EFFECT ANALYSIS OF THE STRING CROSS-SECTION ON THE ELECTROSTATIC SPINNING PROCES

SKRIVANEK Josef[1], BILEK Martin[1], VALTERA Jan[1], LeVan Khoa[1], BATKA Ondrej[1]

[1]*TUL - Technical University of Liberec, Department of Textile Machine Design, Liberec, Czech Republic, EU*

Abstract

The article deals with an experiment that was carried out on a test spinning device designed for the production of nanofibres by electrostatic spinning from a string. In the experiment, a spinning device was created in the form of a vertical stringed moving electrode. This was rewound between two coils and a polymer solution was continuously delivered to the electrode surface by a special dosing device. The intensity of the electric field and the distance of the Taylor cones. Nozzles from which emerging nanofibers travel to the collector, depend on the different cross sections of the strings used. The aim of the experiment was to find critical voltage for different strings. Critical voltage is one in which the spinning process starts. This value is very important as it creates a requirement for a minimum supply voltage. The work selects and points out to different cross-sections of the strings and the corresponding distance of the Taylor cones.

Keywords: Taylor cones, spinning, electrostatic

1. INTRODUCTION

Nano fibres are textile fibres with a diameter of less than 1 micron. Due to their good properties these fibres are used especially in medical applications, filtration of bacteria, and also in the automotive industry as composite fillers [1]. Another large sector that uses nano fibres is the aerospace industry where carbon nano fibres are used to a greater extent as a composite filler. The nano fibres and materials are often designated as materials of the third millennium or also materials of the future. Nano fibres may be obtained using many techniques. They are most commonly produced by spinning of liquid polymers [2].

The basic accessories necessary for realisation of the process of electrostatic spinning is a power supply source, spinning electrode, dosing device, a polymer solution and collector, on which the created fibres are caught [3].

The principle of electrostatic spinning is based on the action of a strong electrostatic field on a suitable polymer solution. The voltage generated between two electrodes acts on the polymer, which is on the spinning electrode [4]. By action of high voltage, electrostatic forces are created, which pull the polymer toward the collector. The surface voltage acts in the opposite direction. As a result of the action of these forces, a change occurs in the surface structure of the polymer solution and creates Taylor cones [5]. This phenomenon occurs upon equalisation of the surface voltage of the polymer solution and the electrode voltage. If the surface voltage is exceeded, fibre jets [6] are emitted from the Taylor cone. These are stable near the Taylor cone, but are prone to bending instability with increasing distance. Polymer drops are emitted at the end of the fibre jets and elongated to form fibres. During the flying action of the fibre from the electrode toward the collector, the fibre is elongated and the thinner evaporates. Dry fibres are then collected on the collector. The elongation of the fibres results in reduction of their diameter [7].

The objective of the experiment was to ensure critical voltage for various strings. The critical voltage is such at which the spinning process starts and the Taylor cones are formed. This value is very important because it creates a requirement for a minimum source of voltage for realisation of the spinning process.

2. EQUIPMENT DESIGN

The experimental equipment was designed for realisation of the tests of currently developed string spinning technology. **Figure 1** shows the 3D model of the wire electrode. The principle is based on a vertical wire electrode, which is winded from reel 3 to reel 8. The drive of reel 8 is via stepping motor 9. The polymer solution is fed to the wire by dosing device 4. Due to reeling of the wire upwards, the polymer solution is evenly applied to the wire surface. DC high voltage is connected to wire 6. The nano fibre created on the electrode is stored on collector 5.

The advantage of this solution is that the application of the solution to the wires does not require a sliding dosing device. It is therefore not necessary to have an additional drive and the structure is substantially simpler. An important advantage is also that the wire is not worn as applies to the known systems [8].

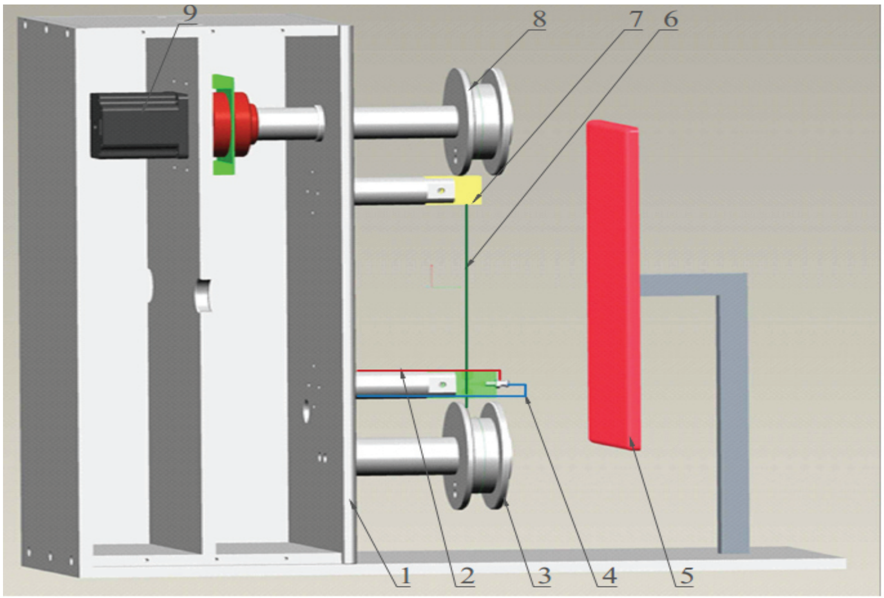

Figure 1 Model of the mobile string spinning electrode device

3. EXPERIMENT

Experiments were performed under the following conditions; temperature 21 ℃, relative humidity 32 %, polymer dosing rate 20ml/h and string winding rate 5 mm/s. Positive voltage was connected to the electrode and negative voltage was connected to the collector, which was at a distance of 150 mm from the electrode. For the spinning process, a water-soluble polymer solution of polyvinyl alcohol (PVA) was used in a concentration of 14 wt%. Testing was done on two cross-sections of the string (star and ring) with two different diameters. On the star cross section of outer diameter 1.3mm and the round cross-section of diameters 1.3mm and 2mm. The string material used was co-polyamide PA 6/12, which is protected by an elastic layer [9].

The situation of the metering station is shown in **Figure 2**. For detailed monitoring of the spinning process, as well as for the purpose of determining the distance between the Taylor cones and the diameter of the polymer layer, the Olympus i-SPEED 3 *1* high-speed camera was used. The spinning process was recorded at a speed of 2000 and 5000 shots per second with a resolution of 1280x1024, or 804x600 pixels. For this purpose, the high performance light source Olympus ILP-1 with a 120 W lamp with a colour temperature of 5600 K [8] was used. The light from this source was focused by means of an optic cable. Analysis of the acquired image was done using i-SPEED Suite software. It is possible on figure 8 to see the spinning device (detail a). The created fibre was captured on collector 4. Its creation was picked up by high-speed camera 1 and camera 2. The voltage is fed to the collector and electrode via high-voltage cables from source 5. The dosing of the polymer solution was via a NEMESYS linear pump.

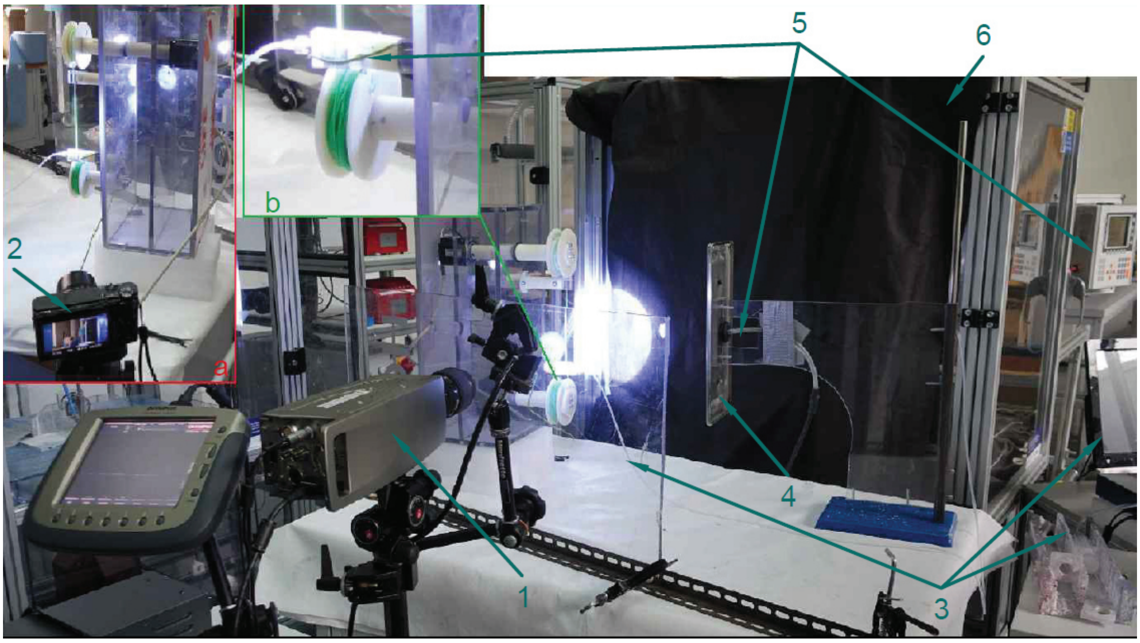

Figure 2 Measuring station for mobile string spinning electrode device

A further measurement task was ascertaining of the critical wavelength, which corresponds to the distance of the Taylor cones from which the nano fibres are created and that are located along the spinning string. The distance of the Taylor cones defines the productivity of the production of nano fibres [3]. The shorter the distance between the cones, the larger the number of cones on the string and the larger the volume of created nano fibres [1, 3]. Measurement was done for multiple types of strings and the impact of the string shape on this distance was assessed. **Figure 3** shows an image of a high-speed camera that captures the positioning of the Taylor cones along the imaging section of the string, round cross-section of outer diameter 1.3 mm. The relevant wavelengths can be read from the image. This recording was done for three types of strings and their corresponding measured wavelengths are shown in **Table 1**.

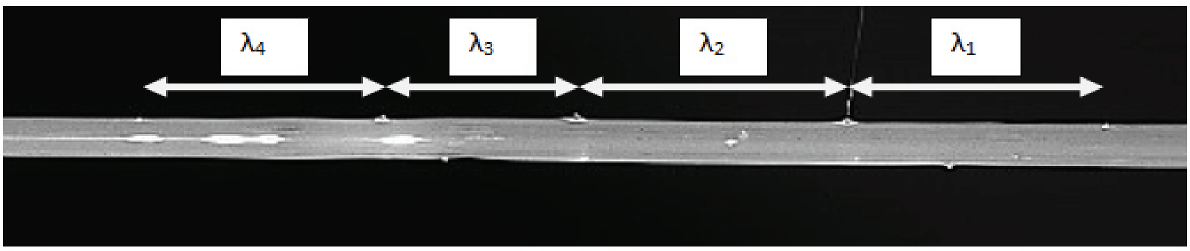

Figure 3 Distance of Taylor cones, star cross-section, outer diameter 1.3 mm

Distance measurement was done in the environment of i-SPEED Viewer camera software using the Reticle function and the critical wavelengths were calculated using the relationship (1) and plotted in **Table 1**.

$$\lambda_{kr} = \frac{d_{st} * X}{Y_{struna}} \quad (1)$$

λ_{kr} : critical wavelengths [mm], d_{st}: string outer diameter, X: arithmetic mean of the distances between the Taylor cones, Y_{string}: thickness of string layer [mm].

Table 1 Distance of Taylor cones and critical wavelength

Cross-section types/ diameter [mm]	Star 1.3 mm	Circle 1.3 mm	Circle 2 mm
Distance of Taylor cones [mm]	43	79	113
Wavelength [mm]	3.73	6.85	10.27

During the experiment, it was further found that at low voltage, the Taylor cones are formed only in the mid-section of the spinning string length. The spinning zone increased with increasing voltage and there was also an increase in the number of Taylor cones. Upon stoppage of the string winding, there was a reversal of the spinning process in all the polymer solution and the spinning process stopped. At high string winding speed, the polymer solution collected on the upper cassette, thus resulting in the formation of drops, which unevenly flowed on the string and caused spinning process instability. This phenomenon can be observed in **Figure 4**.

From the course of the experiment, it is evident that the quality of the spinning process is to a large extent influenced by several factors. The main ones in this case are electric voltage on the string, polymer dosing and the speed of the string rewinding. Among these factors, it is advisable to find optimal values so as to achieve the desired state of the spinning process. This is where the field of further research opens for various modifications to the spinning process.

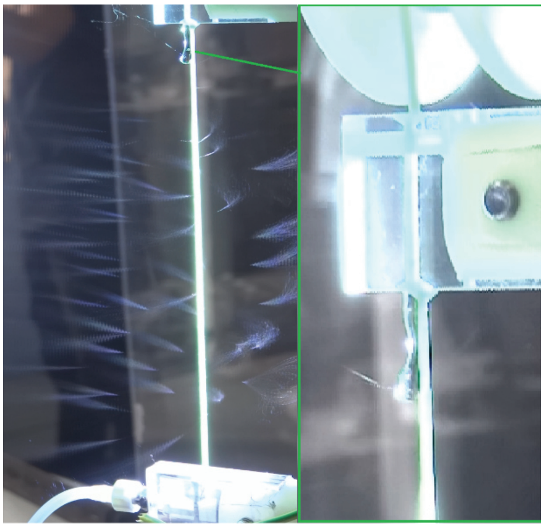

Figure 4 Distance Taylor cones

4. CONCLUSION

From the results plotted in **Table 1**, it is clear that the smallest wavelength was measured at the string with star cross-section of diameter 1.3 mm, while the biggest was measured at the round string of diameter 2 mm. This finding shows that the shape of the string cross-section has a substantial effect on the critical wavelength. As a result of shorter wavelengths, a larger number of Taylor cones can be created along the full length of the string. A larger number of cones initiates a larger number of fabricated nanoparticles. It can be stated that use of a string with a star cross-section shall have a substantially high impact on the productivity of nanofibres. This ensures greater performance of the entire spinning process, which is generally one of the basic criteria for evaluating the process.

It is furthermore apparent from the experiment that the process of nanofibers productivity on the string electrodes is substantially dependent on the set parameters of the spinning device, in particular the electrical voltage on the string, the speed of the string rewinding and the rate of dosing of the polymer solution.

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REFERENCES

[1] D.H. RENEKER, A.L. YARIN, E.A. EVANS, W. KATAPHINAN, R. RANGKUPAN, W. LIU, S. Koombhongse, H. Xu (2001), Electrospinning and nanofibers, *New frontiers in fiber science*.

[2] J. RŮŽIČKOVÁ (2006), Electrostatic spinning of nano fibres, Skriptum. ISBN 80-7372-066-3, TUL

[3] MACDIARMID, A.G., JONES, W.E., NORRIS, I.D., GAO, J., JOHNSON A.T. JR., PINTO, N.J., HONE, J. , HAN, B., OKUZAKI, H., LLAGUNO, M. (2001). Electrostatically-generated nanofibers of electronic polymers, Synthetic Metals 119, 27-30.

[4] JIN, H.-J., FRIDRIKH, S.V., RUTLEDGE, G.C., KAPLAN, D.L. (2002), Electrospinning Bombyx mori Silk with (Polyethylene oxide), Biomacromolecules 3 (6), 1233-1239.

[5] TONKS, L. (1935). A Theory of Liquid Surface Rupture by a Uniform Electric Field, Phys. Rev. 48.

[6] KOMAREK J., VALTERA J., SOUKUPOVA J., VYSLOUZILOVA L., SKRIVANEK J., ZABKA P., BERAN J., LUKAS. D. (2015), Verification of the mathematical model of the rod electrode in the electrospinning process, Nanocon 2015

[7] VYSLOUŽILOVÁ, L. V. (2010), Needleless co-axial electrospinning. *In: Nanofibers for the 3rd Millenium* . North Carolina, USA.

[8] LE VAN KHOA (2017), Analysis of the wire electrospinning, Thesis, Technical university in Liberec.

[9] Struna žací, [Online], http://www.sekacky-online.cz/zaci-struna-profi-kulata-prumer-1-3-mm-a-delka-15-m/