A NOVEL METHOD FOR FABRICATION OF FASCINATED NANOFIBER YARNS

by

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Potential applications of nanofibers as a new-generation of material will be realized if suitable nanofiber yarns become available. Electrospinning has been widely accepted as a feasible technique for the fabrication of continuous nanofiber yarns. However its low output limited its industrial applications. This paper presents a new processing approach to fabrication of fascinated nanofiber yarns which possess excellent properties of nanofibers while enhancing its mechanical strength by the core yarn.

Key words: *blown bubble spinning, bubble electrospinning, nanofiber yarn*

Introduction

Along with the rapid development of nanotechnology, the textile industry has focused on the production and applications of nanofiber yarns. Compared with traditional yarns, nanofiber yarns possess novel properties such as small pore size, large surface area, high thermal insulation, and excellent air/vapor permeability. They have found applications in biomedical engineering, aerospace, military, environment, microelectronics, tissue scaffolds, reinforced composite, modern textile engineering, and other challenging fields. Nanofiber yarn is defined as a twisted nanofiber bundle with a morphology like filament yarn or spun yarn, and which is mechanically suitable for textile processing like weaving and knitting [1]. Nanocomp Technologies, Inc., considers nanofiber yarns as the best materials for bulletproof vest due to its remarkable mechanical and thermal characteristics. The nanofiber yarns they produced have been incorporated into the Juno space-craft.

Blended with nanoadditives like ZnO, SiO, and AgO, the nanofiber yarns have been recognized as protective properties. The antimildew, antibacterial, deodorant, and anti-ultraviolet performance together with the function of repelling water and sweat makes the nanofiber yarn the best choice for comfortable underwear materials. The coefficient of friction drag can be minimized by incorporating nanofiber yarns into the surface of moving objects like bullet trains and aircrafts.

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Spider silk is the natural nanofiber yarn composed of fibers with diameter of about 20 nm. Spider silk is lighter, thinner, more flexible, and tougher than steel. With its superior mechanical characteristics, it will surpass the current generation of high-performance fibers. The ability of this natural silk to absorb in excess of 100,000 joules of kinetic energy makes it the potentially ideal material for structural blast protection. Other applications of spider silk include use as structural material and for any application in which light weight and high strength are required.

The idea of man-made nanofiber yarn originated from carbon nanotube (CNT) in 1990 which is the ideal nanofiber yarn. The Nobel Prize in Physics 2010 was awarded jointly to Geim and Novoselov "for groundbreaking experiments regarding the two-dimensional material graphene". Graphene is a thin layer of pure carbon which is the building blocks for graphite while nanotube is a cylindrical nanostructure rolled from graphene. They represented 1-D and 2-D nanomaterials separately. How to construct 3-D nanomaterials is another major challenging. The CNT has drawn wider attention due to its superior performance since 1991. Scientists have been researching new procedures for mass producing CNT yarns since then. Although great progress has been achieved, substantial breakthrough is still on the way. Yin *et al.* [2] proposed the idea of super CNT which is efficient in achieving nanofiber yarn. Yarns of any scale can be obtained theoretically with the drawback of high cost. The fascinating phenomena arise when the diameter of substance is less than 100 nm, this phenomena do not depend upon bulk material, but strongly depend upon its fractal structure which is called Nano-effects [3]. The CNT have been replaced by normal materials because of its high cost [4-6].

Electrospinning has been considered as the most versatile process capable of producing nanofiber yarns [7-10]. Ko *et al.* [11] presented a new manufacturing technique to obtain carbon nanotube-filled nanofiber yarns thus enhancing the mechanical properties. Although this method is easy to manipulate, it is hard to produce continuous nanofiber yarns with the fragile strength and the short length of single nanofibers. It is pointed out in [12] that the diameters of nanofiber yarns are hard to effectively control and the mechanical properties in large part depend upon parameters like twist. To overcome these drawbacks, researchers [8, 13-22] have been contributing their efforts in this field. Wang *et al.* [13, 14] proposed self-bundling electrospinning for the first time to manufacture aligned nanofiber yarns with excellent mechanical performance. This method laid solid foundation for the industrial application of nanofiber yarns. Li *et al.* [23] employed the funnel-shape collector with high speed airflow inside to prepare nanofiber yarns. Chen *et al.* [8] successfully fabricated highly aligned nanofiber bundles with high strength. Wu and Qin [15] used the theory of electrospinning and rotating airflow to prepare nanofiber yarn. Li *et al.* [16] and Pan *et al.* [17] reported that the mechanical strength of nanofiber yarns can be enhanced by drawing the as-spun. Pan *et al.* [20], Li *et al.* [21], and Yao *et al.* [22] developed a process referred to as conjugated electrospinning to produce poly(L-lacticacid) continuous yarns from oppositely charged electrospun nanofibers.

Senthilram *et al.* [4] obtained twisted nanofibers by rotating needle assembly without high voltages. However, this set-up is in the trial stage for the mass production. And the nanofiber yarns obtained using this approach are as a matter of fact false twisted yarns [24]. The rotating needle assembly can be replaced by rotating air vortex which is widely adopted in traditional textile spinning process [24]. Dalton *et al.* [5] used dual collection rings as collector. The two grounded rings are placed equidistantly from the spinneret. An array of highly-aligned fiber bundles is formed between the collection rings. The twist is added by rotating one of the collection rings. This approach has not been the mainstream for fabrication of nanofiber yarns with the limit of fragile properties of single nanofiber. Teo *et al.* [6] manipulate the nanofibers through the use of a water vortex which is much similar to the air vortex used in traditional textile spinning process. During the electrospinning process, fiber was deposited on the surface of the water. Due to the presence of the vortex, fibers deposited close to the vortex were pulled along with the falling water through the hole at the bottom of the basin and simultaneously bundled together to form a continuous yarn. This is not suitable for water-soluble fibers. The twist added to the yarn is not evitable because of the slow vortex. Furthermore, the strength of vortex is hard to control.

Fascinated nanofiber yarns arise in response to the proper time and conditions [25]. They are prepared by the adoption of traditional spinning technology [24]. The facile method could reduce the costs of nanofiber yarns which twisted the nanofibers around continuous filament.

All these explorations supply us with novel ideas of developing fascinate nanofiber yarns with high mechanical performance. However, the major drawback of these electrospinning is that the production rate is low and the generation of fibers is dependent upon a number of factors such as feasibility, continuous winding. We put forward novel approach for fabricating fascinated nanofiber yarns by blown bubble spinning. The rotating air flow completed the spinning process by overcoming the surface tension of bubble and twisting it as well. The blown bubble spinning have been proposed by Dou *et al.* [26] for the fabrication of nanofibers without electric. The blown bubble spinning eliminate all the problems caused by electric and are not limited by the spinnability [27, 28]. The spinnability does not depend on viscosity and dielectric constant of polymer as long as the bubble could be generated on the surface of polymer or melts.

We put forward a novel approach for fabrication of fascinated nanofiber yarn which is an economic method for producing yarns with nanofiber properties while retaining excellent mechanical strength. As seen in fig. 1, the fascinated nanofiber yarns combine the SIROFIL spinning technology [24] with nanotechnology. The core yarn is formed by twisting the micro-meter onto the core filament. The nanofibers are twisted outside of the former yarn which contributed to a hierarchical yarn possessing excellent ventilation property [29, 30]. We are inspired by the hierarchical structure of silk cocoon with particular air permeability [31-34]. It is reported that [31] the cocoon imposes no barrier to the diffusion of oxygen or water vapor. We takes advantage of the technology of blown bubble on the basis of mature vortex spinning to successfully design a new avenue for the fabrication of fascinated nanofiber yarn [35]. As seen in fig. 2, rotating flows of air are exerted around the blown bubbles. The nanofiber bundles are formed and twisted in one step [29, 30].

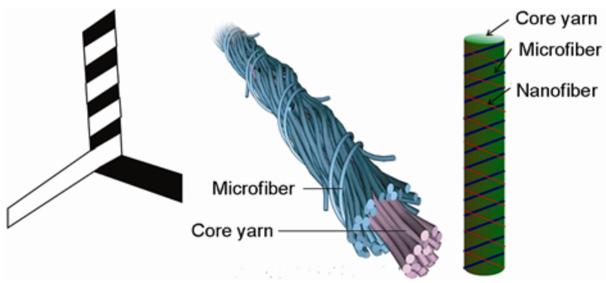

Figure 1. Schematic diagram of fascinated nanofiber yarn in hierarchical structure

Conclusions

This paper reports a novel approach for fabrication of fascinated nanofiber yarns. The fascinated nanofiber yarns manufactured possess both nanofiber's excellent properties and high mechanical strength which can sustain traditional textile processing like weaving or knitting. The experimental results illustrated the efficacy of this method. The process adopted blown air instead of electrostatic as power eliminating the pollution and hazards caused. This is the potential method for mass producing nanofiber yarns.

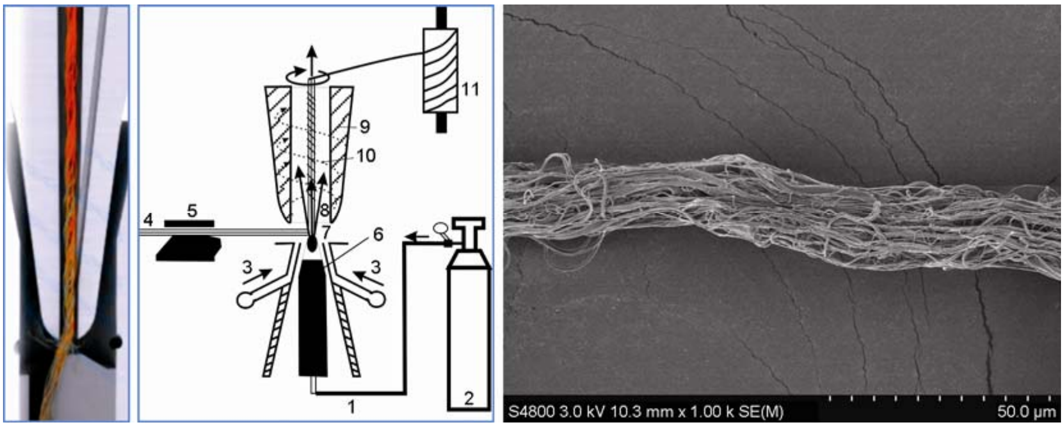

Figure 2. Set-up of fascinated nanofiber yarns' fabrication (Patent No. ZL 2013 2 0720637.9) and nanofiber yarns; *1 – tube, 2 – gas storage, 3 – hot air, 4 – yarn, 5 – yarn guide, 6 – solution, 7 – bubble, 8 – nanofiber, 9 – nozzle, 10 – vortex, 11 – wind-up*

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