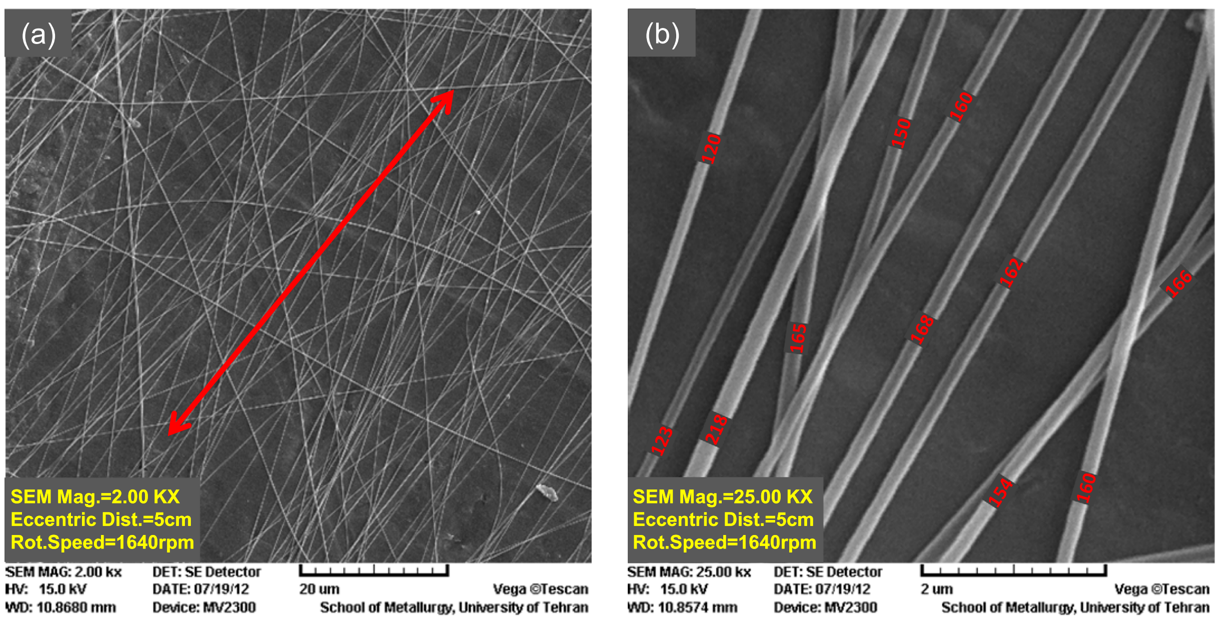

Figure 2. Electrospun nanofibers using rotating grid collector with eccentric distance of 5 cm and rotation speed of 1640 rpm (linear deposition speed of 8.6 m/s).

and the rotating grid is connected to ground. The application of a grid-like collector is predicted to help in focusing the splaying fibers by electric field lines converging on the rod surface.

3. Experimental procedure

In a typical experiment, the 10 wt.% PAN/DMF solution was held in a 10 ml glass syringe (20 mm inner diameter) fitted with a 22-gauge (0.7 mm inner diameter) stainless steel needle. PAN polymer of 70 000 g/mol of molecular weight was purchased from PolyAcryl Iran Corporation and dissolved in DMF obtained from Merck. The syringe was clamped horizontally to a micro pump (Fanavaran-Nano-Meghyas, SP1000) to control the solution flow rate. In this experiment the solution flow rate was held constant at 1 mL/h. An aluminum grid with aluminum foil in the rod areas was attached to a DC motor and used as a counter electrode. The rotational speed of the DC motor was controlled by a potential meter and varied from 1150 to 2100 rpm. In order to control the eccentric distance, an adjustable syringe holder with distance number indicator was used. Different linear fiber deposition speeds (ranged from 4.0 to 8.6 m/s) implies different rotation speeds and different eccentric distances. The tip to collector distance was fixed at 15 cm. The needle and collector were enclosed in a glass box in order to reduce the effect of air flow on the trajectory of the polymer jet.

At the beginning of the experiment, a pendant droplet of polymer solution was suspended from the tip of the syringe. When the potential difference between the droplet and the collector was increased, the droplet acquired a cone-like shape (Taylor cone). At a certain potential difference, a stable jet emerged from the cone and moved downward toward the plate. After the jet flowed away from the droplet in a nearly straight line, it bent into a cone-like path [11]. As the polymer jet approached the collector, it was pulled toward the rod of the rotating grid and at a certain point above the collector the usual cone turned into an unshaped path. Then the jet reached the rod surface and was wound around its perimeter. The apparent change in the jet path may be reflective of the accumulated charges on the rod surface that exerted a pulling force on the polymer jet and forced the fibers to be collected onto the rod. A decrease in rod diameter is believed to increase the pulling force and therefore result in better alignment in nanofibers but decrease