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Construction and automation of rotating cylinder device for an electrospinning system

João de Deus Pereira de Moraes Segundo[1*], Maria Oneide Silva de Moraes[2], Patrick Nasser Oliveira Martins[3], Walter Ricardo Brito[2]

[1]*Department of Manufacturing and Materials Engineering, University of Campinas, São Paulo, Brazil*
[2]*Department of Chemistry, Federal University of Amazonas, Amazonas, Brazil*
3Department of Mechanical Engineering, Federal University of Amazonas, Amazonas, Brazil

ABSTRACT : *The electrospinning technique is widely used to produce fibers with unique characteristics from viscous fluids and the electrostatic forces. Rotating cylinder device is an essential item in the electrospinning system. It is responsible for collecting the fibers during their formation. The type of device (apparatus) changes the morphology of the fibers and fibrous mats produced by electrospinning. A rotating cylinder device for an electrospinning system was constructed and tested. The electrospun poly(caprolactone) (PCL) fibers were produced and observed by scanning electron microscopy - SEM. The test was performed with rotation speed N = 450 RPM, which gave random fibers with diameters of 2.5 ± 0.70 µm. The aligned PCL fibers were obtained with N = 1,500 RPM with diameters of 1.02 ± 0.30 µm. The rotating cylinder device successfully aligned the PCL fibers and has potential application in the biomedical field. This article contributes as a guide for researchers who wish to develop a rotating cylinder device for electrospinning.*

KEYWORDS : *Electrospinning, poly(caprolactone), Aligned fibers, rotating apparatus.*

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I. INTRODUCTION

Electrospinning is a technique widely used to produce fibers from viscous fluids subjected to electrostatic forces. The scientific and technological community explore the combinations of metallic and ceramic materials with electrospun polymeric fiber to obtain unique properties, including natural polymer, synthetic polymer, and copolymers [1-3].

Fibers produced by electrospinning can acquire nanometric dimensions, and their main characteristics are porosity and a surface-area-to-volume ratio [4-6]. The application areas are sensors, ultrafiltration, purification, absorption, energy devices (solar cells, fuel cells, photocatalytic material, and hydrogen generation), protective clothing, smart materials, biotechnological and biomedical [7,8].

The electrospun fibers are formed by applying a potential difference between the electrospinning solution (metallic needle) and the metallic collector (apparatus) grounded. The metallic collector is an essential device in the electrospinning system because it collects the fibers formed during its processing; depending on the type of device, the fibrous mat produced by electrospinning may have different morphologies [5].

Static rectangular metallic collector offers mat formed by fibers of random orientations, forming porous structures [9] that are excellent candidates as scaffold in the tissue engineering area due to mimetic the natural extracellular matrix architecture. On the other hand, aligned fibers have improved mechanical, electrical, and optical properties compared to random fibers [10,11]. Several devices have been developed to promote fibers' alignment, the apparatus as parallel magnetic bars, metallic meshes, rotating cylinder collector, and rotating disk are most used [12].

Rotating cylinder collectors are preferable due to their productivity for the aligned fibers. Furthermore, they are versatile because high rotation speeds align the fibers, and with low rotation speeds, the fibers are random [13]. This work aims to demonstrate the construction and automaton steps of a rotating cylinder device to production random and aligned fibers.

II. EXPERIMENTAL

The essential items for the construction and automation of the rotating cylinder device are listed below with their respective specification:

- Servo Motor 4 N.m and 2000 RPM Leadshine - ES-M23440
- Servo Driver 80V, 8.2A Easy - ES-D808
- Servo Power Supply Leadshine - SPS407
- Encoder cable 4 N.m Easy - Cableh-BM5M5
- Arduino UNO USB cable controller - UNO SMD
- Polyacetal, sheet (30mmX300mmX500mm) supplied by Tuboaços da Amazonia LTDA
- Aluminum billet (Ø = 70 mm) supplied by Tuboaços da Amazonia LTDA

After the construction, assembly and automation of the rotating cylinder device, a polymeric solution was prepared using polycaprolactone (PCL, MM=80,000 g/mol) as polymer to produce random fibers and aligned by the variation of rotation speed of rotating device.

The PCL (1g) was dissolved in chloroform and acetone with a 1: 1 mass ratio, previously stirred for 15 minutes. PCL solution was kept under mechanical stirring at room temperature that was obtained after 16 hours. The solution was inserted into a syringe and conducted to the electrospinning system, which was operated with the parameters: flow rate of 8 mL / h, voltage of 14kV, needle diameter of 0.8mm, and distance from the needle to the rotating cylinder device of 170 mm [4]. The aluminum cylinder of rotating cylinder device was covered with aluminum paper sheet for later removal of the electrospun fibers. During the test, the temperature and humidity recorded were 26 ° C and 57%, respectively.

The tested rotation speeds were N = 450 RPM for obtaining random fibers and N = 1,500 RPM for obtaining aligned fibers.

Electrospun PCL fibers obtained were observed using scanning electron microscope-SEM (ZEISS – Model Evo MA 15), before analysis the samples were coated with 10 nm of gold using a sputter coater (BAL TEC - Model CPD 050). The measurements of the fiber diameters were obtained as described in the literature [4].

III. CONSTRUCTION AND AUTOMATION OF ROTATING CYLINDERDEVICE

The electrospinning system operates with very high voltages ranging from 5 to 50kV [14]. For this reason, the electric field generated between the rotating cylinder device and the metallic needle must be well defined, without leakage of electrostatic charges during the operation of the electrospinning system. Therefore, only the collector must be metallic and with good electrical conductivity in the device. The rotating cylinder device typically performs high rotations during its operation. A good selection of materials is essential for the correct functioning of the electrospinning system. The components produced and the components acquired are shown in Fig. 1.

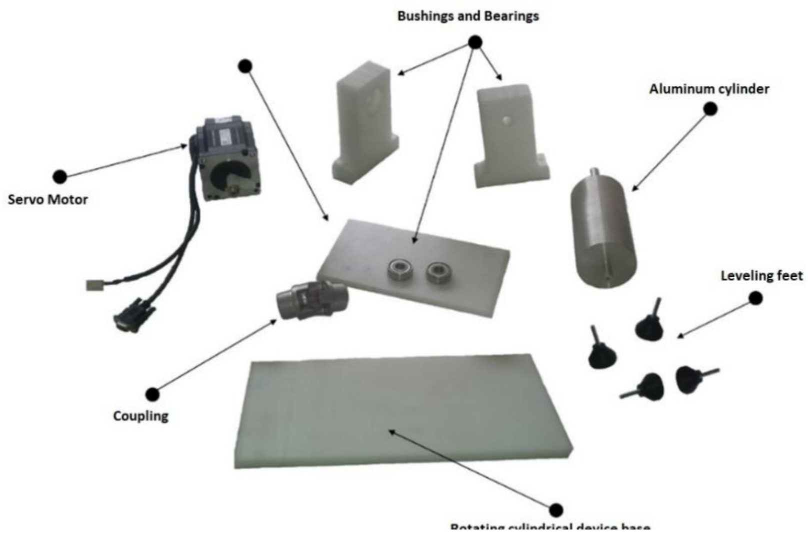

Fig. 1. The main components of the rotating cylinder device used in the assembly.

The structural components of rotating cylinder device, such as the device base, motor base, and bearings were made of polyacetal, and their dimensions were previously established and made in a Machining

Center (ROMI, model D800). The aluminum cylinder was made in a Machine Tool (ROMI-Model IH40) with diameter of 60 mm and length of 150 mm. Bearings, couplings, screws, and leveling feet were used as received. The machine elements used are essential for the rotating cylinder device, and the selection of these components was carried out according to the device's operating requirements, such as maximum rotation speed and electrical protection.

The complete assembly of the rotating cylinder device is shown in the Fig. 2.a. The useful structural dimension of the rotating cylinder device was 15cmX40cm and can be easily conducted and used inside a fume hood due to the safety requirement related to the evaporation of toxic solvents [9].

The rotation speed control of the rotating cylinder device was carried out combining the servo motor, servo driver, servo power supply, encoder cable, Arduino Uno, and programming language. Fig. 2 shows a flowchart with the main components used for the automation of the rotating cylinder device, including the rotating cylinder device. Using a USB cable from the Arduino Uno connected to the computer, it was possible to insert the Arduino IDE input data. Fig. 2.b shows the program code that was developed to activate the servo motor. The maximum rotation speed was of 2,000 RPM.

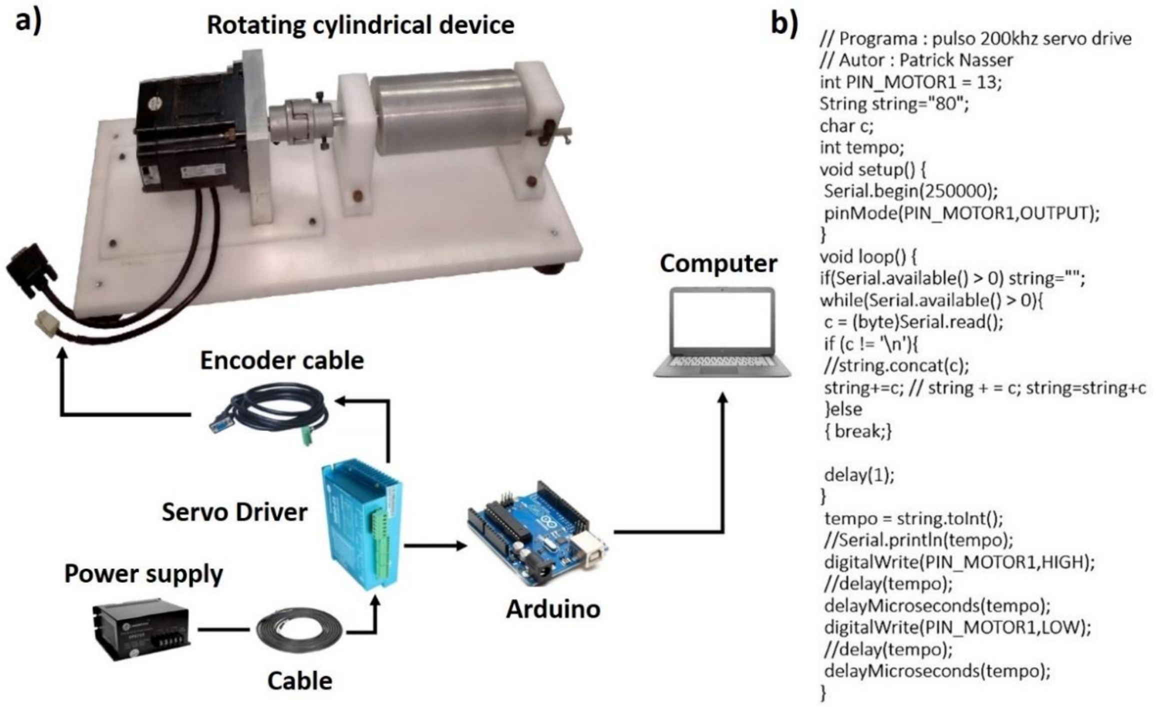

Fig. 2. Complete assembly and flowchart with the main components used for the automation of the rotating cylinder device (a). Program code used to control the rotation speed of the servo motor (b).

The rotating cylinder device was tested with the parameters that were described in the methodology. In Fig. 3.a, electrospun PCL fibers are shown and were collected by the rotating cylinder device. It is possible to see clearly by comparing Fig. 2.a and Fig. 3.a; note that the fibers were deposited only on the aluminum cylinder due to the electrical isolating. The continuous and overlapping deposition of the PCL fibers forms a fibrous mat composed of fine fibers. Fig 3.b shows the fibrous PCL mat removed after its production by electrospinning.

Electrospun PCL fibers were produced using N = 450RPM; the SEM image in Fig. 4.a shows the morphology of the random fibers. The increase to N = 1,500RPM conferred direction to the PCL fibers. The SEM image of Fig. 4.b shows the aligned fibers; note that the comparison between the morphological images of the fibers obtained with different rotation speeds clearly shows the effect of the PCL fibers' alignment using the rotating cylinder device. In addition, it shows the versatility of producing fibrous mats from random and aligned fibers. Both possess structural characteristics for application in tissue engineering for use as scaffolds. The aligned fibers have highlight because they can direct the proliferation of cell growth. The alignment of loaded fibers with conductive or semiconductor nanoparticles is interesting for developing electronic components with unique properties.

The diameters of the random and aligned fibers were 2.5 ± 0.70 and 1.02 ± 0.30 μm, respectively. The diameters of the aligned fibers were smaller compared to the random fibers. This effect was due to the rotation speed. Similar results are founded in the literature [12]. Therefore, this paper helps as a guideline for researchers who wish to develop a rotating cylinder device used in laboratory electrospinning.

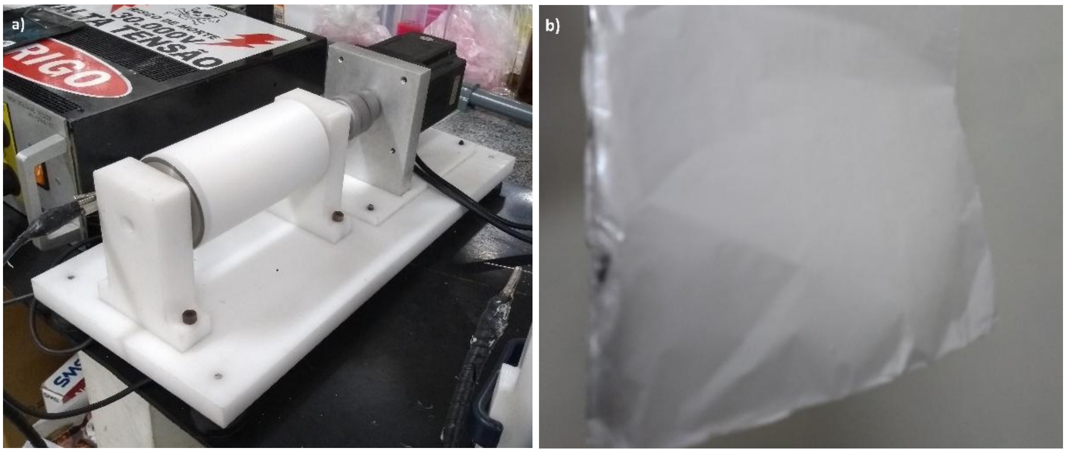

Fig. 3. Electrospun PCL fibers and collected by the rotating cylinder device (a) and fibrous PCL mat removed after its production (b).

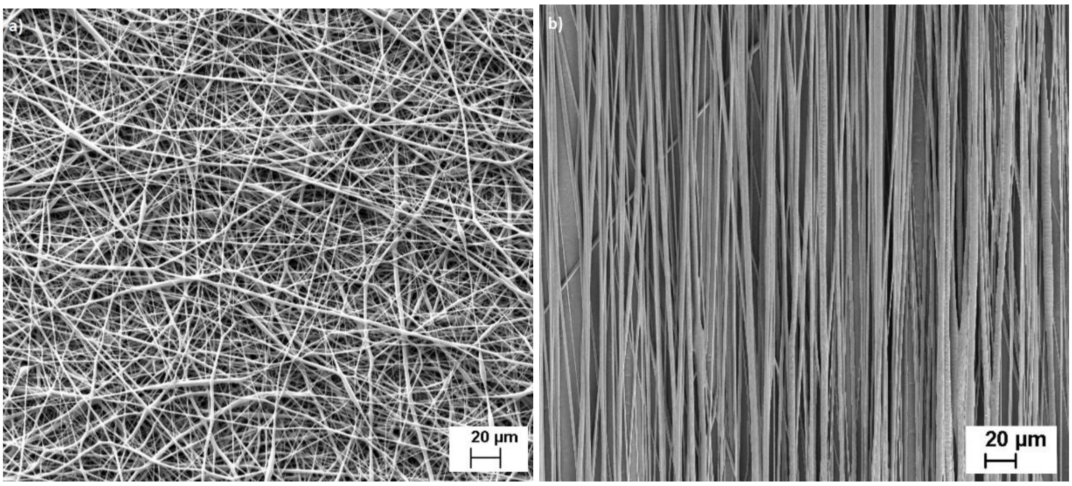

Fig. 4. SEM images of random PCL fibers obtained with rotation speed N = 450 RPM (a) and aligned PCL fibers obtained with rotation speed N = 1,500 RPM (b).

IV. CONCLUSION

A rotating cylinder device for an electrospinning system was constructed, automated, and tested. Electrospun PCL fibers were produced with N = 450 RPM that showed a random behavior and diameters of 2.5 ± 0.70 µm. The N = 1,500 RPM conferred for the electrospun PCL fibers an uniaxial alignment with diameters of 1.02 ± 0.30 µm. The rotating cylinder device has successfully aligned the PCL fibers and is an interesting biomedical application. Therefore, this paper helps as a guideline for researchers who wish to develop a rotating cylinder device used in laboratory electrospinning.

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