RELATION BETWEEN SPINNING CONDITION AND BEADS FORMATION IN ELECTROSPINNING OF POLY (VINYL ALCOHOL)

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We investigate formation of beads on electrospinning by changing conductivity of poly(vinyl alcohol) (PVA) aqueous solutions and spinning conditions, such as applied voltage, distance between the tip of needle and the collector, and humidity. From the results of experiments done by changing conductivity of PVA aqueous solutions and spinning conditions, we found that the beads formation is suppressed at lower electric charges. When the applied voltage changes to be same electric charge in respective distances between the tip of needle and the collector, beads less fibers are fabricated in all cases.

Introduction

Electrospinning is one of spinning techniques to produce nonwoven fabrics consist of ultra thin fibers from polymer solutions or melts by applying a high voltage between a tip of needle and a grounded collector. This technique enables us to easily fabricate ultra thin fibers than the conventional fiber spinning processes based on melt and solution spinnings. The electrospun fibers have quite thinner diameters and larger surfaces than those obtained by the conventional fiber spinning processes. These unique characteristics bring us possibilities of a number of applications, for example, filtration for bacteria or nano-sized materials, tissue scaffolding and other biomedical applications. One of the most serious problems in applications of electrospinning is a formation of beads on fibers. The formation of beads makes functions of products deteriorate. It has been reported that the beads formation is related to the jet instability such as a bending instability due to change the surface tension or electric field strength [1, 2]. The jet instability depends on the electric charges [3]. Therefore, we focused on the electric charges in electrospinning processes. In the present study, we changed the spinning conditions which relate to the electric charges in the electrospinning, for example, applied voltages, distance between the tip of needle and the collector, electric conductivity of PVA aqueous solutions by adding salt (NaCl) and relative humidity. We investigated relation between the electric charges and beads formation in electrospinning of PVA.

Experimental

-Samples

The sample used in this study was poly(vinyl alcohol) (PVA) solution. PVA with molecular weight of 40,000g/mol was purchased from Aldrich Chemical Corporation and dissolved in distilled water. The concentration of PVA aqueous solution was adjusted to be 15wt%, because beads were formed easier at this concentration than other concentrations in possible electrospinning processes. In order to change the conductivity of PVA solutions, the salt (NaCl) was added to PVA solutions at different concentration from 0.01 to 0.25wt%.

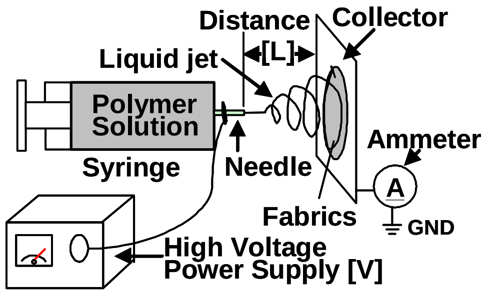

Fig.1 Electrospinning set-up.

-Electrospinning

Using the PVA solution, electrospinning was performed at room temperature in the horizontal mode as shown in Fig.1. Experimental conditions were as follows; the distance between the tip of needle and the collector was changed from 5 to 20cm, the applied voltage was changed from 4.5 to 24kV, relative humidity was controlled in the range from 20 to 75%, and feed rate of PVA solution was set to be 0.5ml/h. The electric charge on the electrospun fibers was evaluated by electric current measurements with an ammeter which was attached to the grounded collector. The current measurement was performed every 0.5s.

The electrospun samples for Scanning Electron Microscopy (SEM) observation were dried under vacuum at 30^{o}C for one day. Diameters of obtained fibers were measured by an image analysis software. To investigate averages diameter of electrospun fibers, we randomly selected fibers more than one hundred and measured their diameters at three positions that were randomly selected on each fiber in SEM images of magnification of 15,000. Beads were excepted from the diameter evaluation of electrospun fibers.

Results and Discussion

Fig.2 shows the effect of distance (*L*) between the tip of needle and the collector on electrospinning of PVA at the constant applied voltage (9kV). In case of *L*=20cm, the electrospinning could not be realized since the strength of applied voltage is too low to elongate the sample. At the distance is 5cm, the many beads were formed. On the other hands, beads-less fibers were fabricated at *L*=10cm and 15cm, respectively. Then, the beads formation tends to make easier with increasing the electric current. Furthermore, higher electric conductivity enhances the beads formation in experiment about the effect of electric conductivity on electrospinning of PVA.

Fig.3 shows the results of SEM observation at different combinations of distance and voltage that give the same electric current (0.2μA). Fig.4 shows the fiber diameter distribution of electrospun fibers. At the constant electric current (0.2μA), even though the applied voltage and distance between the tip of needle and the collector are different, beads-less fiber was fabricated in all cases. Additionally, average diameter and distribution of fiber diameter are almost same as shown in Fig.3. These results indicate that the electric current is highly related to formation of beads.

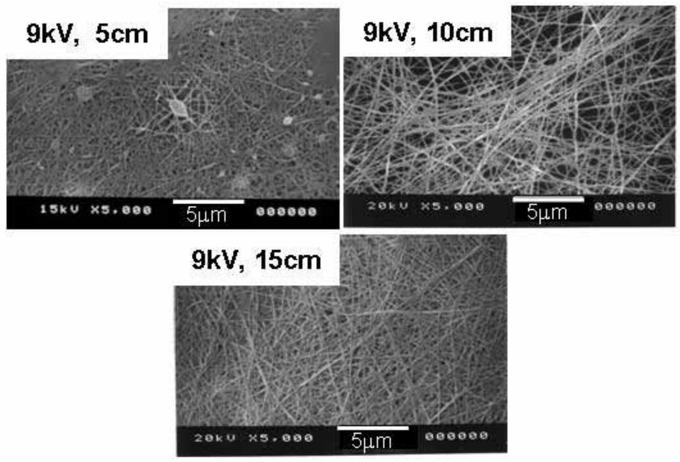

Fig.2 SEM images of electrospun fibers at different distances between the tip of needle and the collector, *L*=5cm, 10cm and 15cm at same applied voltage of 9kV.

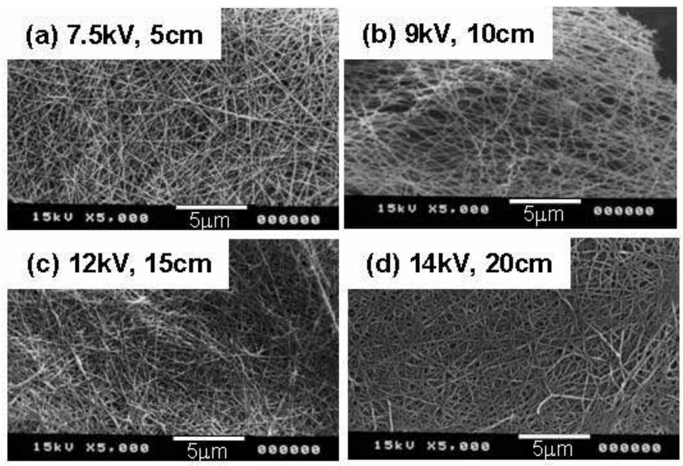

Fig.3 SEM images of resultant fibers at same electric current condition (0.2μA), (a) 7.5kV and 5cm, (b) 9kV and 10cm, (c) 12kV and 15cm, (d) 14kV and 20cm.

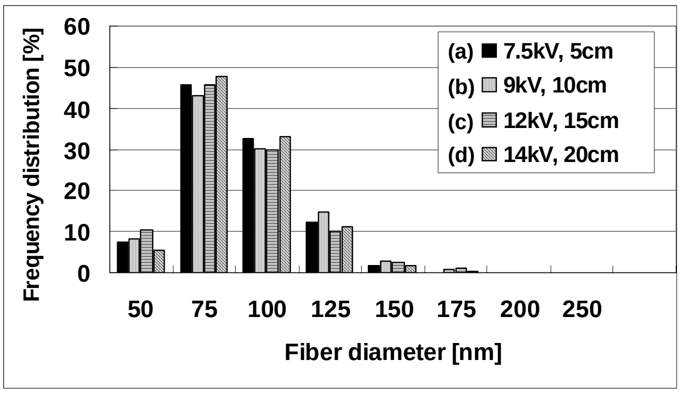

Fig.4 Diameter distribution of electrospun PVA fibers at same electric current condition (0.2μA), (a) 7.5kV and 5cm, (b) 9kV and 10cm, (c) 12kV and 15cm, (d) 14kV and 20cm.

Conclusion

From the results of all experiments, we found that the beads formation is induced the higher electric current in the electrospinning of PVA. The electric current is closely related to charge density of fibers. This result indicates that the formation of beads can be suppressed completely without changing average diameters of fibers by controlling the charge density of fibers. We succeeded in making beads less nanofibers of 80nm.

References

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