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Manufacturing of Twisted Continuous PAN Nanofiber Yarn by Electrospinning Process

F. Dabirian, S. A. Hosseini Ravandi*, R. Hashemi Sanatgar, and J. P. Hinestroza[1]

Department of Textile Engineering, Nanotechnology & Advanced Materials Institute, Isfahan University of Technology, 84156 83111, Isfahan, Iran

[1]*Department of Fiber Science and Apparel Design, College of Human Ecology, 242 Martha Van Rensselaer Hall, Cornell University, Ithaca, NY 14853, USA*

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Abstract: The development of a modified method to produce heat treated twisted nanofibrous yarns using two oppositely metallic spinnerets system is presented. This method allows the production of more uniform, stronger twisted poly acrylonitrile (PAN) yarns. The novelty of this system permits for in-situ heat treating of the nanofiber yarns. The average diameter of twisted nanofiber yarns is 340.65 μm with 5.8 CV%. The values of the initial modulus and stress of heat treated yarns increase from 1.90 GPa and 61.30 MPa in untreated one to 4.51 GPa and 116.56 MPa, respectively. In order to quantify the alignment of the nanofibers Fourier power spectrum (FPS) and image analysis were used. So the treated yarn shows more degree of nanofiber alignments than the untreated one.

Keywords: Electrospun yarn, Mechanical properties, Heat setting, Fourier power spectrum, Image analysis

Introduction

Electrospinning uses an electric field to control the formation of polymer nanofibers. Customary electrospining equipment consists of four main parts: a metallic capillary, a high voltage source, a pump and a collector. During the electrospining process, an electrical potential is being applied to a polymer droplet flowing out from the tip of a needle. Charging of the droplet results in the formation of a flow phenomenon known as Taylor Cone. When the electrical forces (electrostatic and columbic interactions) overcome the surface tension of polymer solution, a charged fluid jet is ejected following a spiral path [1]. The electrical forces elongate the jet thousands of times and the jet stretches toward the grounded electrode. Electrospun nanofibers are often collected as randomly oriented structures in the form of nonwoven mats which are acceptable for some applications such as filters [2], wound dressings [3], composites [4], tissue engineering scaffolds [5], protective clothing [6], electronics [7], sensor applications [8,9], ceramic fibers [10], drug delivery materials [11,12] and many other applications [13-15].

Various structures such as aligned nanofibers, arrayed nanofibers and uniaxially aligned electrospun nanofibres yarn have been achieved using different mechanical collection devices and the manipulation of the electric field [16]. Several approaches used to align electrospun nanofibers include the use of a rotating collector [17-22], spinning onto the sharp edge of a thin rotating wheel [23], using dual grounded collection plate [24-26], a scanning tip [27], a copper wire drum [28], using a metal frame collector [29], parallel auxiliary electrodes [30], a rotating jet [31]. Aligned nanofibers in particular can be tailored for use in microelectronics, photonics and in a variety of electrical, optical, mechanical, and biomedical applications [20,24,32-34].

Many attempts have been made to produce yarn from nanofibers. One of the proposed methods introduces an auxiliary electrode or electrical field, with vertically oriented rings connected in series and charged at the same polymer jet voltage applied to a syringe needle to produce yarns of only 1 inch length [35]. Another method involves applying a high frequency oscillation in a metal grounded frame within the jet [36]. The other method developed by Smith *et al.* consist in depositing nanofibers into water to eliminate the charges of the charged nanofibers, which are collected together, and yarns are drawn out [37]. Pan *et al.* used two oppositely charged feeding needles to combine coming fibers to form a yarn which was wound by a cylindrical collector rotating at a high speed [38]. Dynamic liquid support system is a new system of assembling the electrospun fiber mesh using water as the supporting and working media to manipulate the deposited electrospun fibers into a continuous yarn. The vortex created aided in the yarn formation and facilitated yarn collection [39].

Some researchers produced twisted nanofibers by controlling the whipping jet and using a modified electric field from an auxiliary electrode [40] or the manipulation of the electric field [41], applying mechanical stretching to the electrospun nanofibers [42], and self-bundling [43] to prepare continuous twisted yarn. An annular collector with circular cross-section was employed to obtain fibrous yarn through electrospinning and post spinning twisting. However, the structure of the produced yarn was nonuniform and hairy [44].

Some researchers applied the two oppositely metallic

*Corresponding author: hoseinir@cc.iut.ac.ir