Manufacturing Technique and Deodorization Effectiveness against Ammonia Gas of Bamboo Charcoal/Spandex Complex Knitted Fabrics

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ABSTRACT
This research creates bamboo charcoal/spandex (BC/S) complex yarns from spandex and bamboo charcoal polyester textured yarn. In order to manufacture a BC/S complex yarn with better mechanical properties in tensile strength and strain, the expanded multiples of the spandex are changed, as are the wrap counts of the BC/S complex yarn and the speed of the rotor twister. The resulting spandex has a maximum breaking strength of 4.52 g/d when the expanded multiple is 3.5, and the BC/S complex yarn has a wrap count of 2 turns/cm. Furthermore, the maximum breaking elongation is 24.57% when the expanded multiple is 3.5, and the wrap count is 4.5 turns/cm. This paper also explores the ammonia gas adsorption properties (deodorization) of BC/S complex yarn, and discovers that polyester knitted fabric is capable of deodorizing 39% of NH_3, while 1.2% bamboo charcoal/polyester knitted fabric can deodorize 53% of NH_3, and BC/S complex knitted fabric can deodorize 55%-61% of NH_3.

Keywords: adsorption; mechanical properties; strength; strain.

INTRODUCTION
Bamboo charcoal is produced using 4-year-old bamboo and a carbonization technique which lasts 10 days. The stages of its production include the following four steps: (1) pretreatment, (2) drying, (3) first carbonization, and (4) second carbonization. Bamboo charcoal posseses the characteristics of far infrared ray emission, heat preservation, deodorization of ammonia gas, reinforcement and the adsorption of methylene blue [1-5].

Far infrared rays (FIR) are electromagnetic waves with a range of wavelengths from 4- 1000 μm. FIR with wavelengths between 4 and 14 μm are growth rays that are efficiently absorbed by a living organism. Hamada et al. [6] indicate that bamboo charcoal emits FIR with ranges from 4 μm to 16 μm and a maximum intensity of ~9 μm. The surface area of bamboo charcoal, however, is three times larger that of wood charcoal, because bamboo charcoal possesses a highly porous structure. Kei et al. [7] point out that bamboo charcoal powder efficiently adsorbs nitrate-nitrogen from underground and surface water.

In the environment where people live, there are many bacteria and microbes, which produce diverse odor when they propagate. The common deodorization processing is adding deodorant in polymer during spinning. For example, copper [8], silver [9], activated carbon [10-11], TiO_2 [12], and bamboo carbon [13] all make good deodorants.

In et al. [14] further indicate that in polyvinyl alcohol (PVA) fiber, the concentration of ammonia (ppm) decreases as the content of bamboo charcoal increases.

Previous studies mostly deal with the complex yarns currently produced by the textile industry, such as spandex fasciated yarns, which use ring spinning to wrap spandex with staple fibers [15]. There are few studies, however, which investigate yarns made by wrapping spandex with filaments. Lin et al [16] study and develop an original method for the production of a highly elastic complex yarn using spandex and a novel rotor twister. Therefore, this research evaluates the mechanical properties of the yarn to determine optimum manufacturing parameters which will fabricate knitted fabrics with fine deodorization, FIR emissivity, and mechanical properties. The fabrication of BC/S complex yarn employs a novel rotor twister machine, invented by the author, Dr. Lin [17], for the rotor twister manufacturing of spandex and bamboo charcoal/polyester textured yarns. An ammonia gas deodorization measurement finally evaluates the knitted fabrics. Also, since bamboo charcoal textured yarn was used as the deorderization material, the resulting fabric is more washable than fabrics coated with a deodorant on the surface.

EXPERIMENTAL

Materials

The Nan Ta Corporation provided 75d/72f/1 polyester textured yarn, which served as the control group, and 75d/72f/1 bamboo charcoal polyester textured yarn. In addition, 40D spandex was provided by Dupont, USA, and Chyn Hsyong Industry Co., Ltd. offered Lycra.

Preparation of Specimens

This experiment used spandex with expanded multiples of 1.5-3.5 (obtained with a multi-section drawing frame) wrapped with bamboo charcoal/polyester textured yarn by a rotor twister machine. The manufacturing parameters of the BC/S complex yarn are as follows: the wrap counts were 2.0-4.5 turns/cm and the speed of the rotor twister was 4000-12000 rpm. The BC/S complex yarn with a better tensile strength was laid-in into knitted fabric using a knitting machine.

Figure 1 shows the configurations of the rotor twister machine. Spandex (A) is expanded using a multi-section drawing frame (B), then passed through the thread eye (C) and fed into the rotor twister (E). The rotary speed of the winding roller (I) determines the feeding speed. The bamboo charcoal/polyester textured yarn is then gathered around the cylinder in preparation for processing by the rotor twister (D). As the rotor twister spins, the bamboo charcoal/polyester textured yarn wraps around the spandex and forms the BC/S complex yarn which is collected by the winding roller (I) [18]. *Figure 2* provides an illustration of the BC/S complex yarn. The core yarn is 40D spandex, and the wrapped yarn is 75D/72f/1 bamboo charcoal/polyester textured yarn.The expanded multiple of the spandex is 1.5, the wrap count of the BC/S complex yarn is 2 turns/cm, and the speed of the rotor twister is 12000 rpm. The BC/S complex yarn is then laid-in with a circular knitting machine (*Figure 3*) into BC/S complex knitted fabric. The BC/S complex yarn in *Figure 3* has a wrap count of 3.5 turns/cm, and the expanded multiple of the spandex is 2.5; the speed of the rotor twister is 8000 rpm [19]. The complex yarn was woven into the knitted fabrics using a 20-gauge circular knitting machine and the weaving structure of the knitted fabric was plain. The density of knitted fabrics was 91 wale/inch in warp direction and 46 course/inch in weft direction.

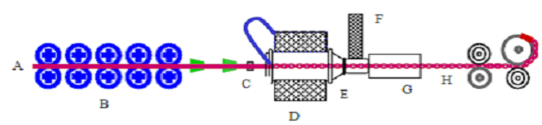

FIGURE 1. The configuration of a rotor twister machine.

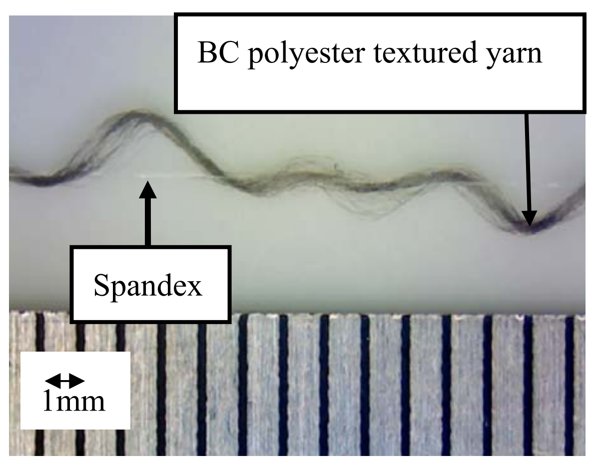

FIGURE 2. BC/S complex yarn.

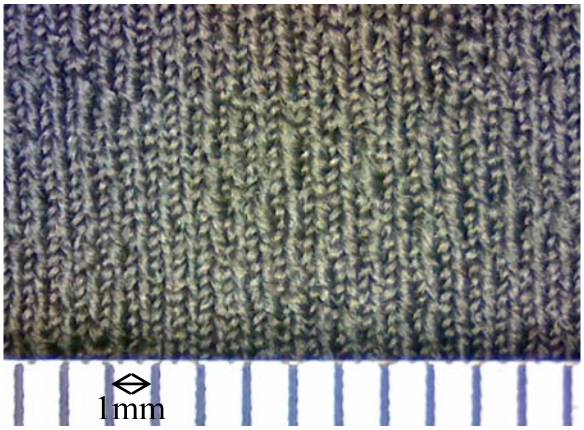

FIGURE 3. BC/S complex fabrics laid-in knitted fabric from BC/S complex yarns.

Testing Methods

Using the STATIMAT ME contributed by TEXTECHNO Herbert Stein GmbH, the maximum breaking strength and elongation of the BC/S complex yarn was evaluated with a test standard based on CRT method and according to CNS11263 L3216. Additionally, the tensile strength, strain measurement, and ammonia gas deodorization measurement of the knitted fabric was evaluated. The tensile strength and elongation, based on the CNS13752 L3243, were determined by the Instron 5566, USA. The ammonia gas deodorization measurement was based on FTTS-F-017(2007), which fulfills the requirements for the deodorization of filler textiles with charcoal, as set by the Committee for Conformity Assessment of Accreditation and Certification on Functional and Technical Textiles. *Table I* displays the product grades for the measurement of ammonia gas deodorization.

TABLE I. Product Grade for the Measurement of Ammonia Gas Deodorization.

Grade	Time Span for the Testing(hr)	The NH_3 Deodorization Rate (%)
A+	2	≧70
A	24	≧70
B	24	≧40

RESULTS AND DISCUSSION

The Influence of the Spandex's Expanded Multiple, the Wrap Count of the BC/S Complex Yarn, and the Speed of Rotor Twister on the Maximum Breaking Strength of the BC/S Complex Yarn

Figures 4 to 8 illustrate the influence of the spandex's expanded multiple on the maximum breaking strength of the BC/S wrapped yarn. When the wrap count and speed of the rotor twister was constant, the maximum breaking strength increased, apparently with the expanded multiples. After the core yarn receives cold drawing and expands, the molecular chain has a more oriented arrangement, heightening the maximum breaking strength. Hence, the maximum breaking strength of the BC/S complex yarn increases with the expanded multiples. Despite a difference of wrap count and speed of rotor twister, the maximum breaking strength of the yarn with an expanded multiple of 2 is higher than that of yarn with expanded multiples of 1.5 by 0.1 to 0.5 g/d. When the expanded multiple is 2, a maximum breaking strength of 3.9 g/d occurs when the speed of the rotor twister is 4000 rpm. When the expanded multiple is between 2.5 and 3.5, the maximum breaking strength of the BC/S complex yarn is between 3.8 and 4.4 g/d. This demonstrates that extension helps to increase the maximum breaking strength of BC/S complex yarn, as shown in *Figures 6 to 8*.

When the wrap count is over 3.0 turns/cm, the twisted angle of the bamboo charcoal/polyester textured yarn is enlarged, decreasing the axial forces of the BC/S complex yarn, as well as the maximum breaking strength. Such a trend is obvious when the speed of the rotor twister is 6000 rpm, at which the maximum breaking strength of the BC/S complex yarns descends slightly, along with the wrap count. When the speed of the rotor twister is between 8000 and 12000 rpm, the twisted angle does not alter much, nor does the maximum breaking strength decrease.

Figures 4 to 8 show that in addition to the expanded multiple of the spandex and wrap count of the BC/S complex yarn, the speed of the rotor twister also subtly influences the maximum breaking strength. When the speed of the rotor twister is increased to between 4000 to 6000 rpm, the tensile strength increases; therefore, acceleration in the speed of the rotor twister may increase the cohesion of the wrapped yarn to the core yarn. Conversely, when the speed is between 8000 to 12000 rpm, tensile strength decreases. This may be due to a lack of stability in the BC/S complex yarn when the speed of the rotor twister is high, thus lowering the tensile strength. When the expanded multiple is between 2.5 and 3.5, and the wrap count is 2 or 3 turns/cm, the maximum breaking strength occurs when the speed of the rotor twister is 6000 rpm. If the wrap count is over 3 turns/cm, however, the maximum breaking strength occurs with a rotor twister speed of 4000 rpm. To summarize, when using different wrap counts, the maximum breaking strength at a rotor twister speed of 4000 to 6000 is greater than that at a speed of 8000 to 12000 rpm; the difference of the maximum breaking strength is ~0.5 g/d.

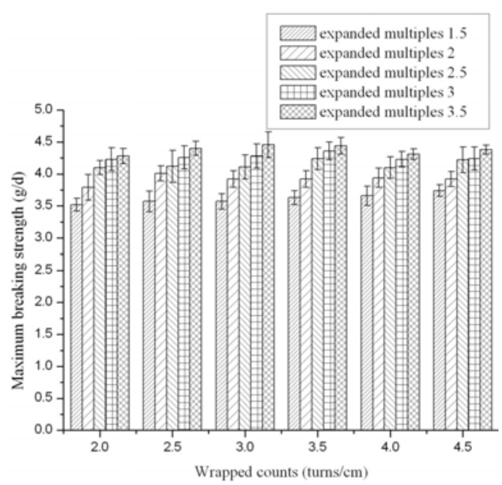

FIGURE 4. The influence of the expanded multiple and wrap count on the maximum breaking strength when the speed of the rotor twister is 4000 rpm.

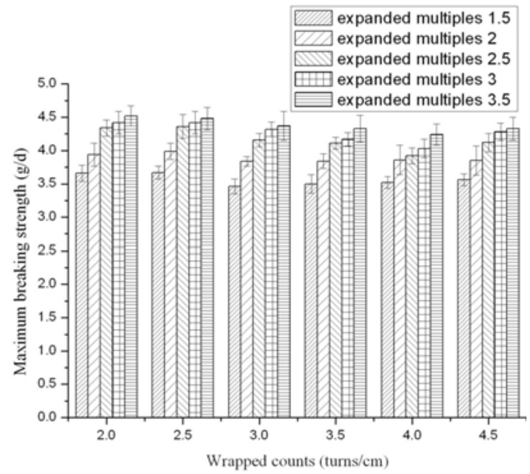

FIGURE 5. The influence of the expanded multiple and wrap count on the maximum breaking strength when the speed of the rotor twister is 6000 rpm.

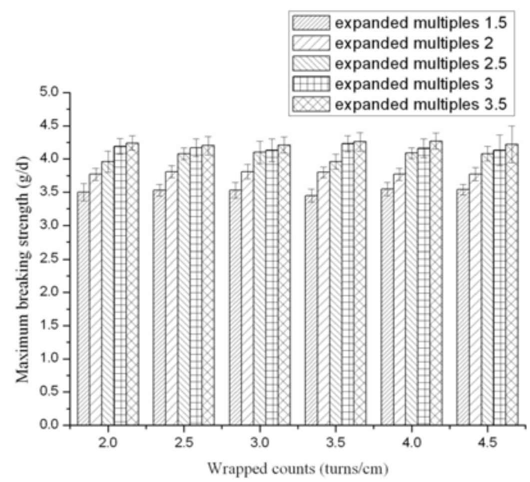

FIGURE 6. The influence of the expanded multiple and wrap count on the maximum breaking strength when the speed of the rotor twister is 8000 rpm.

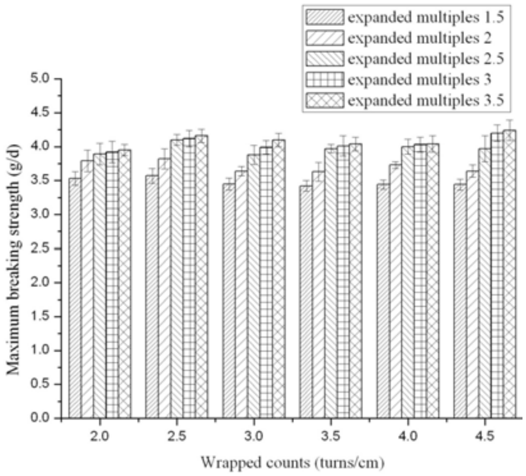

FIGURE 7. The influence of the expanded multiple and wrap count on the maximum breaking strength when the speed of the rotor twister is 10000 rpm.

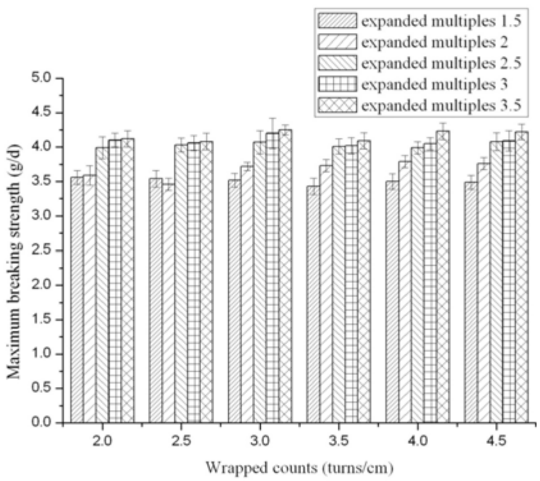

FIGURE 8. The influence of the expanded multiple and wrap count on the maximum breaking strength when the speed of the rotor twister is 12000 rpm.

<u>The Influence of the Expanded Multiple of the Spandex, the Wrap Count of the BC/S Complex Yarn, and the Speed of the Rotor Twister on the Maximum Breaking Elongation of BC/S Complex Yarn</u>

Figures 9 to 13 demonstrate that the maximum breaking elongation increases with a rise in the spandex's expanded multiple. Due to the cold drawing, the oriented arrangement of the molecular chain is raised, thus increasing the maximum breaking elongation of the BC/S complex yarn, which follows the increase of the expanded multiple. Particularly, when the wrap count is more than 3 turns/cm, the maximum breaking elongation increases with the expanded multiple. A greater wrap count contributes to a higher elongation. *Figure 10* shows that when the speed of the rotor twister is 6000 rpm, the expanded multiple of the spandex is 2.5, and the wrap count is below 3 turns/cm, the maximum breaking elongation of the BC/S complex yarn is 21%-22%. With a wrap count of 3 turns/cm and the same expanded multiple, the maximum breaking elongation changes to 22%-24% when the speed of the rotor twister is between 6000 and 8000 rpm.

The maximum breaking elongation of the BC/S complex yarn decreases when the speed of the rotor twister ranges from 4000 to 12000 rpm. If the rotor twister's speed is high, the core yarn and the wrapped yarn easily create friction, which is responsible for the decrease of maximum breaking elongation. In particular, when there are expanded multiples of 1.5 to 3, as well as various wrap counts, the maximum breaking elongation occurs with varying rotor twister speeds of 6000 to 8000 rpm.

The wrap count of the BC/S complex yarn also holds influence over the maximum breaking elongation, as shown in *Figures 9 to 13*. When the expanded multiples were the same, more wrap counts benefitted from the maximum breaking elongation of the BC/S complex yarn. The maximum breaking elongation occurs when the wrap count is 4.5 turns/cm, during which more movable space given to the BC/S complex yarn, allowing it to endure strain, and thus increasing the maximum breaking elongation.

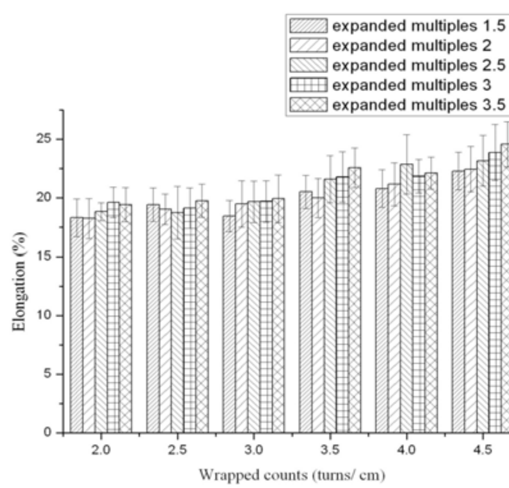

FIGURE 9. The influence of the spandex's expanded multiple and the wrap count of the BC/S complex yarn on the maximum breaking elongation when the speed of the rotor twister is 4000 rpm.

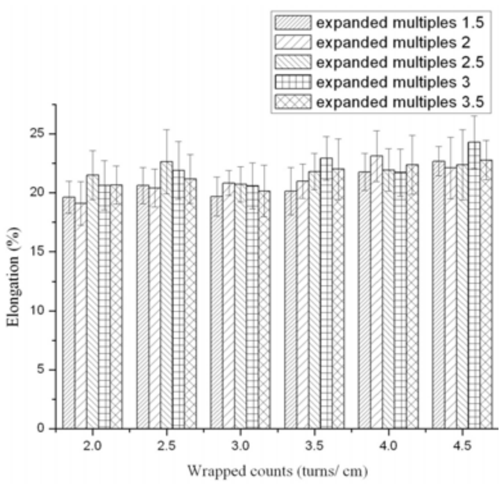

FIGURE 10. The influence of the spandex's expanded multiple and the wrap count of the BC/S complex yarn on the maximum breaking elongation when the speed of the rotor twister is 6000 rpm.

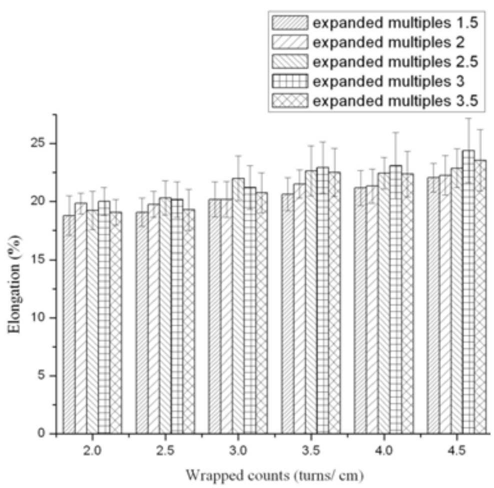

FIGURE 11. The influence of the spandex's expanded multiple and the wrap count of the BC/S complex yarn on the maximum breaking elongation when the speed of the rotor twister is 8000 rpm.

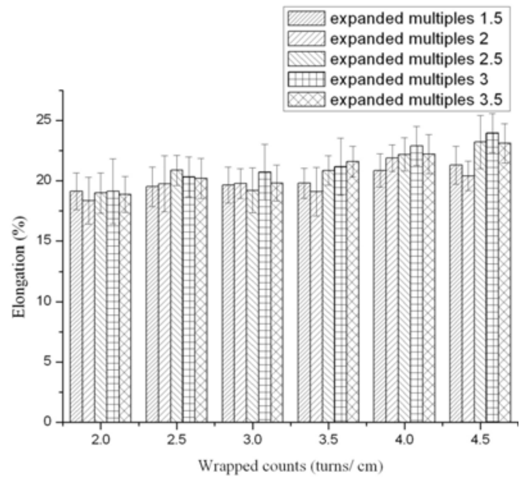

FIGURE 12. The influence of the spandex's expanded multiple and the wrap count of the BC/S complex yarn on the maximum breaking elongation when the speed of the rotor twister is 10000 rpm.

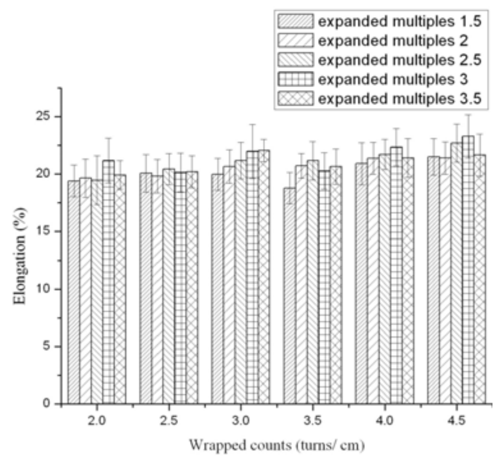

FIGURE 13. The influence of the spandex's expanded multiple and the wrap count of the BC/S complex yarn on the maximum breaking elongation when the speed of the rotor twister is 12000 rpm.

The Influence of Bamboo Charcoal Knitted Fabrics on Tensile Strength

The 40D spandex is expanded and wrapped in accordance with these manufacturing parameters: the speed of the rotor twister is 8000 rpm, the wrap count of the BC/S complex yarn is 3.5 turns/cm, and the expanded multiples of the spandex are 1.5, 2, 2.5, 3, and 3.5. According to *Figure 14*, the tensile strength of the BC/S complex knitted fabric ascends with the expanded multiple of the spandex. In this experiment, the weave of the knitted fabric is stable and the strength of the BC/S complex yarn affects the tensile strength of the BC/S complex knitted fabric. Therefore, the strength of the BC/S complex yarn grows with the expanded multiple of the spandex; the BC/S complex knitted fabric exhibits the same trend.

Figure 14 reveals that the tensile strength of the polyester knitted fabric is 7 N higher than that of the bamboo charcoal knitted fabric when they both have the same denier. The spandex was wrapped with bamboo charcoal/polyester textured yarn, forming the BC/S complex yarn and knitted fabric. Owing to the elastic recovery rate, the tensile strength increases with the expanded multiple. When the expanded multiple is 1.5, the tensile strength of the BC/S complex knitted fabric is 170N, which is 27 N greater than that of bamboo charcoal knitted fabric. However, with an increase in the expanded multiple of the spandex and the wrap count, the tensile strength of the BC/S complex knitted fabric increases to 179 N.

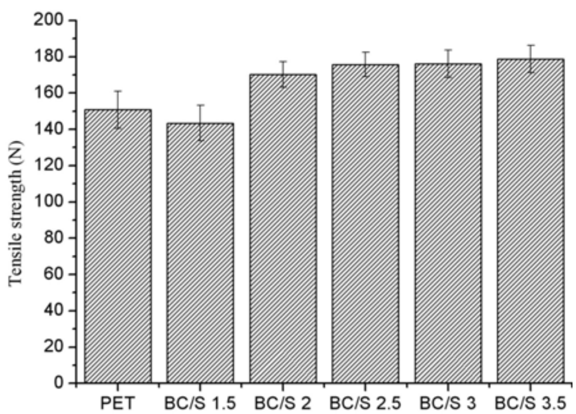

FIGURE 14. The influences of the spandex's expanded multiple on the tensile strength of the BC/S complex knitted fabric.

The Influence of Bamboo Charcoal Knitted Fabric on the Deodorization Rate of NH_3

Figure 15 gives the measurements of NH_3 concentrations remaining after 24 hours in three groups: polyester knitted fabric, bamboo charcoal knitted fabric, and BC/S complex knitted fabric. It also includes two control groups: polyester knitted fabric made of 75d/72f/1 polyester textured yarn, and bamboo charcoal knitted fabric made of 1.2% 75d/72f/1 bamboo charcoal/polyester textured yarn. The speed of the rotor twister is 8000 rpm, and the wrap count is 3.5 turns/cm.

The expanded multiples of the spandex for the BC/S complex knitted fabric are 1.5, 2, 2.5, 3, and 3.5. The NH_3 concentration remaining after 24 hours is 90 PPM in a blank specimen, 55 PPM in polyester knitted fabric, 42 PPM in bamboo charcoal knitted fabrics was, and between 41 and 35 PPM in BC/S complex knitted fabrics with different expanded multiples. According to the results, the BC/S complex knitted fabrics retains the least NH_3.

Figure 16 exhibits the deodorization rate of NH_3 in the specimens measured after 24 hours. Using calculations based on the equation, the deodorization rates in polyester knitted fabric, bamboo charcoal knitted fabric, and BC/S complex knitted fabric (with expanded multiples of 1.5, 2, 2.5, 3, and 3.5) are 39%, 53%, 55%, 58%, 59%, 60%, and 61%. The deodorization rate in the polyester knitted fabrics was 39%, which is 14% lower than that of the bamboo charcoal knitted fabric (53%). The deodorization rate in the BC/S complex knitted yarn, however, is a high 55%-61%. Because the spandex was expanded and wrapped with bamboo charcoal/polyester textured yarn, there is more bamboo charcoal spread over the fibrous surface of the BC/S complex knitted fabric, giving the BC/S a deodorization rate superior to that of the bamboo charcoal knitted fabric. As *Figure 15* illustrates, the deodorization rate of NH_3 in the BC/S complex knitted fabric increases with the expanded multiple of the spandex. Because the spandex in the BC/S complex yarn has a higher expanded multiple, the BC/S complex knitted fabric subsequently obtains more bamboo charcoal, which in turn is able to deodorize more NH_3, giving the fabric a higher deodorization rate.

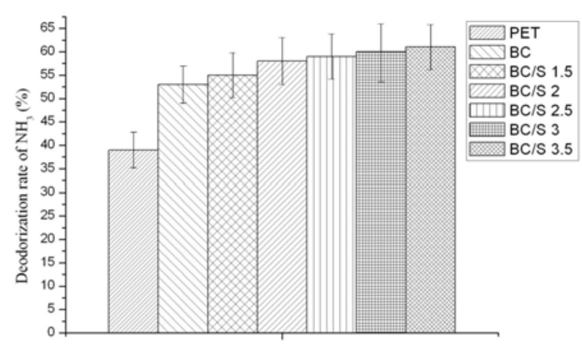

FIGURE 15. The deodorization rates of NH_3 in polyester knitted fabric, bamboo charcoal knitted fabric, and BC/S complex knitted fabric.

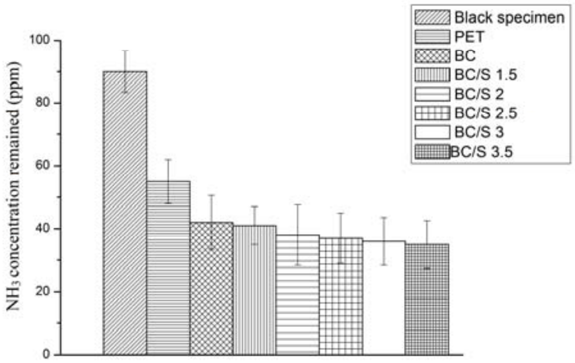

FIGURE 16. The remaining NH_3 concentrations in polyester knitted fabric, bamboo charcoal knitted fabric, and BC/S complex knitted fabric.

CONCLUSIONS

This research investigated the properties of spandex wrapped with functional bamboo charcoal/polyester textured yarn and the manufacture of BC/S complex yarn and knitted fabric using a novel rotor twister technique. The BC/S complex yarn has a maximum breaking strength of 4.52 g/d and a maximum breaking elongation of 24.57 %.

The polyester knitted fabric has a tensile strength of 150.77 N, which is 7.39N higher than that of the bamboo charcoal knitted fabric (143.38 N). The strength of the polyester single yarn is higher than the strength of the bamboo charcoal polyester; therefore, the tensile strength decreases 4.9% after knitting. When BC/S complex knitted fabric is fabricated with expanded multiples of 1.5, 2, 2.5, 3, and 3.5, its tensile strength is raised.

This study further compared the amount of NH_3 concentration remaining in the three types of fabrics after a deodorization period of 24 hours. The bamboo charcoal knitted fabric attained 53% deodorization, while the BC/S complex knitted fabric with five expanded multiples obtained a 55% to 61% deodorization rate. The results of the remaining NH_3 concentration test indicate that out of all the specimens, the BC/S complex knitted fabric performed best. However, the deodorization performance of both the bamboo charcoal knitted fabric and the BC/S complex knitted fabric surpassed a rate of 40 %, qualifying them for deodorization grade B (according to FTTS-F-017 [2007]). Therefore, the bamboo charcoal knitted fabric is also proven to possess deodorization capabilities. BC/S complex knitted fabrics could also be made into towels, bedding, pajamas, baby clothes, socks, and so forth.

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