Effect of Target Shapes on Distribution of Polyacrylonitrile Nanofibers Prepared by Electrospinning Process

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ABSTRACT

The influence of target shapes on the distribution of as-spun polyacrylonitrile nanofibers prepared by electrospinning process was investigated. Electrospun polyacrylonitrile fibers were obtained with different shapes of target and various distances between needle and target using high voltage DC generator rated 20 kV. Additionally, the effect of magnetic field on the distribution of resulting nanofibers was also examined. The results showed that the maximum of fiber accumulation was obtained at the lowest distance between needle and target. Moreover, it was found that the target shape provided no significant effect on the distribution of resulting fibers. However, the distribution of fibers varied when the target was induced by magnetic field.

Key words: Electrospinning, Electrospun polyacrylonitrile, Polymeric nanofibers, Electric field, Magnetic field

INTRODUCTION

Electrospinning is a simple technique for producing nanofibers of inorganic oxide materials and organic polymers. The principle behind electrospinning is relatively simple: A polymer solution flows out of the tip of the capillary where a droplet is formed under the effect of the surface tension of the solution. A sufficiently-high electric charge is applied to the solution which leads to repulsive electrostatic forces between polymer and solvent molecules to overcome the surface tension, and a jet of polymer shoots away from the capillary towards a grounded collector (or target). Finally, nanofibers were collected on the grounded collector as a randomly-oriented web (Xianyan et al., 2002; Cory et al., 2004; Seong et al., 2005; Veli et al., 2005). Because of the small pore size and high surface area inherent in electrospun textiles, these fibers exhibit promise for exploitation in filtration, soldier's protective clothing applications (Deitzel et al., 2001; Gibson et al., 2001). Other applications that are being explored include scaffolding for tissue growth, optical and electronic applications (Christopher et al., 1999; Ian et al., 2000; Dhamaraj et al., 2004; Min et al., 2004).

Many process variables, including the electric field, the viscosity of solution, the nozzle-to-collector distance and the solution flow rate can affect the electrospinning process (David, 2000; Myung et al., 2004; Bumsu et al., 2005). However, the area deposited with electrospun fibers is still quite large. The control of deposition area is useful for nanofiber applications. In this contribution, we investigate the effect of target shapes and external magnetic fields on the distribution of as-spun polyacrylonitrile nanofibers.

MATERIALS AND METHODS

Polyacrylonitrile, having the concentration of 12% w/v in N,N-dimethylformamide used as solvent, was employed in the preparation of polymeric nanofibers via electrospinning method. The electrospinning set-up utilized for these experiments is illustrated in Figure 1. The apparatus consisted of a high-voltage power supply, a polymer solution contained in a syringe and the grounded collector (or target). The high-voltage power supply is used to apply a voltage between the polymer solution and the grounded collector. A pendant drop was formed at the tip of the nozzle and voltage of approximately 20 kV was used to create electrical forces at the surface of the polymer drop. The resulting electrical fields were sufficient to overwhelm surface tension of polymer solution and created an electrically-charged jet. During jet travelling, the solvent evaporated and the remaining solid polymer fiber deposited on the grounded collector. Nanofibers accumulated and spread on the collector as long as the nozzle tip was continually supplied with polymer solution. Finally, an interconnected web of small filaments or a nonwoven fiber was created on the surface of the grounded target.

The grounded collectors were conical in shape. One cone represented one target. Each target in cone shape was set up on the metal plate. The position of spinning was varied from the center of metal plate (Figure 1(a)) to the distance of 2 cm from the center (Figure 1(b)). The height between the nozzle tip and the target surface was constant at 10 cm.

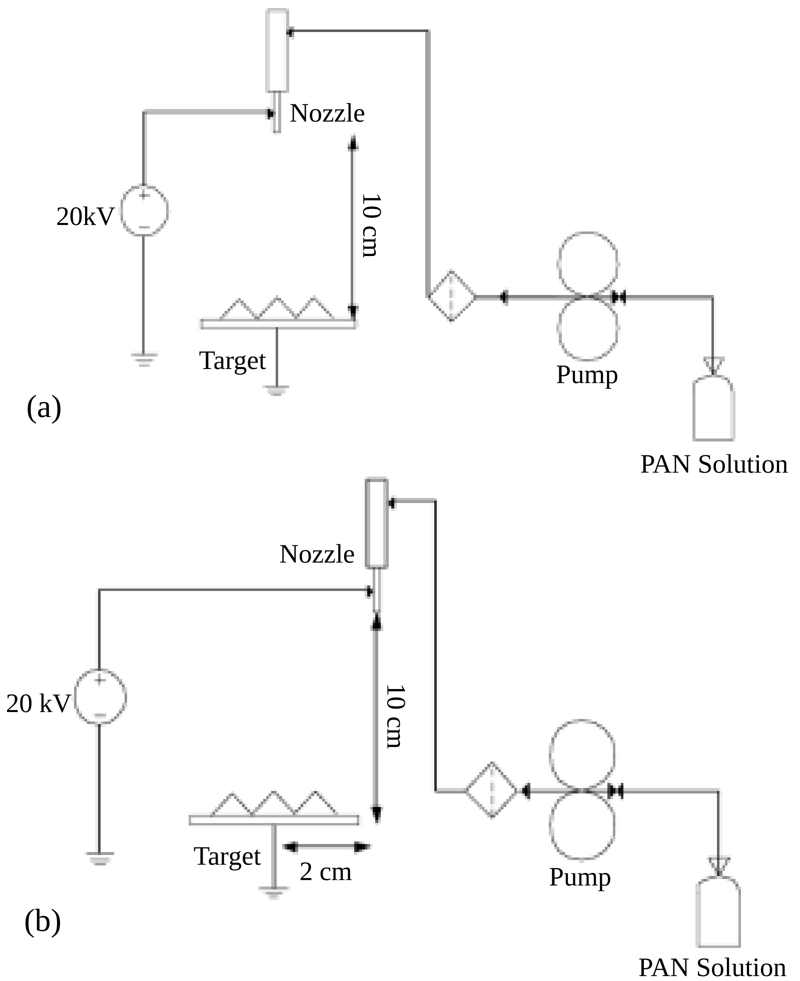
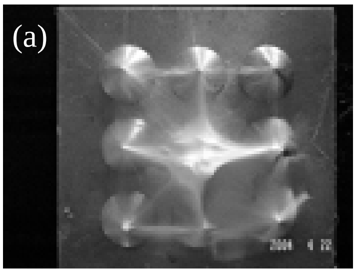


Figure 1. Typical electrospinning set-up. The high-voltage power supply was employed to apply a voltage of around 20 kV between the polymer solution in the nozzle and the grounded collector.

RESULTS AND DISCUSSION

Figure 1 shows the electrospun polyacrylonitrile fibers obtained from the spinning at the center position of metal plate, using the targets in cone shape at various numbers of cones with the spinning height of 10 cm. It can be noted that most fibers obtained accumulated at the apex of cone which has the shortest nozzle-to-target distance as exhibited in Figure 2(a). When the nozzle-to-target distance was the same, the accumulation of fiber on three cone targets occurred uniformly, as illustrated in Figure 2(b).



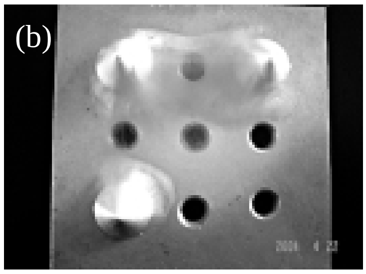


Figure 2. The accumulation of PAN fibers obtained from the spinning at the center position of plate with different number of cones (a) 9 cones, (b) 3 cones.

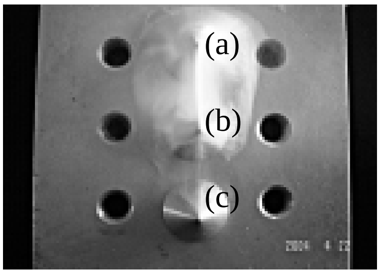


Figure 3. The accumulation of PAN fibers derived from the spinning at the position 2 cm from the center of metal plate and the spinning height of 10 cm.

At the spinning position next to the center, polyacrylonitrile fibers accumulated at the apex of cone having the shortest distance between the nozzle and the cone target, as demonstrated in Figure 3(a). The accumulation of fiber decreased when the distance between the capillary needle and the target increased (Figure 3(b) and (c)). Moreover, it was also found that the accumulation of fibers changed when the metal target was induced by external magnetic field. Figure 4 illustrates that the accumulation of fibers occurred only at the shortest distance between the nozzle and the target when the permanent magnet was placed under the metal plate. It can be obviously seen that the area of deposition decreased when the grounded collector was influenced by external magnetic field. It might be due to the electrical conductivity of metal target itself. According to Ampere's law, when an electric current flows through metal target or a current-carrying conductor, a magnetic field is produced (Mohan et al., 1995). The external magnetic source located under the metal plate resulted in the cancellation between the magnetic field produced from a current-carrying conductor and that generated from external permanent magnet. This leads to a deterioration of an electric field around the metal collector. In addition, a magnetic field decreased when the distance between the needle and the cone target increased. A decrease in a magnetic field also results in a reduction in an electric field around target. Therefore, the cone near the nozzle has more electric field leading to the accumulation of fibers on that cone target as demonstrated in Figure 4(a).

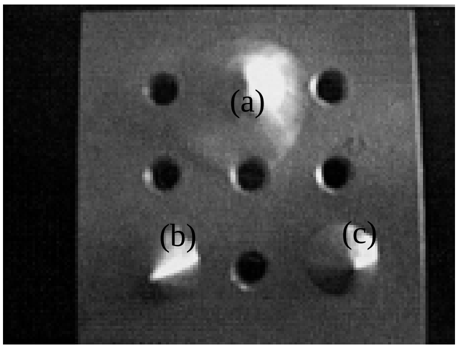
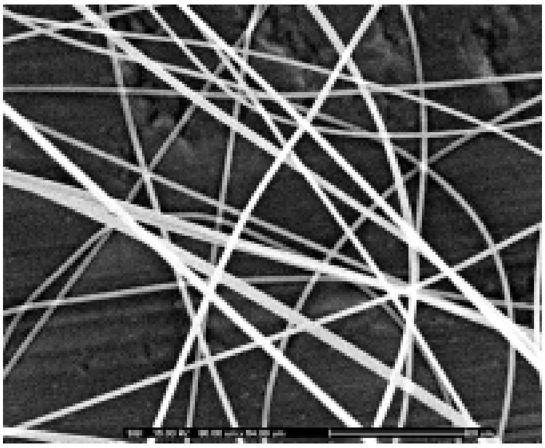


Figure 4. The accumulation of PAN fibers prepared by the induction of external magnetic field.

To investigate the microstructures of fibers spun via electrospinning technique, scanning electron microscope was applied. SEM micrograph of one sample of nanofibers polyacrylonitrile (PAN) electrospun is illustrated in Figure 5.



20 μm

Figure 5. SEM micrograph of resultant PAN nanofibers. The fibers were spun at a flow rate of 0.1 ml/min and a voltage of 20 kV with a standard nozzle from a 12% (w/v) N,N-dimethylformamide solution.

CONCLUSION

PAN fibers have been spun on the stationary grounded collector with different shapes via electrospinning technique. The maximum of fiber accumulation was obtained at the shortest distance between tip of nozzle and target. The target shape or the nozzle position provided no significant effect on the distribution of fibers. Additionally, the accumulation of fibers changed when the grounded collector was induced by external magnetic field. The preliminary results demonstrate that it is possible to control the deposition area of electrospun fibers through the use of an external magnetic source in the metal target.

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