MACROMOLECULAR-SCALE ELECTROSPINNING
Controlling Inner Topologic Structure Through a Blowing Air

by

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Macromolecules are the foundation stone to construct a nanofiber in the electrospinning. Their distribution and orientation greatly affect the product's properties. In this paper, a rotary blowing air is used to control the radial topological structure of a nanofiber, and a macromolecule-scale inner structure can be designed. The influence of the flow properties on nanofibers' mechanical properties is studied experimentally.

Key words: *electrospinning, nanofiber, air vortex, angle, tensile force, adhesive force*

Introduction

Electrospinning is widely used to prepare various functional nanofibers due to its simplicity and efficiency [1-8], but the mechanical property of nanofiber membranes prepared *via* electrospinning is poor, and their applications are limited in many applications. So far, little attention in the academic world was paid on the effect of the internal structure on the performance; much research was focused on the application part [9-11].

It is a known fact that the internal structure of nanofibers can greatly affect nanofiber's properties, ordered distribution, and well orientation of macromolecules in the nanofiber will enhance its mechanical, thermal, and electronic properties [12].

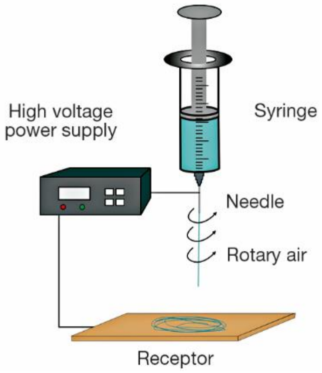

Figure 1. The electrospinning process to control macromolecules distribution and orientation in a nanofiber through a rotary blowing air

The air vortex in the electrospinning process, fig. 1, can improve the mechanical properties of nanofiber membrane [12]. In our previous experiment, we found that through this method, the mechanical properties of nanofiber membranes are significantly improved. The air vortex has a certain stretching effect on the spinning jet, but it can control the radial topological structure of the jet.

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Materials and instrument

Polyvinyl alcohol (PVA) particles (Aladdin Industrial Corporation, China) were used in our experiment without any further purification, the sample was stored at room temperature, and its alcoholysis degree was 97.5-99.0%.

Nanofiber morphology was analyzed using the S4800 cold field SEM (Hitachi S-4800, Japan). The experimental operation followed exactly the machine guidelines. The 500 fibers from 50 SEM images were chosen for diameter distribution analysis using IMAGEJ software (National Institute of Mental Health, USA).

Tensile test was measured by the mechanical property testing machine (INSTRON-3365, INSTRON Company, USA). The fiber membrane was sheared as a rectangle with a width of 2 cm and a length of 4 cm as required. The thickness of the fiber membrane was measured by a micrometer. All experimental data given in this paper were average ones by at least three times of measurement. In the test, the holding length was 20 mm. The tensile speed was 20 mm/min.

The pore size distribution was measured for the nanofiber membranes by a capillary flow porosimetry (Porometer 3G, Quan-tachrome Instruments, USA). As required, all samples were circular membranes with a diameter of 25 mm. The Profil wetting solution was used in our experiment.

Experimental design and experimental results

The 1.6 g PVA powders were put into 18.4 g deionized water with a temperature of 80 ^{o}C, and the mixture was then magnetically stirred on a heating magnetic stirrer (DF-101S, Xinrui Instrument Inc., China) until a transparent solution was obtained. In this experiment, except for the air-flow in the spinning process, other conditions were kept unchanged in the spinning process. The inlet angle of the air can be changed, as shown in fig. 2.

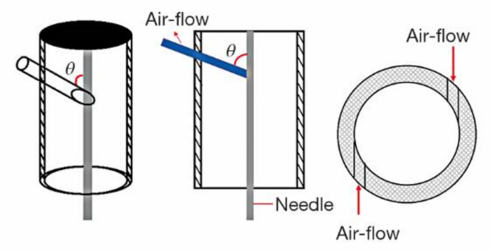

Figure 2. Schematic diagram of the angle between the pumped air-flow and the needle

Figure 3 and tab. 1 show the effect of the change of pumped air-flow angle on the morphology of the prepared nanofibers. It can be clearly seen from fig. 2 that when the angle between the pumped air-flow and the needle is 0°, the diameter of the prepared PVA nanofibers is the smallest. This is because the blowing air is the force acting the spinning jet. The force due to the blowing air is $F\cos\theta$, where F is the force acting on the jet surface. When $\theta = 0°$, the moving jet can be further accelerated, and according to the mass conservation, $\pi r^2 \rho u = Q$, where Q is a constant, a higher velocity u leads to a smaller radius r. When $\theta = 90°$, the air-flow can not stretch the moving jet, and the fiber diameter is the largest.

The radius force is $F\sin\theta$, which is to control the vortex motion of the macromolecules, their distribution and orientation can be controlled by θ.

Different angles of the air-flow also have an effect on the morphology of the prepared nanofibers, and the mechanical properties of the nanofiber membrane should also be changed. Figure 4 shows the mechanical property test of PVA nanofiber membranes prepared at different air-flow angles. It can be seen from fig. 3 that, as the angle increases, the maximum

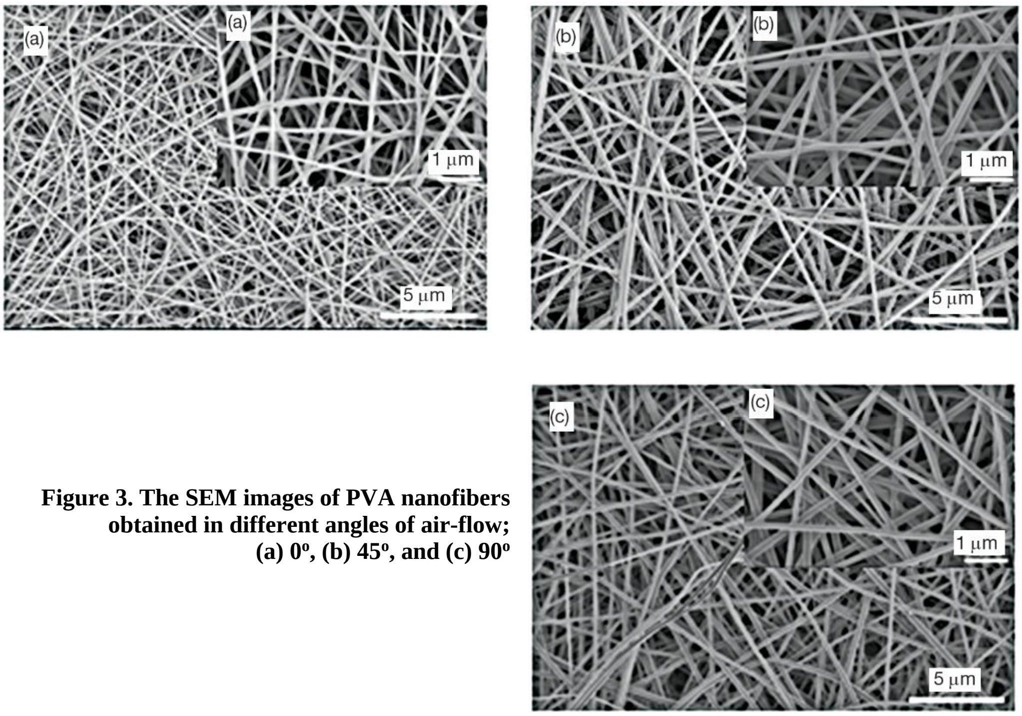

Figure 3. The SEM images of PVA nanofibers obtained in different angles of air-flow; (a) 0º, (b) 45º, and (c) 90º

breaking strength of the nanofiber membrane gradually increases. This is because when the angle is 0°, the air-flow has only a stretching effect on the jet in electrospinning and does not change the internal structure of the nanofibers. When the angle increases to 45°, the radius force $F\sin\theta$ makes the macromolecules move radically and can entangle with each other, this entanglement can greatly enhance the mechanical property.

Table 1. The relationship between the pumped air-flow angle and the average diameter of PVA nanofibers

Angle [º]	Average diameter, $\bar{D}$, [nm]	Standard deviation, σ, [nm]	Confidence interval [nm]
0	98	±15.2	±3.0
45	126	±19.0	±3.7
90	137	±19.6	±3.8

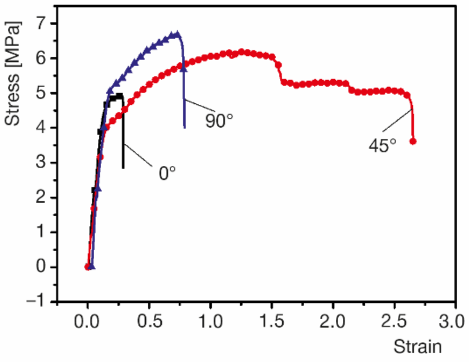

Figure 4. Mechanical property tests for PVA nanofiber membranes fabricated by the pumped air-flow at different angles

Figure 5 shows the pore size distribution of PVA nanofiber membranes. It can be seen from fig. 5, as the angle increases, the pore size of the nanofiber membrane increases. From the previous SEM, we can see that when the angle is 0°, the nanofiber diameter is the smallest, the porosity size scales with the fiber diameter, so we see the smallest pore size in fig. 5 when the angle is zero.

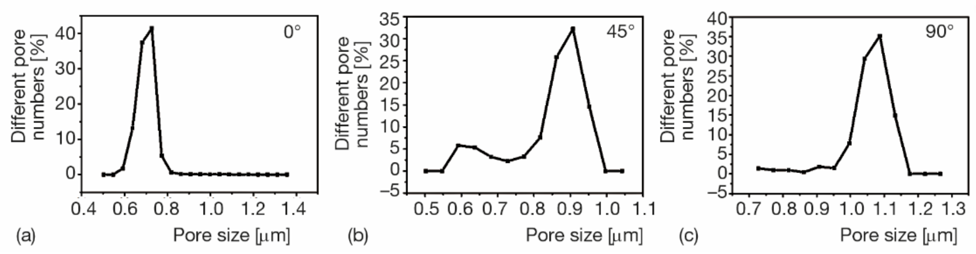

Figure 5. Pore size distributions of PVA nanofiber membranes fabricated by the pumped air-flow at different angles

Conclusions

This paper shows the basic principle of the macromolecule-scale electrospinning, which can control the inner topologic structure of a nanofiber. It is similar to that of air vortex twist in air-jet spinning. The influences of the air-flow angle on nanofiber's morphology and mechanical property are experimental studies. The pores of the nanofiber membranes given in fig. 5 also elucidates the reliability of the macromolecule-scale electrospinning.

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