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Characteristics of Yarn and Fabric Made out of Nanofibers

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Abstract

Nowadays, while human requirements are extending, producing nanofibers and nanofiber based products are progressing rapidly. Nanofibers have received considerable study in recent years using various polymers and methods. PAN (Polyacrylonitryle) nanofibers have shown a great potential in producing nanofibers and nanofibre yarn as precursor polymers for making high performance carbon fiber. There is a lack of information about yarn and woven fabrics made out of nanofibers. Current research is aiming to manufacture yarn using well-known electrospinning technique and converting it to woven fabric. A continuous yarn was produced by changing production parameters and using simultaneous twisting and collecting. Values of twist and rate of fiber collecting made it possible to prepare yarn from nanofibres. Consequently, the yarns were used for producing plain weave fabric manually. Some characteristics of the yarn, such as diameter and its distribution along the yarn, specific density, thin and thick places were assessed using image processing technique. Also, characteristics of fabric appearances were investigated.

Keywords

1. Introduction

Development of science in nanotechnology has made expansion of science horizons. Electrospinning was first designated as a fabrication technology by Rayleigh in 1897 [1], and finally patented by Formhals in 1934 [2].

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There are more than three manufacturing approaches to fabricate nanofibrous structures; *i.e.* electrospinning, phase separation, and self-assembly. Structures created by each of these approaches are quite different and thus have their own unique advantages. The phase separation technique allows the control of pore architectures, while structures produced by electrospinning provide more control on morphology and high aspect ratio, variable pore-size distribution, and high porosity [3].

Due to their characteristics, nanofibers have been studied in different area, *i.e.*, medical science, filtration, drug delivery, tissue engineering, and wound healing [4].

Nanofibers are collected in the form of a web. Some studies are conducted to produce yarn from nanofibers and many researches have reported different methods for preparing nanofiber yarns [5]-[11]. In most of these methods, produced yarn didn't have suitable length.

Current study has used an innovative method to prepare a continual yarn strand in order to produce woven fabrics woven fabric. The characteristics of nanofiber yarn and woven fabric are studied as well.

By using introduced method and applying suitable polymers, especially biopolymers it could be possible to produce continuously strand of nanofibers with tailored physical, chemical, biological and mechanical properties which are attractive for design of ecologically friendly products in a range of applications from personal care to healthcare such as hospital apparel, suture, drug delivery systems, and scaffolds for tissue engineering and tissue regeneration.

The aim of this study is analyzing different properties of nanofiber yarn and produced fabric. Yarn linear density, coefficient of variance of yarn diameter (CV%), thin and thick places of yarn were calculated. Also, coefficient of agreement of surface irregularity, cover factor, weft and warp spacing of prepared fabric were calculated using image processing.

2. Experimental

2.1. Materials

Polyacrylonitril (PAN) powder and Dimethylformamide (DMF) as solvent were mixed to make a polymer solution with 14% concentration. Mean molecular weight (Mw) of PAN was 100,000 g/mol. The scanner which was used for image processing of sample fabric was Canon-Canoscan 8400 f with 2000 dpi.

2.2. Yarn Preparation

The schematic setup for preparing nanofiber yarn is presented in **Figure 1** [12] [13]. In this method, a high voltage DC supplier creates an electrostatic field between two nozzles with opposite charge. Also, it consists of a high voltage-power supply, two syringe needles, a conductive hemisphere, a feeder unit and a take up unit. The hemisphere diameter was 8 cm. The syringe needles were located 2 cm from the hemisphere and 21 cm from take up unit. Electrospinning was done between two syringe needles, then electrospun nanofibers collected on hemisphere surface and twisted by rotating the hemispherical collector. Take up unit can twist the yarn without forming a balloon while taking up the yarn. The take up unit was controlled by a three phase motor for twisting the yarn and was controlled by an inverter. A stepper motor controlled the speed of take up and was controlled by a microcontroller. To provide the required input current for the stepper motor, a buffer was used to connect the output port of microcontroller to the stepper motor. Users can control the rotation speed of the stepper motor with a switch connected to the input port of the microcontroller. After production of the yarn, they were heat treated and stretched two times. The value of twist per meter was 2900. For this purpose, each yarn was drawn by fastening end of yarn with fixed jaw and drawing it in hot water (100°C). This procedure causes improvement in the strength of yarns [14] [15]. **Figure 2** shows typical SEM of heat setted nanofiber yarn.

2.3. Fabric Production

Nanofiber yarns don't have enough length to get a large yarn package to enable it to be used in construction of fabric using a weaving loom. So, this work has devised a manual procedure to produce plain woven fabrics. A wooden framework and 4 weaving reeds were used for this purpose. These reeds had a guiding rule for yarns to stabilize them and keep space between yarns (weft and warp density). By crossing the yarns between reed teeth, the fabric density was kept steady.

The densities of yarns were 15 ends/cm and 15 picks/cm for warp and weft yarns, respectively. **Figure 3(a)** and **Figure 3(b)** show chematic and typical image of plain woven fabric respectively.
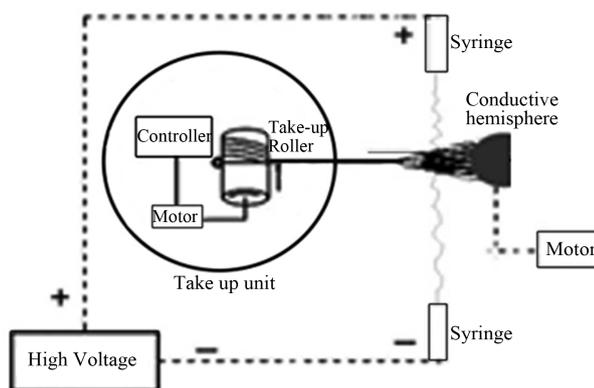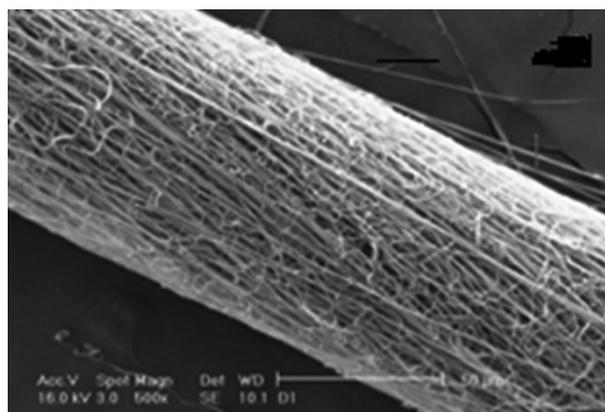
Figure 1. Yarn production unit.
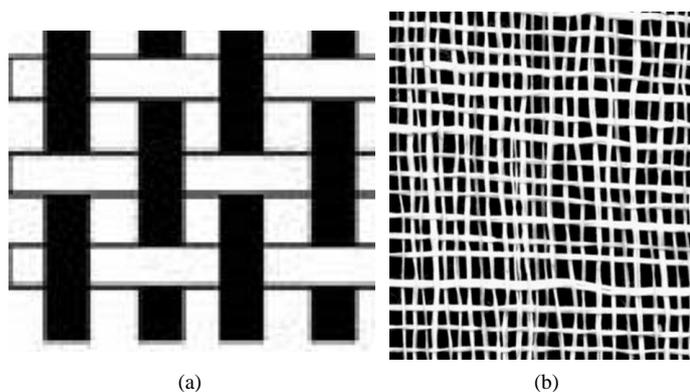

Figure 2. Typical SEM heat set yarn.

(a)   (b)

Figure 3. (a) Schematic image of plain woven fabric; (b) Typical image of plain woven fabric.

3. Results and Discussions

3.1. Yarn Specific Density

For evaluation of yarn specific density, various solutions were used. More prevalent solutions are: Benzene, Nitrobenzene, Olive Oil, CCl_4 and Acetic Acid. For each solution, the yarn specific density values were assessed to be 1.065, 0.927, 1.039, 1.119 and 0.928 g/cm^3, respectively. Mean specific density of yarns found to be 1.015 g/cm^3. The amount of Acrylic yarn density generated from melt spinning (1.14 - 1.18 g/cm^3) [16]. The reason of this discrepancy is related to porous structure of nanofiber yarn which in turn affects the yarn volume.

3.2. Yarn Diameter Determination

To determine yarn diameter, we scanned 25 SEM samples of different yarns in 2000 dpi and 256 grayscale. Length of each sample was 30 cm. **Figure 4** shows a part of diameter variation along the one sample yarn.

Yarn count was determined 21 Tex using the Equation (1):

$$\text{Tex} = A \times \rho \times 10^5 \tag{1}$$

where; A is cross section of the yarn (cm^2) and $\rho = 1.015$ g/cm^3.

Nominal diameter and CV% of yarn were obtained 0.1656 mm and 19.82%, respectively. The actual yarn count was 19 Tex.

3.3. Thin and Thick Places

For calculating the thin and thick places we applied a simple procedure using the mean and STD (Standard Deviation) of yarns diameter as the Equation (2) [17]:

$$a = b \pm c \tag{2}$$

where; a is thick place (thin place), b is mean diameter of yarn and c is STD of yarn diameter.

When a column (or row) of yarn image is taken, each part which has diameter more (less) than the amount of $b + c$ (or $b - c$), that part is a thick (thin) place. **Table 1** shows the thick (thin) places along the 25 sample yarns.

3.4. Fabric Characteristics

To evaluate the fabric geometry and fabric appearance, the fabrics were scanned in 400 dpi and 256 grayscale.

3.4.1. Warp and Weft Spacing

To appraisal of spacing, we selected some columns and rows of fabric images. Then using of Fourier Transforms and image processing, the spacing was calculated. **Figure 5** shows two typical Fourier Transforms of line density of images in the warp and weft direction.

Warp and weft spacing were obtained 41.35, and 53.25 pixels, respectively. Warp and weft density (X) obtained 13 ends/cm and 16.4 picks/cm, respectively, using the Equation (3):

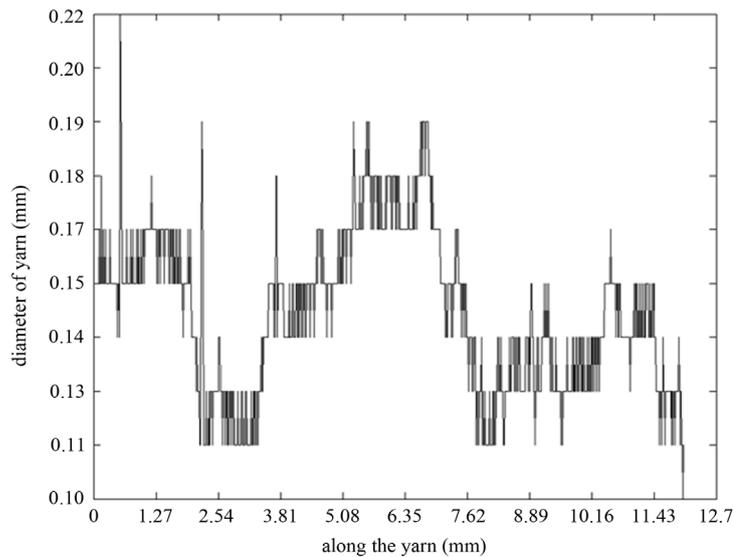$$X = \frac{10}{\left(N \times 25.4\right)/\left(DPI \times K\right)} \tag{3}$$

Figure 4. Typical diameter variation along the one sample yarn.

Table 1. Evaluation of yarn diameter, thin and thick places.

Yarn No.	Mean diameter (mm)	Number of thin places	Number of thick places
1	0.18	400	219
2	0.19	384	489
3	0.21	192	254
4	0.14	145	200
5	0.13	29	64
6	0.14	123	217
7	0.16	157	237
8	0.19	291	343
9	0.19	291	362
10	0.17	242	402
11	0.14	261	317
12	0.17	296	490
13	0.19	393	341
14	0.16	263	179
15	0.16	495	438
16	0.21	461	347
17	0.20	859	762
18	0.17	748	535
19	0.13	476	331
20	0.13	521	363
21	0.13	485	645
22	0.12	302	286
23	0.17	547	245
24	0.19	351	364
25	0.17	349	337

where; $K = 0, 1, 2, \cdots, 511$, $N = 512$ and $DPI = 400$.

The difference between real fabric density and calculations could be attributed to the fact that the yarns had a very flexible structure and this caused the yarns to overlap together.

3.4.2. Coefficient of Agreement of Surface Irregularity

Autocorrelation function (ACF), is a method for realizing correspondence between surface are a relative to each other. This method is able to be used for studying in image features like color, intensity, reflection. ACF and power spectrum (PS) are reversal of each other.

For calculating of ACF in image, at first step we calculate PS, using FFT and then using inverse FFT (IFFT), ACF will be found [18]. **Figure 6** shows the flowchart to calculate ACF. In this study ACF has been used for evaluating the fabric surface irregularity. Scanned image of fabric was divided into 10 areas with similar surface area.

At first, ACF of all images were taken. Then by taking a central row of each image as a base line, FFT was calculated. Maximum AFC value in each area was taken as a comparison parameter between areas. **Figure 7** shows the results.
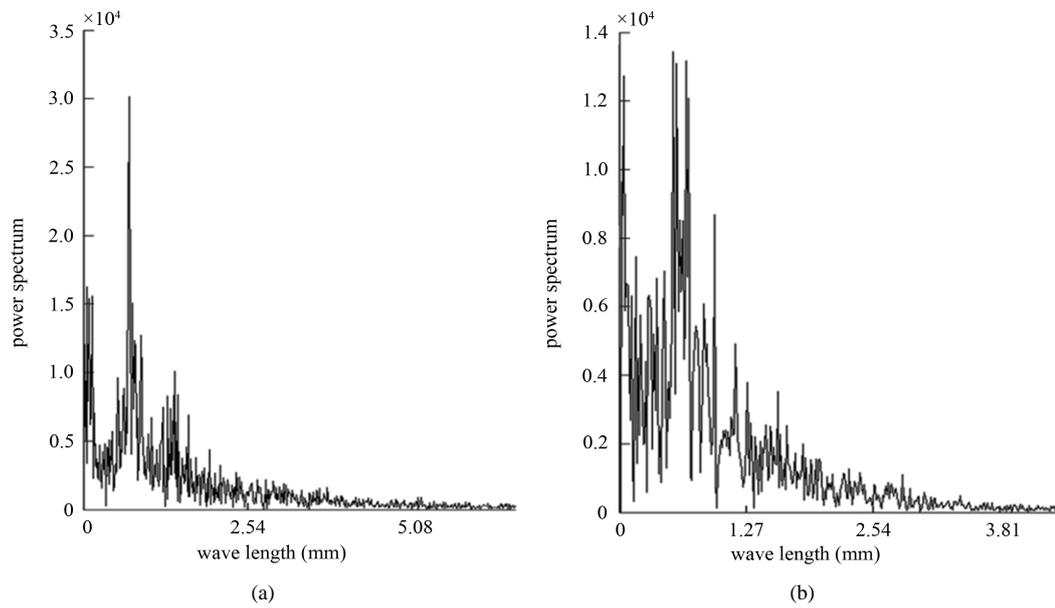
Figure 5. (a) Typical Fourier Transform diagram of one selected row which were used for calculating warp spacing in plain pattern; (b) Typical Fourier Transform diagram of one selected row which were used for calculating weft spacing in plain pattern.
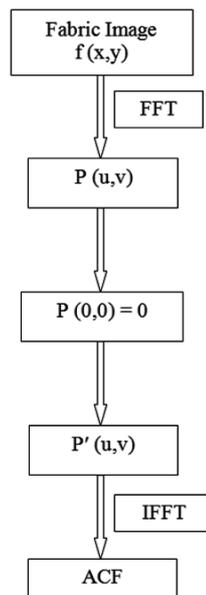

Figure 6. Flowchart to calculate ACF.

The results of the statistical tests indicate that there is no significant difference between the surfaces area of fabrics at different parts at the 95%, so the fabric surface can be consider as a regular surface.

3.5. Cover Factor

Cover factor is the ratio of the area covered by yarns and the total area of the fabric surface. In this study, cover factor was calculated using the image processing. After scanning the fabrics, the cover factor obtained 0.4467. Also, cover factor was 0.42 according to the Equation (4) [19]:

$$\text{Cover Factor} = n_1 d_1 + n_2 d_2 - n_1 n_2 d_1 d_2 \qquad (4)$$
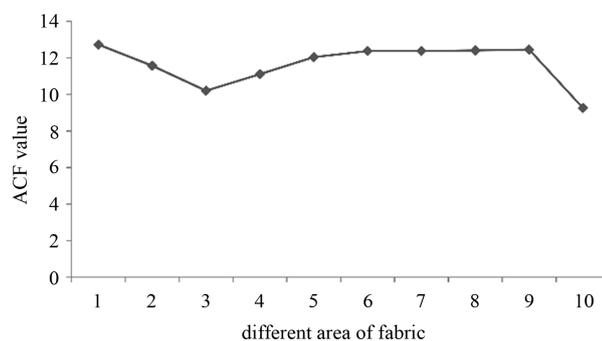
Figure 7. ACF values for plain woven fabric.

where n_1, n_2 are densities of warp and weft yarns, respectively and d_1, d_2 are diameters of warp and weft yarns, respectively.

4. Conclusions

The aim of this study was to introduce a methodology to produce continuously strand of nanofibers and fabric. Nanofibre yarn properties such as specific density, linear density, thin and thick places were obtained using image processing method.

Nominal linear density and specific density of yarn were close to the actual values. Fabric geometry as well as fabric appearance, *i.e.*, warp and weft density, coefficient of agreement of surface irregularity (CASI) and cover factor were determined. The index of CASI showed that surface areas of fabric had a regular appearance.

By using introduced method and applying suitable polymers, especially biopolymers it could be possible to produce continuously strand of nanofibers with tailored physical, chemical, biological and mechanical properties.

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