Evaluation on Manufacturing Technique and Surface Resistivity of the Bamboo Charcoal/ Polyurethane Complex Yarns and Knitted Fabrics

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Abstract

In this research, the bamboo charcoal/ polyurethane (BC/P) complex yarns and knitted fabrics were made of bamboo charcoal polyamide textured yarn and polyurethane fibers. The polyurethane fibers were expanded and then wrapped with the bamboo charcoal polyamide textured yarn. Three manufacture parameters were depicted as follows: the speeds of the rotor twister were 4000- 12000 rpm, the wrapped counts of the BC/P complex yarns were 200- 400 turns/m; and the expanded multiple of the polyurethane fibers was 3. Afterward we fabricated the BC/P complex knitted fabrics using a circular knitting machine. The tenacity of the BC/P complex yarns was 37258.4 cN/tex when the speed of the rotor twister was 4000 rpm, and the wrapped counts were 200 turns/m. Meanwhile, the elongation of the BC/P complex yarns was 35.77% when the speed of the rotor twister was 4000 rpm and the wrapped counts were 400 turns/m. The lower surface resistivity of the BC/P knitted fabrics was 3.33×10^{10} *(Ω/Square) when the wrapped counts were 400 turns/m and the polyurethane fibers were 70D. Moreover, when the wrapped counts were 200 turns/m the optimum air permeability of the BC/P complex knitted fabrics with 40D polyurethane fibers was 47.2* $cm^3/cm^2/s$ *which was better than that with 70D polyurethane fibers.*

Key words: *polyurethane fibers, knitted fabrics, a multi-section drawing frame, a*

rotor twister machine, surface resistivity.

Introduction

The dramatic changes brought by modern technology have caused stresses in life rapidly and various modern diseases. In order to prevent diseases, health protection has gained popularity and become human’s major concern. The goals of the latest development for modern technology are majorly about life with good quality concerning people’s mental and physical health. Basic daily necessity industries for eating, clothing, living and transportation largely invest to develop and improve the special functions of the products, such as heat preservation, elasticity, electromagnetic shielding, and anti-static electricity. Bamboo charcoal fiber gets the most attention nowadays and the whole serial fabric products made of bamboo charcoal fiber are now becoming popular [1]. On the other hand, polyurethane possesses high resilience and elasticity as rubber does, and polyurethane fibers has superior tensile strength, elongation, abrasion resistance, aging resistance, chemical resistance to rubber. Meanwhile, polyurethane fibers have attributes like comfort, wearability and the least deformation. At present, a small amount of polyurethane fibers (5-20 %) is usually used to weave with other major fibers. Because polyurethane fibers are able to change the fabric property, they can be used with different textiles, e.g., underwear, sportswear, lace, stockings, snug outfit, corset and so on [2-4].

Due to the heat carbonization, bamboo charcoal can release far infrared ray which accelerates the blood circulation and improves the metabolism. Far infrared ray absorbs the heat energy emitted by the sun radiation or human body and further releases the far infrared ray at between 4 μm and 14 μm. By absorbency and resonance, the organic molecules and water molecules within the object are excited and results in the heat raising inside the object and preserving the heat. Bamboo charcoal is characterized by high density and high absorbency and such attributes grant the bamboo charcoal textured yarn deodorization, humid adjustment, and antibacterial effect. Moreover, bamboo charcoal textured yarn is able to release anions. By means of the friction with the air, bamboo charcoal knitted fabrics can naturally generate anions with negative electricity.

Many scholars around the world have conducted relevant research on bamboo charcoal fiber or polyurethane fibers; moreover, they have improved the properties, productive analysis and relevant improvement considerably. Nevertheless, most complex yarns were polyurethane fasciated yarns which were polyurethane fibers being wrapped with staples using a ring spinning [5-15]. In addition, not many studies were about the polyurethane fibers wrapped by filaments, in particular, by bamboo charcoal polyamide textured yarn using a special rotor twister machine [16-23].

In this paper, a rotor twister machine wrapped the polyurethane fibers with bamboo charcoal polyamide textured yarns to make the BC/P complex yarns; a circular knitting machine wove the BC/P complex yarns into fabrics. The complex yarns were subjected to the maximum breaking strength and elongation testing for the optimum manufacture parameters for producing the fabrics. Then the knitted fabrics were tested for air permeability and surface resistivity.

Experimental

Materials

The 70D/48f bamboo charcoal polyamide textured yarn, which was composed of 3.0 wt% bamboo charcoal powder and 97.0 wt% polyamide polymer, was provided by Hua Mao Nano-Tech Co., Ltd. The 40D and 70D polyurethane fibers were offered by Haojey Co., Ltd.

Manufacturing Techniques for BC/P Complex Yarns and Knitted Fabrics

BC/P Complex Yarns

Figure 1 shows the configuration of a rotor twister machine. The polyurethane fibers (A) were expanded using a multi-section drawing frame (B), and pulled through the thread eye (C) into the rotor twister (E). The rotary speed of winding roller (I) determined the feeding speed. Afterward the bamboo charcoal polyamide textured yarns were gathered around the cylinder to be put around the rotor twister (D) which was operated by the tangent belt (F) activated by a motor. When the rotor twister rotated, the bamboo charcoal polyamide textured yarn wrapped the polyurethane fibers to form the BC/P complex yarns (H) which were collected by the winding roller (I). The bearing (G) was used to fix the rotor twister. The wrapped counts of the BC/P complex yarns were 200, 300, and 400 turns/m; the speeds of the rotor twister were 4000, 6000, 8000, 10000, and 12000 rpm; the expanded multiple was 3; and the deniers of the polyurethane fibers were 40D and 70D.

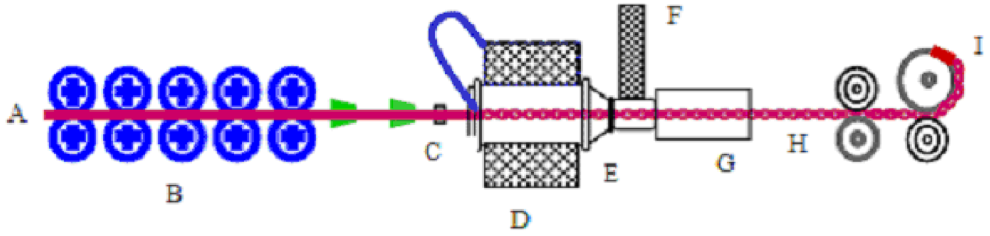

Figure 1. *The configuration of a rotor twister machine [24].*

BC/P Knitted Fabrics

Complex fabrics were made from BC/P complex yarns with a 20-gauge circular knitting machine (Greeng Tyan Enterprise Co., Ltd, Taiwan, R.O.C.). Figs. 2 and 3 show the pictures of the BC/P complex yarns and BC/P complex knitted fabrics.

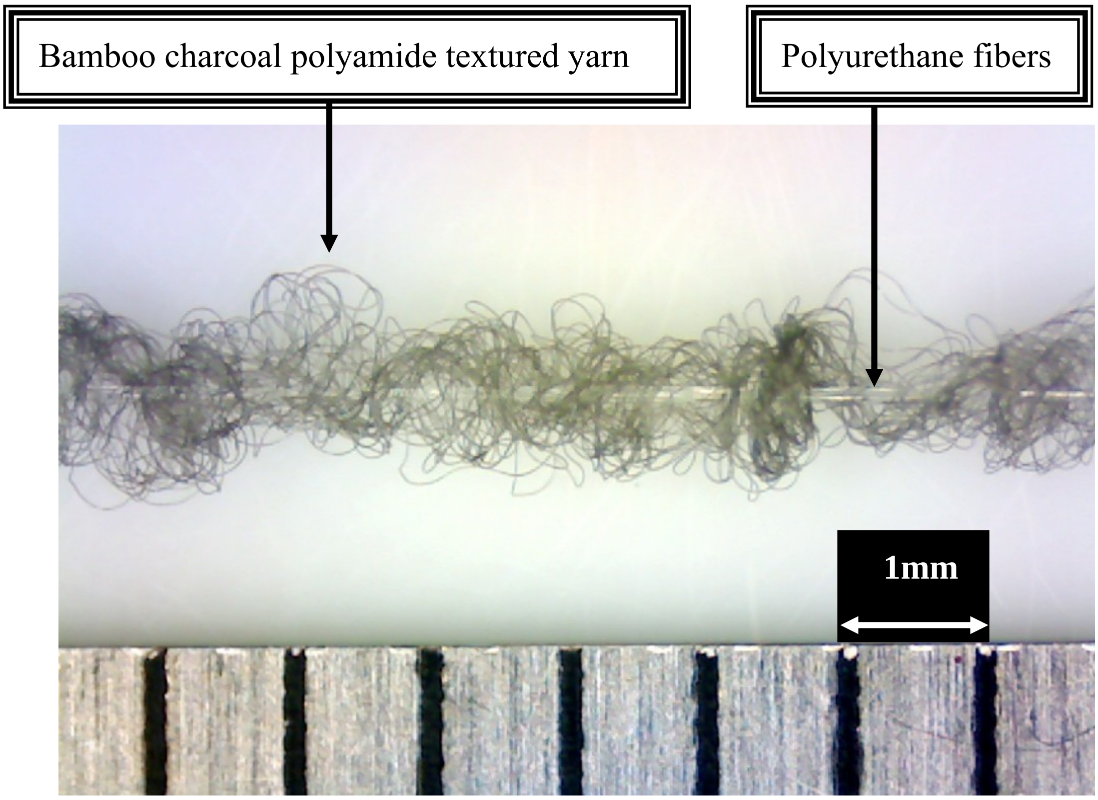

Figure 2. *The BC/P complex yarns are made of polyurethane fibers (core yarn) and bamboo charcoal polyamide textured yarn (wrapped yarn). The wrapped counts of the BC/P complex yarns are 300 turns/m, expanded multiple of the 40D polyurethane is 3, and the speed of the rotor twister is 4000 rpm.*

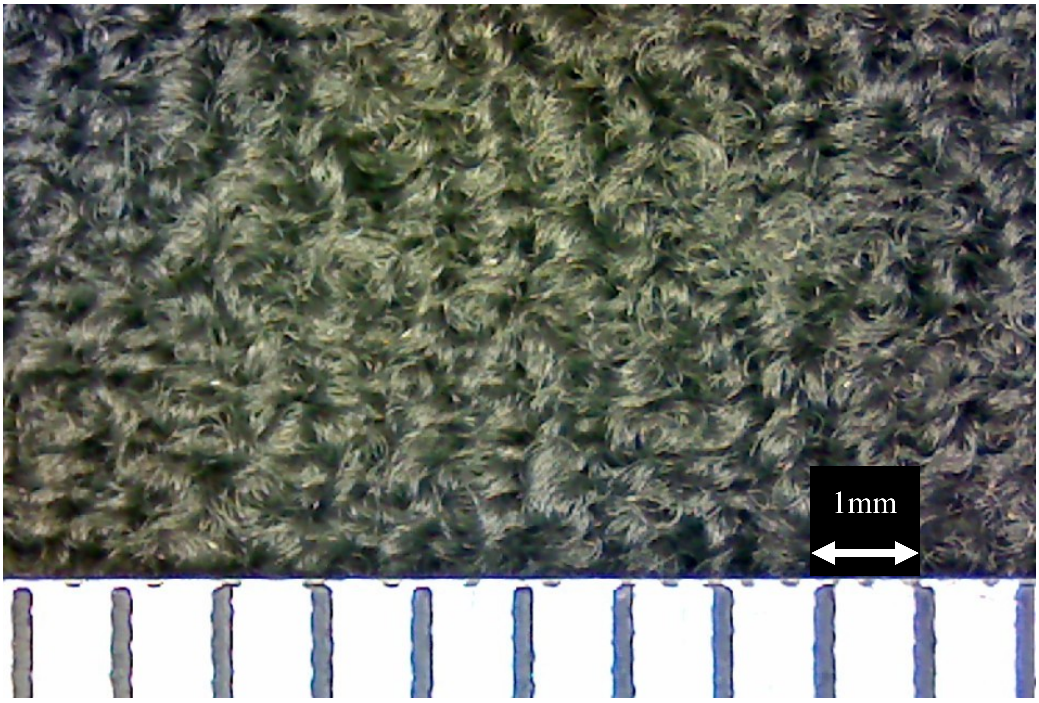

Figure 3. *The BC/P complex knitted fabrics made of BC/P complex yarns. The BC/P complex yarns are fabricated with 70D polyurethane fibers and 70D bamboo charcoal polyamide textured yarn. The wrapped counts of the BC/P complex yarns are 200 turns/m, the expanded multiple of the polyurethane fibers is 3, and the speed of the rotor twister is 4000 rpm.*

Testing Methods

Single end strength and elongation testing

According to CNS-11263, we tested the BC/P complex yarns in tenacity (cN/tex) and elongation (%) using a single end strength and elongation tester made by Textechno, Germany. The gauge distance was 250 mm and the tensile speed of the clamps was 300 mm/min. Each specimen was tested for 20 times for the mean.

Air permeability testing for the BC/P complex knitted fabrics

Based on CNS 5612 L3081, we carried out the air permeability measurement for the BC/P complex knitted fabrics. The BC/P complex knitted fabrics could be used directly without trimming and if they needed to be trimmed, the ideal sample size was 255 x 255 mm. Each specimen was tested for 10 times from different locations and the values were recorded and averaged.

The surface resistivity measurement

This measurement was based on JIS L1094. We put the specimens on the Teflon laminate for complete insulation. The tester was loaded with a 5 lb-weight in order to keep two parallel electrode plates well contacted with the surface of the objects to be tested. Each specimen was tested for 20 times from different locations and the average values were recorded. Fig. 4 shows the RT-1000 surface resistivity tester which we used in this experiment.

Figure 4. *The picture of the surface resistivity tester.*

Results and Discussion

The influence of the speed of the rotor twister and wrapped counts of the BC/P complex yarns on the tenacity of the BC/P complex yarns

Fig. 5 shows the influence of the speed of the rotor twister and the wrapped counts of the BC/P complex yarns on the tenacity of the BC/P complex yarns with 40D polyurethane fibers. The tenacity of the BC/P complex yarns increased with the reduction of the wrapped counts of the BC/P complex yarns. The axial direction of the bamboo charcoal polyamide textured yarn and that of the polyurethane fibers were close to parallel because of the decrease of the wrapped counts, so the overall tenacity of the BC/P complex yarns increased. In addition, the speed of the rotor twister influenced the tenacity of the BC/P complex yarns only when the wrapped counts were 400 turns/m. Thus, accelerating the speed of the rotor twister did not influence the overall tenacity of the BC/P complex yarns.

Moreover, when the wrapped counts were 400 turns/m, the tenacity of the BC/P complex yarns started decreasing with the speed of the rotor twister. The stress could not operate on the BC/P complex yarns directly from the axial direction because of the enlarged wrapped angle of the BC/P complex yarns. Therefore, the BC/P complex yarns had worse morphological stability and further the instability brought by the high-speed manufacture parameter began to affect the tenacity of the BC/P complex yarns. The tenacity of the BC/P complex yarns was 37258.4 cN/tex when the speed of the rotor twister was 4000 rpm and the wrapped counts were 200 turns/m.

Fig. 6 shows the influences of the speed of the rotor twister and the wrapped counts of the BC/P complex yarns on the tenacity of the BC/P complex yarns with 70D polyurethane fibers. When the wrapped counts decreased, the tenacity of the BC/P complex yarns increased. Because the reduction of the wrapped counts would bring the axial direction of the bamboo charcoal polyamide textured yarn and that of the polyurethane fibers close to parallel, the overall tenacity of the BC/P complex yarns went up. The BC/P complex yarns had higher tenacity when the wrapped counts were 200 turns/m and the speeds of the rotor twister were 4000 and 10000 rpm. Accordingly, the bamboo charcoal polyamide textured yarn could wrap the polyurethane fibers evenly when the rotor twister was at a lower speed. Furthermore, the stress which the BC/P complex yarns received could be dispersed evenly onto the yarns, and the tenacity of BC/P complex yarns increased. In particular, the tenacity of the BC/P complex yarns was higher when the rotor twister was at the speed of 10000 rpm. With the accelerating speed of the rotor twister, the bamboo charcoal polyamide textured yarn would produce larger air circle and bigger centrifugal force and further wrap the polyurethane fibers tighter so the tenacity of the BC/P complex yarns declined. In particular, when the speed of the rotor twister was 10000 and the wrapped counts were 200 turns/m, the BC/P complex yarns yielded the tenacity as 34168.2 cN/tex.

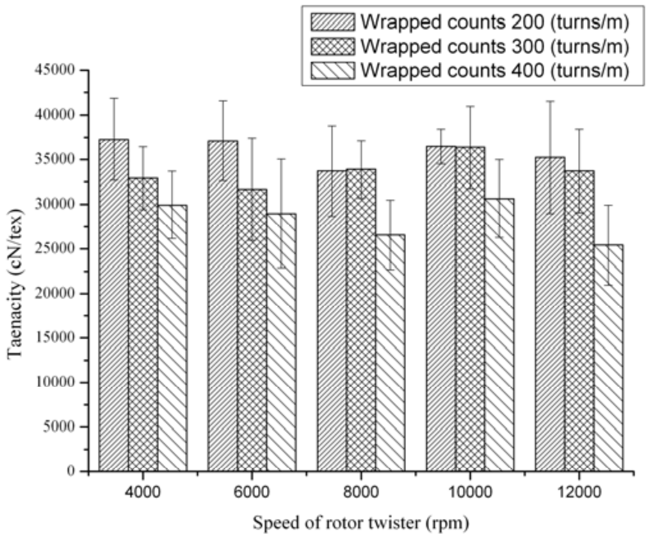

Figure 5. *The influences of the speed of the rotor twister (4000, 6000, 8000, 10000, and 12000 rpm) and the wrapped counts (200, 300, and 400 turns/m) of the BC/P complex yarns on the tenacity of BC/P complex yarns. The BC/P complex yarns are fabricated with 40D polyurethane fibers and 70D bamboo charcoal polyamide textured yarn. The polyurethane fibers are expanded and then wrapped with the bamboo charcoal polyamide textured yarn.*

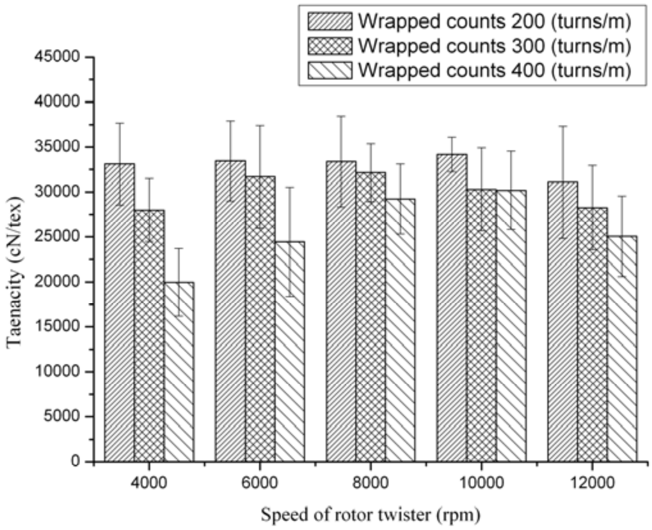

Figure 6. *The influences of the speed of the rotor twister (4000, 6000, 8000, 10000, and 12000 rpm) and the wrapped counts (200, 300, and 400 turns/m) of the BC/P complex yarns on the tenacity of BC/P complex yarns. The BC/P complex yarns are fabricated with 70D polyurethane fibers and 70D bamboo charcoal polyamide textured yarn. The polyurethane fibers are expanded and then wrapped with the bamboo charcoal polyamide textured yarn.*

The influences of the speed of the rotor twister, the wrapped counts of the BC/P complex yarns on the elongation of the BC/P complex yarns

Fig. 7 shows when the rotor twister is at the speed of 4000 rpm, the elongation of the BC/P complex wrapped yarns decreases with the reduction of the wrapped counts of the BC/P complex yarns. The twisted angle between the axial direction of the bamboo charcoal polyamide textured yarn and the axial direction of the polyurethane fibers became smaller with the reduction of the wrapped counts. Because the extension was imposed onto the BC/P complex yarns, the bamboo charcoal polyamide textured yarn took the stress directly and broke earlier. Fig. 7 also shows when the speed of the rotor twister is 4000 rpm and the wrapped counts are 300 and 400 turns/m, there are no significant differences of the elongation of the BC/P complex yarns with the speed of the rotor twister. When the speed of the rotor twister was over 6000 rpm, the centrifugal force increased. Thus, the bamboo charcoal polyamide textured yarn could wrap the polyurethane fibers and limit the expansion. In particular, when the speed of the rotor twister was 4000 rpm and the wrapped counts were 400 turns/m, the elongation of the BC/P complex yarns was 31.75%.

Figs. 7 and 8 display that elongation of the BC/P complex yarns increase with the wrapped counts of the BC/P complex yarns. The increase of the wrapped counts enhanced the cohesion force; therefore, the stress could be dispersed effectively, which reduced the opportunities for the wrapped yarn or the core yarn to take the stress alone.

Fig. 8 shows when the speeds of the rotor twister are 4000 and 10000 rpm, the elongation of BC/P complex yarns decrease with the reduction of the wrapped counts of the BC/P complex yarns. However, we did not see such trend with other speeds of the rotor twister. Because the wrapped counts decreased, the twisted angle between the axial direction of the bamboo charcoal polyamide textured yarn and the axial direction of the polyurethane fibers became smaller. Thus, when extension was imposed onto the BC/P complex yarns, the bamboo charcoal polyamide textured yarn took the stress and broke earlier.

The elongation of the BC/P complex yarns was higher when the speed of the rotor twister was 4000 rpm. If the speed of the rotor twister was lower, the manufacture of the BC/P complex yarns were more stable. Furthermore, the bamboo charcoal polyamide textured yarn could wrap the polyurethane fibers more evenly so that the elongation of the BC/P complex yarns was heightened. The centrifugal force of the rotor twister increased with the speed of the rotor twister so that the bamboo charcoal polyamide textured yarn could not wrap the polyurethane fibers evenly. In particular, the BC/P complex yarns reached 35.77% when the speed of the rotor twister was 4000 rpm and the wrapped counts were 400 turns/m.

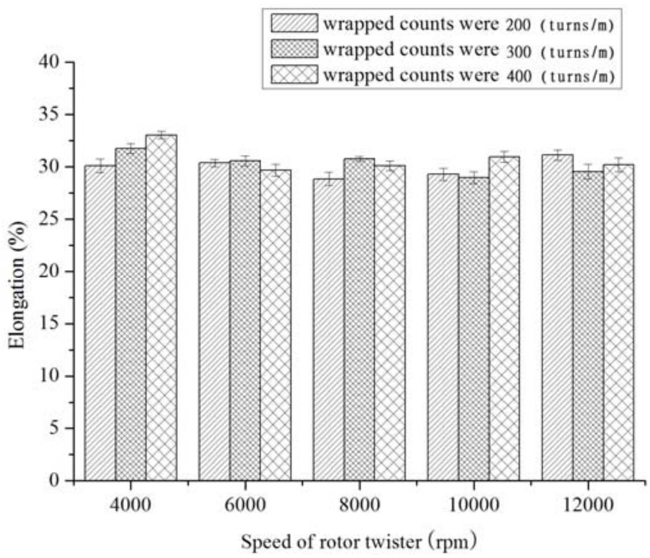

Figure 7. *The influences of the speed of the rotor twister (4000, 6000, 8000, 10000, and 12000 rpm) and the wrapped counts (200, 300, and 400 turns/m) of the BC/P complex yarns on the elongation of BC/P complex yarns. The BC/P complex yarns are fabricated with 40D polyurethane fibers and 70D bamboo charcoal polyamide textured yarn. The polyurethane fibers are expanded first and then wrapped with the bamboo charcoal polyamide textured yarn.*

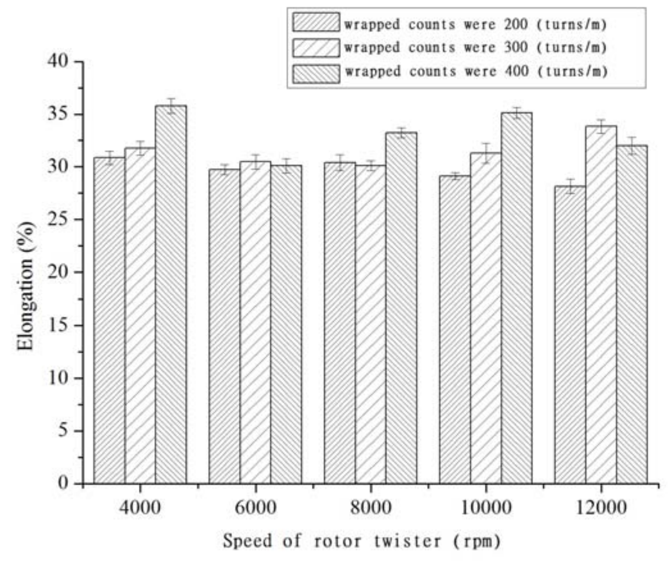

Figure 8. *The influences of the speed of the rotor twister (4000, 6000, 8000, 10000, and 12000 rpm) and the wrapped counts (200, 300, and 400 turns/m) of the BC/P complex yarns on the elongation of BC/P complex yarns. The BC/P complex yarns are fabricated with 70D polyurethane fibers and 70D bamboo charcoal polyamide textured yarn. The polyurethane fibers are expanded first and then wrapped with the bamboo charcoal polyamide textured yarn.*

The influences of the thickness of the polyurethane fibers and the wrapped counts of the BC/P complex yarns on the air permeability of the BC/P complex knitted fabrics

Fig. 9 indicates that there is no significant influence on the wrapped counts of the BC/P complex yarns on the air permeability of BC/P complex knitted fabrics with 40D polyurethane fibers. Knitted fabrics were constituted with loops at the same size so the knitted fabrics density was the same. Hence, increasing wrapped counts did not influence the density of the knitted fabrics much. However, from Fig. 9, if BC/P complex yarns fabricated with 70D bamboo charcoal polyamide textured yarn and 70D polyurethane fibers, the wrapped counts of the BC/P complex yarns had a distinct influence on the air permeability of the BC/P complex knitted fabrics. The BC/P complex yarns with 70D polyurethane fibers were thicker than those with 40D polyurethane fibers; furthermore, the loops were relatively bigger during the fabrication. The pores between loops were smaller with the increase of the wrapped counts so the permeability of the BC/P complex knitted fabrics was lower. In particular, when the wrapped counts were 200 turns/m, the BC/P complex knitted fabrics had the optimum air permeability as 47.2 ($cm^3/cm^2/s$).

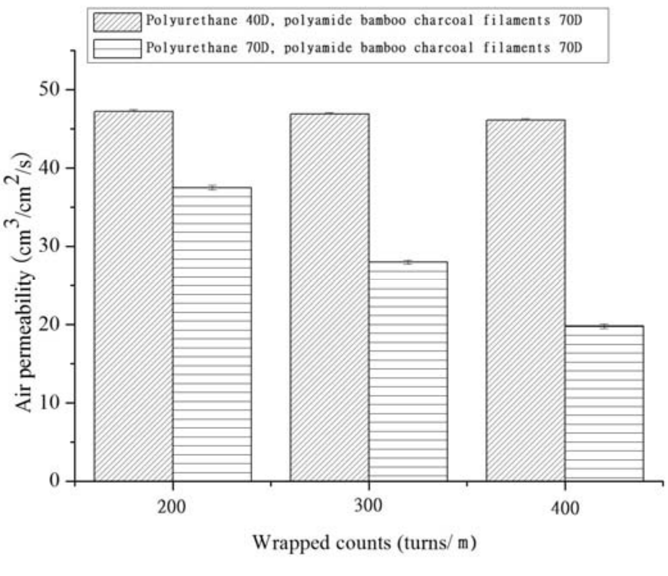

Figure 9. *The influences of the wrapped counts (200, 300, and 400 turns/m) of the BC/P complex yarns and the thickness of the polyurethane fibers (40D and 70D) on the air permeability of the BC/P complex knitted fabrics. The BC/P complex knitted fabrics are fabricated with the BC/P complex yarns using a circular knitting machine.*

The influences of the direction of loop yarn and wrapped counts of the BC/P complex yarns on the surface resistivity of the BC/P complex knitted fabrics

Fig. 10 displays that the average surface resistivity of the BC/P complex knitted fabrics decreases with the wrapped counts of BC/P complex yarns obviously. When the wrapped counts of the BC/P complex yarns increased, the bamboo charcoal polyamide textured yarn increased, and the content of the bamboo charcoal also increased relatively. Therefore, the electric conductivity raised and the average surface resistivity descended. Moreover, if the BC/P complex yarns were with 70D polyurethane fibers, the average surface resistivity was lower than that of the BC/P complex yarn with 40D polyurethane fibers. 70D polyurethane fibers were thicker than 40D ones so the 70D polyurethane fibers would be wrapped with more bamboo charcoal polyamide textured yarn within the same length. When electrical current passed through the BC/P complex yarns, it needed to pass more bamboo charcoal so the surface resistivity descended.

By Fig. 10, the average surface resistivity in the weft loop direction was lower than that in the warp loop direction, which was related to the structure of the knitted fabrics. Because the loops in weft direction were continual and loops were formed by the same yarns, the electrical current was fluent. However, the loops in warp direction were connected with each other, when the electrical current passed through the loops, it would be blocked by the jointed points. Therefore, the surface resistivity in the warp loop direction was higher than that in the weft loop direction. In particular, when the wrapped counts were 400 turns/m, the BC/P complex yarns with 70D polyurethane fibers had lower surface resistivity as 3.33×10^{10}(Ω/Square).

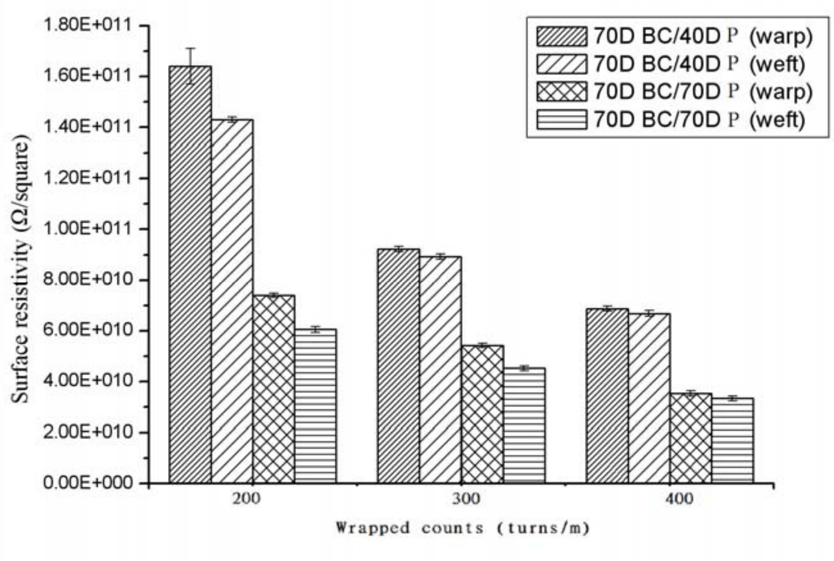

Figure 10. *The influences of the wrapped counts (200, 300, and 400 turns/m), the thickness of the polyurethane fibers (40D and 70D), and the loop direction of the BC/P complex knitted fabrics on the surface resistivity of the BC/P complex knitted fabrics. The BC/P complex knitted fabrics are fabricated with the BC/P complex yarns using a circular knitting machine.*

Conclusions

We successfully manufactured the BC/S complex yarns and knitted fabrics using a novel rotor twister machine and a circular knitting machine, respectively. When the speed of the rotor twister was 4000 rpm, the BC/S complex knitted fabrics containing

40D polyurethane fibers displayed higher tenacity at lower wrapped counts. The tenacity at 200 turns/m was higher than that at 400 turns/m by 19.7%. In contrast, when the speed of the rotor twister was 4000 rpm, the BC/S complex knitted fabrics containing 70D polyurethane fibers exhibited higher elongation at higher wrapped counts. The elongation at 400 turns/m was higher than that at 200 turns/m by 8.9%. The air permeability only depended on the polyurethane fibers type. When the wrapped counts were 200 turns/m, the knitted fabrics containing 40D polyurethane fibers had higher air permeability than that containing 70D polyurethane fibers by 20.6%. Thus, BC/P complex knitted fabrics containing 40D polyurethane fibers were suitable for clothing. Surface resistivity was lower when the BC/S complex knitted fabrics contained 70D polyurethane fibers instead of 40D ones. When the wrapped counts were 400 turns/m, the knitted fabrics containing 70D polyurethane fibers displayed two times lower surface resistivity. In addition, all the BC/P complex knitted fabrics also exhibited lower surface resistivity at weft loop direction. In sum, all the BC/P complex knitted fabrics were suitable for electrostatic dissipative materials as they displayed surface resistivity between 3.33×10^{10} and 1.64×10^{11}.

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