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Evaluation of a Manufacturing Technique of Polyamide Bamboo Charcoal/ Polyurethane Complex Yarns and Knitted Fabrics and Assessment of their Electric Surface Resistivity

Abstract

In this research, bamboo charcoal polyamide / polyurethane (BCP/PU) complex yarns and knitted fabrics were produced from bamboo charcoal polyamide textured yarn and polyurethane fibres. The polyurethane fibres were expanded and then wrapped with the bamboo charcoal polyamide textured yarn. Three manufacturing parameters were depicted as follows: the speeds of the rotor twister were 4000-12000 r.p.m., the wrapped counts of the BCP/PU complex yarns - 200 - 400 turns/m; and the expanded multiple of the polyurethane fibres was 3. Afterwards we fabricated BCP/PU complex knitted fabrics using a circular knitting machine. The tenacity of the BCP/PU complex yarns was 37258.4 cN/tex when the speed of the rotor twister was 4000 r.p.m. and the wrapped counts - 200 turns/m. Meanwhile, the elongation of the BCP/P complex yarns was 35.77% when the speed of the rotor twister was 4000 r.p.m. and the wrapped counts - 400 turns/m. The lower electric surface resistivity of the BCP/PU knitted fabrics was 3.33×10^{10} (Ω /Square) when the wrapped counts were 400 turns/m and the polyurethane fibres - 78 dtex. Moreover, when the wrapped counts were 200 turns/m, the optimum air permeability of the BCP/PU complex knitted fabrics with 44 dtex polyurethane fibres was 47.2 cm³/cm²/s, which was better than that with 78 dtex polyurethane fibres.

Key words: polyurethane fibres, knitted fabrics, multi-section drawing frame, rotor twister machine, electric surface resistivity.

Introduction

The dramatic changes brought out by modern technology have caused great stress in life very rapidly as well as various modern diseases. In order to prevent diseases, health protection has gained popularity and become a major human concern. The goals of the latest developments in modern technology mainly concern the quality of life with respect to people's mental and physical health. The basic daily necessity industries i.e. eating, clothing, living and transportation largely invest to develop and improve the special functions of their products, such as heat preservation, elasticity, electromagnetic shielding, and anti-static electricity. Bamboo charcoal polyamide fibre gets the most attention nowadays, and a whole series of fabric products made of bamboo charcoal polyamide fibre are now becoming popular [1]. On the other hand, polyurethane possesses as high resilience and elasticity as rubber does, and polyurethane fibres have superior tensile strength, elongation, abrasion resistance, aging resistance, and chemical resistance to rubber. Meanwhile polyurethane fibres have attributes like comfort, wearability and the least deformation. At present, a small amount of polyurethane fibres (5 - 20%) is usually used to weave along with other major fibres. Because polyurethane fibres are able to change the fabric property, they can be used with differ-

ent textiles, e.g., underwear, sportswear, lace, stockings, snug outfits, corsets and so on [2 - 4].

Due to heat carbonisation, bamboo charcoal polyamide can release a far infrared ray which accelerates blood circulation, thereby improving the metabolism. The far infrared ray absorbs heat energy emitted by the sun's radiation or the human body and further releases the far infrared ray at between 4 and 14 μ m. Through absorbency and resonance, the organic molecules and water molecules within the object are excited, resulting in the heat rising inside the object as well as its preservation. Bamboo charcoal polyamide is characterised by a high density and high absorbency, and such attributes grant bamboo charcoal polyamide textured yarn deodorisation, humidity adjustment, and an antibacterial effect. Moreover, bamboo charcoal polyamide textured yarn is able to release anions. By means of friction with air, bamboo charcoal polyamide knitted fabrics can naturally generate anions with negative electricity.

Many scholars around the world have conducted relevant research on bamboo charcoal polyamide fibre or polyurethane fibres and have improved their properties considerably. Nevertheless, the most complex yarns are the polyurethane fasciated variety, which are polyurethane

fibres wrapped with staples by ring spinning [5 - 15]. In addition, not many studies have been done about polyurethane fibres wrapped in filaments, in particular, in bamboo charcoal polyamide textured yarn using a special rotor twister machine [16 - 23].

In this paper, a rotor twister machine was used to wrap polyurethane fibres with bamboo charcoal polyamide textured yarns to make BCP/PU complex yarns, and a circular knitting machine was used to weave the BCP/PU complex yarns into fabrics. The complex yarns were subjected to the maximum breaking strength and elongation to establish optimum manufacturing parameters for producing the fabrics. Then the knitted fabrics were tested for air permeability and electric surface resistivity.

Experimental

Materials

The 78 dtex/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., and the 44 dtex and 78 dtex polyurethane fibres were supplied by Haojey Co., Ltd.

Manufacturing Techniques for BCP/PU Complex Yarns and Knitted Fabrics

BCP/PU Complex Yarns

Figure 1 shows the configuration of a rotor twister machine. The polyurethane fibres (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 the winding roller (I) determined the feeding speed. Afterwards the bamboo charcoal polyamide textured yarns were gathered around the cylinder to be wrapped around the rotor twister (D), which was driven by the tangent belt (F), activated by a motor. When the rotor twister rotated, the bamboo charcoal polyamide textured yarn was wrapped in polyurethane fibres to form BCP/PU complex yarns (H), which were collected by the winding roller (I). A bearing (G) was used to fix the rotor twister. The wrapped counts of the BCP/PU complex yarns were 200, 300, and 400 turns/m, the speeds of the rotor twister - 4000, 6000, 8000, 10000 and 12000 r.p.m., the expanded multiple - 3, and the deniers of the polyurethane fibres were 44 dtex and 78 dtex.

BCP/PU Knitted Fabrics

Complex fabrics were made from the BCP/PU complex yarns using a 20-gauge circular knitting machine (Greeng Tyan Enterprise Co., Ltd, Taiwan, R.O.C.). **Figures 2 & 3** show pictures of the BCP/PU complex yarns and BCP/PU complex knitted fabrics.

Testing Methods

Single end strength and elongation testing

According to CNS-11263, we tested the BCP/PU complex yarns for their tenac-

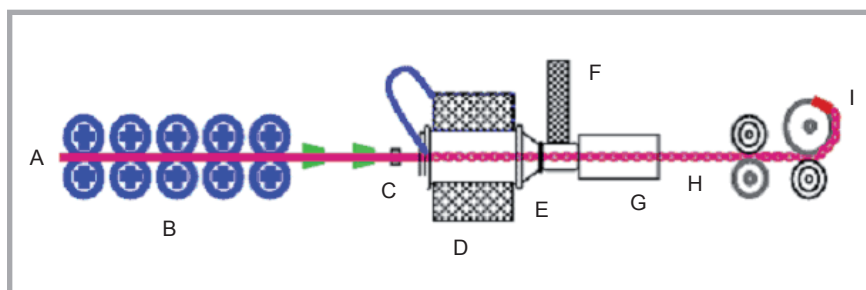


Figure 1. Configuration of a rotor twister machine [24]; polyurethane fibres (A), multi-section drawing frame (B), thread eye (C), rotor twister (D), rotor twister (E), tangent belt (F), bearing (G), BCP/PU complex yarns (H), winding roller (I).

ity in cN/tex and elongation in % 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 - 300 mm/min. Each specimen was tested 20 times to determine the mean.

Air permeability testing of the BCP/PU complex knitted fabrics

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

Electric surface resistivity measurement

This measurement was based on JIS L1094. We put the specimens on Teflon laminate for complete insulation. The tester (RT-1000) was loaded with a 5 lb-weight in order to keep the two parallel electrode plates in close contact with the surface of the objects to be tested. Each

specimen was tested 20 times from different locations and average values recorded.

Results and discussion

Influence of the speed of the rotor twister and wrapped counts of the BCP/PU complex yarns on the tenacity of the BCP/PU complex yarns

Figure 4 shows the influence of the speed of the rotor twister and wrapped counts of the BCP/PU complex yarns on the tenacity of the BCP/PU complex yarns with 44 dtex polyurethane fibres. The tenacity of the BCP/PU complex yarns increased with a reduction in their wrapped counts BCP. The axial direction of the bamboo charcoal polyamide textured yarn and that of the polyurethane fibres were close to parallel because of the decrease in wrapped counts; hence the overall tenacity of the BCP/PU complex yarns increased. In addition, the speed of the rotor twister influenced the tenacity of the BCP/PU complex yarns only when the wrapped counts were 400 turns/m; hence, accelerating the speed of the rotor twister did not influence the overall tenacity of the BCP/PU complex yarns.

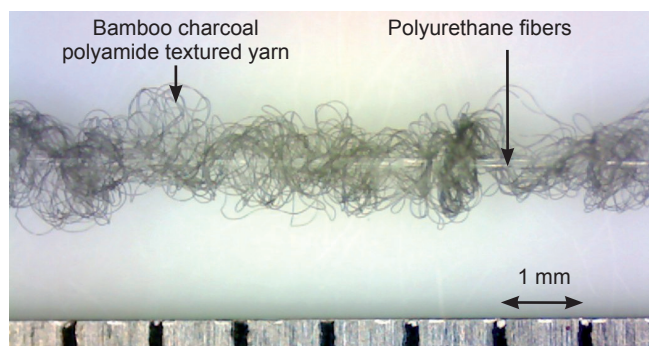


Figure 2. BCP/PU complex yarns made of polyurethane fibres (core yarn) and bamboo charcoal polyamide textured yarn (wrapped yarn). The wrapped counts of the BCP/PU complex yarns was 300 turns/m, the expanded multiple of the 44 dtex polyurethane - 3, and the speed of the rotor twister was 4000 r.p.m.



Figure 3. BCP/PU complex knitted fabrics made of BCP/PU complex yarns. The BCP/PU complex yarns were fabricated with 77 dtex polyurethane fibres and 70D bamboo charcoal polyamide textured yarn. The wrapped counts of the BCP/PU complex yarns were 200 turns/m, the expanded multiple of the polyurethane fibres - 3, and the speed of the rotor twister was 4000 r.p.m.

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

Figure 5 shows the influences of the speed of the rotor twister and wrapped counts of the BCP/PU complex yarns on the tenacity of the BCP/PU complex yarns with 78 dtex polyurethane fibres. When the wrapped counts decreased, the tenacity of the BCP/PU complex yarns increased. Because the reduction in wrapped counts brought the axial direction of the bamboo charcoal polyamide textured yarn and that of the polyurethane fibres close to parallel, the overall tenacity of the BCP/PU complex yarns went up. The BCP/PU complex yarns had higher tenacity when the wrapped counts were 200 turns/m and the speeds of the rotor twister - 4000 & 10000 r.p.m.. Accord-

ingly, the bamboo charcoal polyamide textured yarn was able to wrap the polyurethane fibres evenly when the rotor twister was at a lower speed. Furthermore, the stress which the BCP/PU complex yarns received could be dispersed evenly onto the yarns, as a result of which the tenacity of the BCP/PU complex yarns increased. In particular, the tenacity of the BCP/PU complex yarns was higher when the rotor twister was at a speed of 10000 r.p.m. With the accelerating speed of the rotor twister, the bamboo charcoal polyamide textured yarn produced a larger air circle and bigger centrifugal force, as a result of which the polyurethane fibres were wrapped more tightly, causing the tenacity of the BCP/PU complex yarns to decline. In particular, when the speed of the rotor twister was 10000 and the wrapped counts - 200 turns/m, the BCP/PU complex yarns yielded a tenacity of 34168.2 cN/tex.

Influences of the speed of the rotor twister and wrapped counts of the BCP/PU complex yarns on the elongation of the BCP/PU complex yarns

Figure 6 shows that when the rotor twister is at a speed of 4000 r.p.m., the elongation of the BCP/PU complex wrapped yarns decreases with a reduction in the wrapped counts of the BCP/PU complex yarns. The twisted angle between

the axial direction of the bamboo charcoal polyamide textured yarn and that of the polyurethane fibres became smaller with a reduction in the wrapped counts. Because extension was imposed on the BCP/PU complex yarns, the bamboo charcoal polyamide textured yarn took the stress directly and broke earlier. **Figure 6** also shows that when the speed of the rotor twister is 4000 r.p.m. and the wrapped counts- 300 and 400 turns/m, there are no significant differences in the elongation of the BCP/PU complex yarns with the speed of the rotor twister. When the speed of the rotor twister was over 6000 r.p.m., the centrifugal force increased. Thus, the bamboo charcoal polyamide textured yarn was able to wrap the polyurethane fibres and limit the expansion. In particular, when the speed of the rotor twister was 4000 r.p.m. and the wrapped counts - 400 turns/m, the elongation of the BCP/PU complex yarns was 31.75%.

Figures 6 and **7** show that the elongation of the BCP/PU complex yarns increase with the wrapped counts of the BCP/PU complex yarns. The increase in 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.

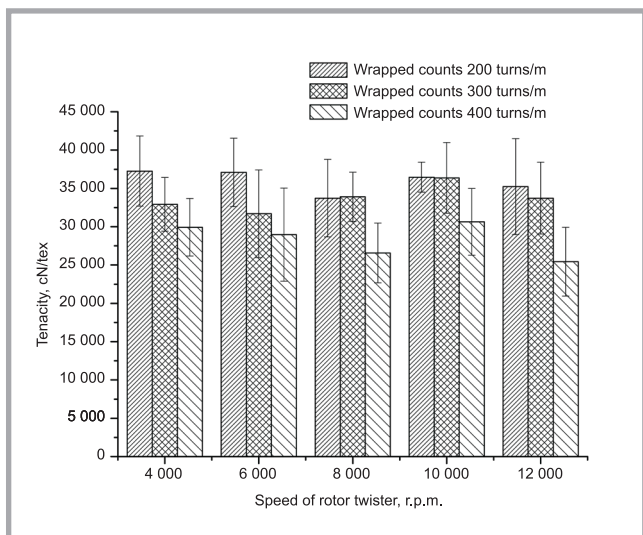


Figure 4. Influences of the speed of the rotor twister (4000, 6000, 8000, 10000 & 12000 r.p.m.) and wrapped counts (200, 300, and 400 turns/m) of the BCP/PU complex yarns on the tenacity of the BCP/PU complex yarns. The BCP/PU complex yarns were fabricated with 44 dtex polyurethane fibres and 78 dtex bamboo charcoal polyamide textured yarn. The polyurethane fibres were expanded and then wrapped with the bamboo charcoal polyamide textured yarn.

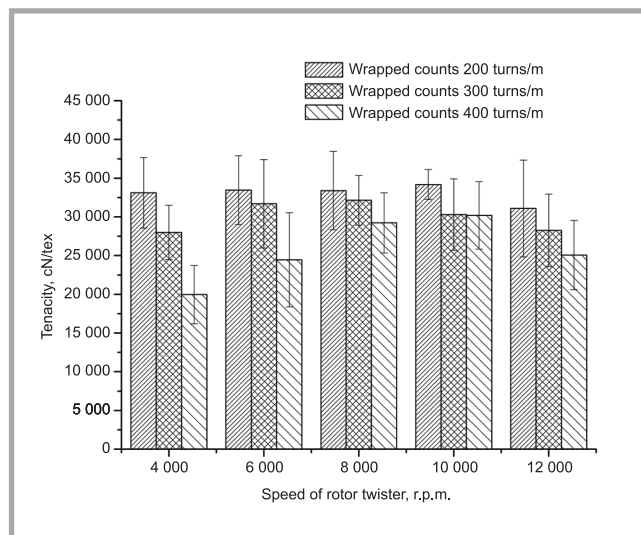


Figure 5. Influences of the speed of the rotor twister (4000, 6000, 8000, 10000, & 12000 r.p.m.) and wrapped counts (200, 300, and 400 turns/m) of the BCP/PU complex yarns on the tenacity of the BCP/PU complex yarns. The BCP/PU complex yarns were fabricated with 78 dtex polyurethane fibres and 78 dtex bamboo charcoal polyamide textured yarn. The polyurethane fibres were expanded and then wrapped with the bamboo charcoal polyamide textured yarn.

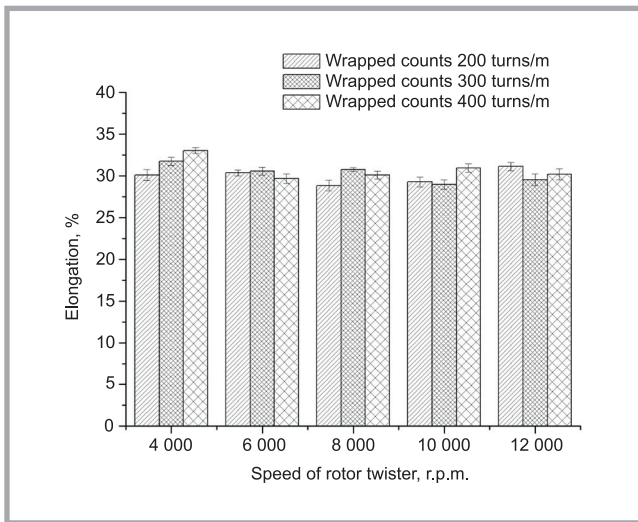


Figure 6. Influences of the speed of the rotor twister (4000, 6000, 8000, 10000, and 12000 r.p.m.) and wrapped counts (200, 300, and 400 turns/m) of the BCP/PU complex yarns on the elongation of the BCP/PU complex yarns. The BCP/PU complex yarns were fabricated with 44 dtex polyurethane fibres and 78 dtex bamboo charcoal polyamide textured yarn. The polyurethane fibres were first expanded and then wrapped with the bamboo charcoal polyamide textured yarn.

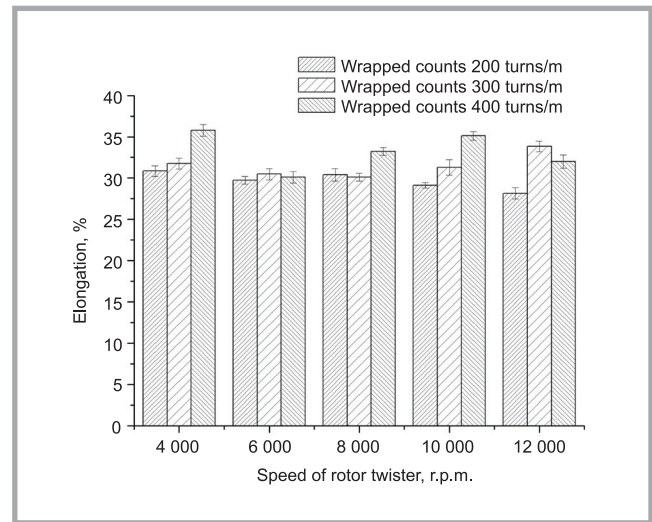


Figure 7. Influences of the speed of the rotor twister (4000, 6000, 8000, 10000, and 12000 r.p.m.) and wrapped counts (200, 300, and 400 turns/m) of the BCP/PU complex yarns on the elongation of the BCP/PU complex yarns. The BCP/PU complex yarns were fabricated with 77 dtex polyurethane fibres and 78 dtex bamboo charcoal polyamide textured yarn. The polyurethane fibres were first expanded and then wrapped with the bamboo charcoal polyamide textured yarn.

Figure 7 shows that when the speeds of the rotor twister are 4000 and 10000 r.p.m., the elongation of the BCP/PU complex yarns decrease with a reduction in the wrapped counts of the BCP/PU complex yarns. However, we did not see such a 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 that of the polyurethane fibres became smaller. Thus, when extension was imposed on the BCP/PU complex yarns, the bamboo charcoal polyamide textured yarn took the stress and broke earlier.

The elongation of the BCP/PU complex yarns was higher when the speed of the rotor twister was 4000 r.p.m.. If the speed of the rotor twister was lower, the manufacture of the BCP/PU complex yarns was more stable. Furthermore the bamboo charcoal polyamide textured yarn wrapped the polyurethane fibres more evenly, as a result of which the elongation of the BCP/PU complex yarns was heightened. The centrifugal force of the rotor twister increased with the speed of the rotor twister, hence the bamboo charcoal polyamide textured yarn could not wrap the polyurethane fibres evenly. In particular the BCP/PU complex yarns reached 35.77% when the speed of the rotor twister was 4000 r.p.m. and the wrapped counts - 400 turns/m.

Influences of the thickness of the polyurethane fibres and wrapped counts of the BCP/PU complex yarns on the air permeability of the BCP/PU complex knitted fabrics

Figure 8 (see page 32) indicates that there is no significant influence of the wrapped counts of the BCP/PU complex yarns on the air permeability of BCP/PU complex knitted fabrics with 44 dtex polyurethane fibres. The knitted fabrics were constituted with loops of the same size, therefore the knitted fabric density was the same. Hence, increasing the wrapped counts did not influence the density of the knitted fabrics significantly. However, from **Figure 8** we can observe that if the BCP/PU complex yarns were fabricated with 78 dtex bamboo charcoal polyamide textured yarn and 78 dtex polyurethane fibres, the wrapped counts of the BCP/PU complex yarns had a distinct influence on the air permeability of the BCP/PU complex knitted fabrics. The BCP/PU complex yarns with 78 dtex polyurethane fibres were thicker than those with 44 dtex polyurethane fibres; furthermore, the loops were relatively bigger during fabrication. The pores between loops were smaller with an increase in the wrapped counts, hence the permeability of the BCP/PU complex knitted fabrics was lower. In particular, when the wrapped counts were 200 turns/m, the BCP/PU complex knitted fabrics had the optimum air permeability - 47.2 (cm³/cm²/s).

Influences of the direction of the loop yarn and wrapped counts of the BCP/PU complex yarns on the surface resistivity of the BCP/PU complex knitted fabrics

Figure 9 (see page 32) shows that the average surface resistivity of the BCP/PU complex knitted fabrics obviously decreases with the wrapped counts of the BCP/PU complex yarns. When the wrapped counts of the BCP/PU complex yarns increased, the bamboo charcoal polyamide textured yarn increased, and the content of bamboo charcoal polyamide also rose relatively. Therefore the electric conductivity grew, and the average surface resistivity declined. Moreover if the BCP/PU complex yarns were with 78 dtex polyurethane fibres, the average surface resistivity was lower than that of the BCP/PU complex yarn with 44 dtex polyurethane fibres. 78 dtex polyurethane fibres were thicker than 44 dtex ones, hence the 78 dtex polyurethane fibres would be wrapped with more bamboo charcoal polyamide textured yarn within the same length. When electrical current passed through the BCP/PU complex yarns, it needed to pass more bamboo charcoal polyamide, as a result of which the surface resistivity decreased.

As shown in **Figure 9**, 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

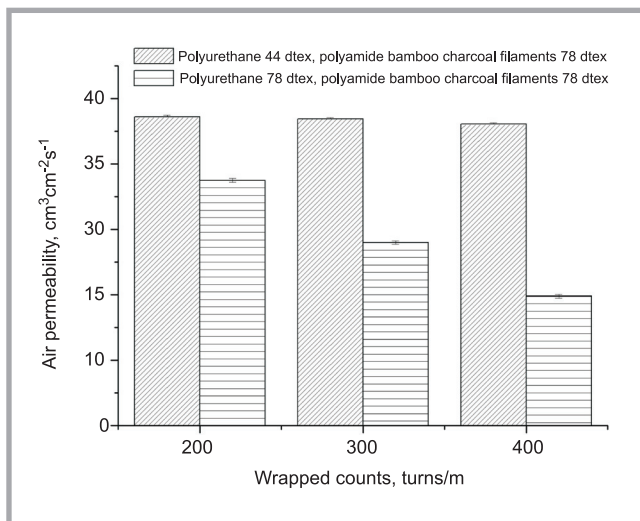


Figure 8. Influences of the wrapped counts (200, 300, and 400 turns/m) of the BCP/PU complex yarns and the thickness of the polyurethane fibres (44 dtex and 78 dtex) on the air permeability of the BCP/PU complex knitted fabrics. The BCP/PU complex knitted fabrics were fabricated with the BCP/PU complex yarns using a circular knitting machine.

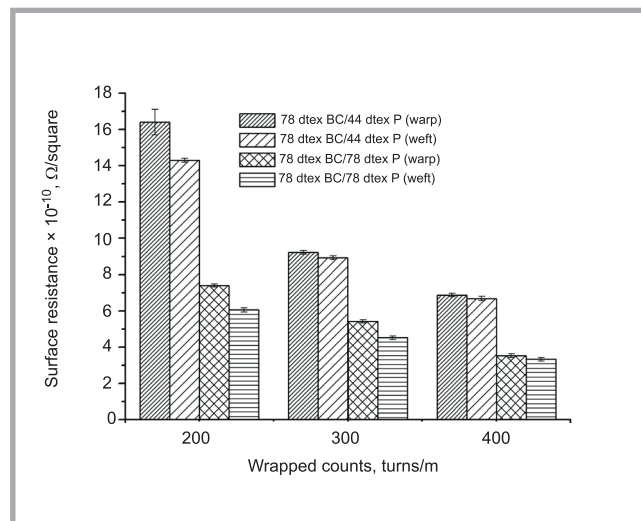


Figure 9. Influences of the wrapped counts (200, 300, and 400 turns/m), the thickness of the polyurethane fibres (44 dtex and 78 dtex), and the loop direction of the BCP/PU complex knitted fabrics on the electric surface resistivity of the BCP/PU complex knitted fabrics. The BCP/PU complex knitted fabrics were fabricated with the BCP/PU complex yarns using a circular knitting machine.

the weft direction were continual and the loops were formed with the same yarns, the electrical current was fluent. However, the loops in the warp direction were connected to each other, when the electrical current passed through the loops, it was 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 BCP/PU complex yarns with 78 dtex polyurethane fibres had lower surface resistivity - $3.33 \times 10^{10} (\Omega/\text{square})$.

Conclusions

We successfully manufactured BCP/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 r.p.m., BCP/S complex knitted fabrics containing 44 dtex polyurethane fibres 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 r.p.m., the BCP/S complex knitted fabrics containing 78 dtex polyurethane fibres 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 depended on the polyurethane fibre type only. When the wrapped counts were 200 turns/m, the knitted fabrics containing 44

dtex polyurethane fibres had a higher air permeability than that containing 78 dtex polyurethane fibres by 20.6%. Thus BCP/PU complex knitted fabrics containing 44 dtex polyurethane fibres are suitable for clothing. The surface resistivity was lower when the BCP/S complex knitted fabrics contained 78 dtex polyurethane fibres instead of 44 dtex ones. When the wrapped counts were 400 turns/m, the knitted fabrics containing 78 dtex polyurethane fibres displayed a two times lower surface resistivity. In addition, all the BCP/PU complex knitted fabrics exhibited lower surface resistivity in the weft loop direction. In summary, all the BCP/PU complex knitted fabrics are suitable as electrostatic dissipative materials as they displayed a surface resistivity between 3.33×10^{10} and 1.64×10^{11} .

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