**Chin-Mei Lin,
Ching-Wen Lin,
*Yi-Chang Yang,
**Ching-Wen Lou,
***An-Pang Chen,
***, ****Jia-Horng Lin**

Department of Fashion Design, Asia University,
Taichung 41354, Taiwan, R.O.C.

*** Department of Fashion Styling and Management, Shih Chien University,**
Taipei, 10462, Taiwan, R.O.C.

**** Institute of Biomedical Engineering and Material Science, Central Taiwan University of Science and Technology,**
Taichung 40601, Taiwan, R.O.C.

*****Laboratory of Fibre Application and Manufacturing, Department of Fibre and Composite Materials, Feng Chia University,**
Taichung 40724, Taiwan, R.O.C.

******School of Chinese Medicine, China Medical University,**
Taichung 40402, Taiwan, R.O.C

Corresponding author: Jia-Horng Lin
E-mail: jhlin@fcu.edu.tw

Evaluation of the Manufacturing and Functions of Complex Yarn and Fabrics

Abstract
In this research, bamboo charcoal/spandex (BC/S) complex yarn was fabricated using spandex as the core yarn, which was then wrapped with bamboo charcoal nylon textured yarn. The core yarn was first expanded and then wrapped with the wrapping yarn on a rotor twister machine at speeds of 4000, 6000, 8000, 10000, and 12000 r.p.m. The wrapping amount of the BC/S complex yarns were 2, 3, and 4 turns/cm. In order to evaluate the physical properties of the BC/S complex yarn, the maximum breaking strength, elongation, and elastic recovery rate were tested. We fabricated BC/S fabrics using circular knitting based on optimal manufacturing parameters. The BC/S complex yarn had an optimum elastic recovery rate of 98.89% when the rotor speed was 10000 r.p.m and the wrap number 4 turns/cm. The optimum tenacity of the yarn containing 44.0 dtex spandex was 4.22 cN/dtex when the rotor speed was 4000 r.p.m. and the wrap number 2 turns/cm. The anion density of the BC/S fabric increased with the wrap number; in particular, the fabric containing 76.9 dtex spandex displayed an optimum anion density of 54 anions/cc.

Key words: *strength, strain, evaluation, elastic, functional, characterization, design, development.*

Introduction

Bamboo charcoal fibres are a new form of bamboo fibre created by transforming bamboo into carbides during a high-tech heat treatment process. The carbides are then ground into ultra-fine particles and mixed into a viscose polymer/polyester solution. The final stage of the process spins the solution into bamboo charcoal fibres. By taking advantage of this advanced technology, manufactures can exploit bamboo's natural characteristics, such as deodorisation and heat preservation abilities, and apply them to the production of textiles, thus enhancing the quality of fabric and, in turn, our lives as well. Therefore bamboo charcoal fibres are rapidly becoming the material with the most potential in the twenty-first century [1 - 4].

Bamboo charcoal emits far infrared rays of 4 to 14 μm, and therefore its fibres also have far infrared ray absorption and emission properties. Far infrared rays are closely related to the growth of all life on earth, thus bearing the name *vital light* or *life light*. The human body easily absorbs these rays, which preserve body heat, increase peripheral blood circulation, and support overall health. Many scholars worldwide have conducted relevant research on bamboo charcoal fibres and spandex, making considerable progress on the analysis of their attributes and the improvement of their manufacturing [5 - 6].

However, in previous studies we found that most yarn fabricated with spandex is made by wrapping the spandex with staple fibres on a ring spinning machine. What is more, not many studies use filaments as the wrapping yarn [7 - 11]. Thus, in this research we fabricated BC/S complex yarn with bamboo charcoal nylon textured yarn and spandex using a novel rotor twister machine. The elastic recovery rate of the yarn was tested, and then BC/S complex knitted fabrics were fabricated, after which their far infrared emissivity, anion density, and air permeability characteristics were measured.

Experimental

Materials

The 76.9 dtex/48f bamboo charcoal polyamide textured yarn, which was composed of 3.0 wt% bamboo charcoal powder and 97.0 wt% polyamide fibres, used as the wrapping yarn, was provided by Hua Mao Nano-Tech Co., Ltd. The core yarn, 44.0 dtex and 76.9 dtex polyurethane fibres were obtained from Haojey Co., Ltd.

Preparation of the BC/S complex yarn and knitted fabrics

Figure 1 (see page 48) gives the configuration of the rotor twister. Spandex (A) is expanded on a multi-sectional drawing frame (B), then threaded through the eye (C) and fed into the rotor twister (E); the rotary speed of the winding roller (I) determines the feeding speed. The tangent belt (F) connects to the motor (G) and rotates the rotor twister (D). The bamboo charcoal polyester textured yarn (blue) is spun around a hollow plastic cylinder, which is then set onto the rotor twister. When the rotor twister rotates, the bamboo charcoal polyester textured

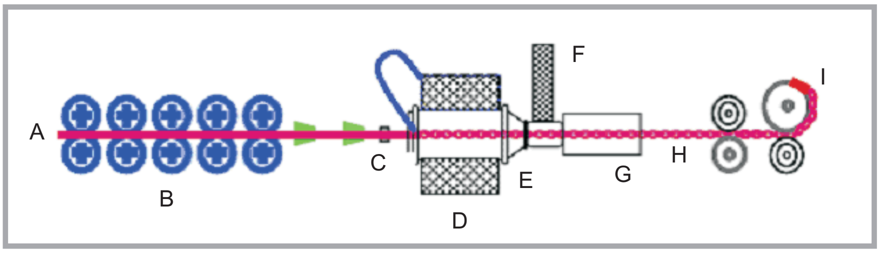

Figure 1. The configurations of a rotor twister [12]; A) spandex, B) multi-sectional drawing frame, C) eye, D and E) rotor twister, F) tangent belt, G) motor, H) complex yarn, I) winding roller.

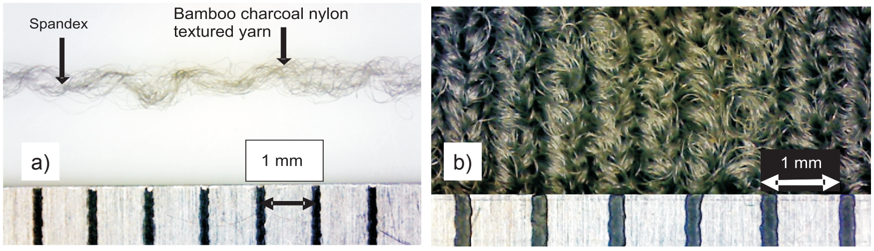

***Figure 2**. (a) BC/S complex yarns. The wrapped number of the BC/S complex yarns is 3 turns/cm, the expanded multiple of the 44.0 dtex spandex - 3, and the rotor speed is 4000 r.p.m., (b) BC/S complex knitted fabric.*

***Table 1.** Influence of the wrap number and rotor speed on the tenacity of the BC/S complex yarn containing (a) 44.0 dtex and (b) 76.9 dtex spandex.*

Count	Speed of rotor twister, r.p.m.	Wrapped number, turns/cm		
		2	3	4
a) 44.0 dtex	4000	4.22 ± 0.48	3.73 ± 0.29	3.39 ± 0.62
	6000	4.20 ± 0.25	3.59 ± 0.49	3.28 ± 0.53
	8000	3.82 ± 0.52	3.84 ± 0.45	3.01 ± 0.51
	10000	4.13 ± 0.54	4.12 ± 0.60	3.47 ± 0.54
	12000	3.99 ± 0.41	3.82 ± 0.52	2.88 ± 0.66
b) 76.9 dtex	4000	3.75 ± 0.52	3.17 ± 0.40	2.26 ± 0.43
	6000	3.79 ± 0.51	3.59 ± 0.65	2.77 ± 0.69
	8000	3.78 ± 0.57	3.64 ± 0.36	3.31 ± 0.44
	10000	3.87 ± 0.22	3.43 ± 0.52	3.42 ± 0.49
	12000	3.52 ± 0.71	3.20 ± 0.53	2.84 ± 0.51

***Table 2.** Influence of the wrap number and rotor speed on the elongation of the BC/S complex yarn containing (a) 44.0 dtex and (b) 76.9 dtex spandex.*

Count	Speed of rotor twister, r.p.m.	Wrapped number, turns/cm		
		2	3	4
a) 44.0 dtex	4000	30.12 ± 0.66	31.75 ± 0.48	33.05 ± 0.35
	6000	30.38 ± 0.35	30.57 ± 0.46	29.67 ± 0.58
	8000	28.85 ± 0.62	30.77 ± 0.25	30.11 ± 0.46
	10000	29.29 ± 0.59	28.96 ± 0.57	30.95 ± 0.51
	12000	31.13 ± 0.49	29.52 ± 0.71	30.20 ± 0.68
b) 76.9 dtex	4000	30.85 ± 0.63	31.78 ± 0.66	35.77 ± 0.72
	6000	29.73 ± 0.47	30.47 ± 0.69	30.10 ± 0.69
	8000	30.41 ± 0.74	30.12 ± 0.47	33.24 ± 0.46
	10000	29.13 ± 0.32	31.29 ± 0.96	35.13 ± 0.52
	12000	28.15 ± 0.67	33.84 ± 0.64	32.00 ± 0.80

yarn wraps the spandex to form the BC/S complex yarn (H), which is then wound into a spool by the winding roller (I).

BC/S complex yarn was made under the following three manufacturing parameters: the wrap numbers were 2, 3, and 4 turns/cm, the rotor speeds - 4000, 6000, 8000, 10000, and 12000 r.p.m., and the expansion multiple of the spandex was 3. We selected high quality yarn, and with circular knitting created fabric using a needle-density of 20 gauges/inch (Greeng Tyan Enterprise Co., Ltd). The yarn was comparatively better when the wrap numbers were 2, 3, and 4 turns/cm, the expansion multiple - 3, and the rotor speed - 4000 r.p.m. ***Figures 2.a*** and ***2.b*** show the configurations of the BC/S yarn and BC/S fabric, respectively.

Testing methods

Single end strength and elongation testing was performed as specified in CNS-11263 using a single end strength and elongation tester (Textechno, Germany). The elastic recovery rate was measured using an elastic recovery tester, assembled in our laboratory and based on the NO 600-05 (Elastic Recovery Determination by Haojey Co., Ltd). First, the yarn was coiled 8 times by a reeling machine. It was then hung on a measurement rack, and a 50 g pendant was attached for one minute; the length of the yarn was recorded as L_0. Next, the 50 g weight was substituted with a 500 g weight for another minute. For the final minute, the 500 g weight was replaced with the 50 g weight, and the yarn's length was L_1. Thus, the elastic recovery rate can be given as:

$$ERR(\%)=\{[(L_0 - L_1)/L_0)] + 1\}\times 100\% \quad (1)$$

Measurement of the far infrared emissions was performed with a far infrared emissivity tester (HOTECH EMS 302M), and an anion density measurement was obtained with an air ion counter (ITC-201A, Japan). The air permeability was measured with an air permeability tester, as specified in ASTM D737. Each specimen was tested twenty times and the average value recorded.

Results and discussion

Influence of the rotor speed and wrap number on the tenacity and elongation of the BC/S complex yarns

Tables 1.a and ***1.b*** illustrate the influence of the rotor speed and wrap number on the tenacity and elongation of the BC/S complex yarn. In ***Table 1.a***, the core yarn is 44.0 dtex spandex, while in ***Table 1.b*** it is 76.9 dtex spandex. The tenacity of the complex yarn increased with a reduction in the wrap number. This may be attributed to the axial directions of the wrap yarn and core yarn, which were almost parallel. Changing the rotor speed when producing the 44.0 dtex spandex yarn did not influence its tenacity

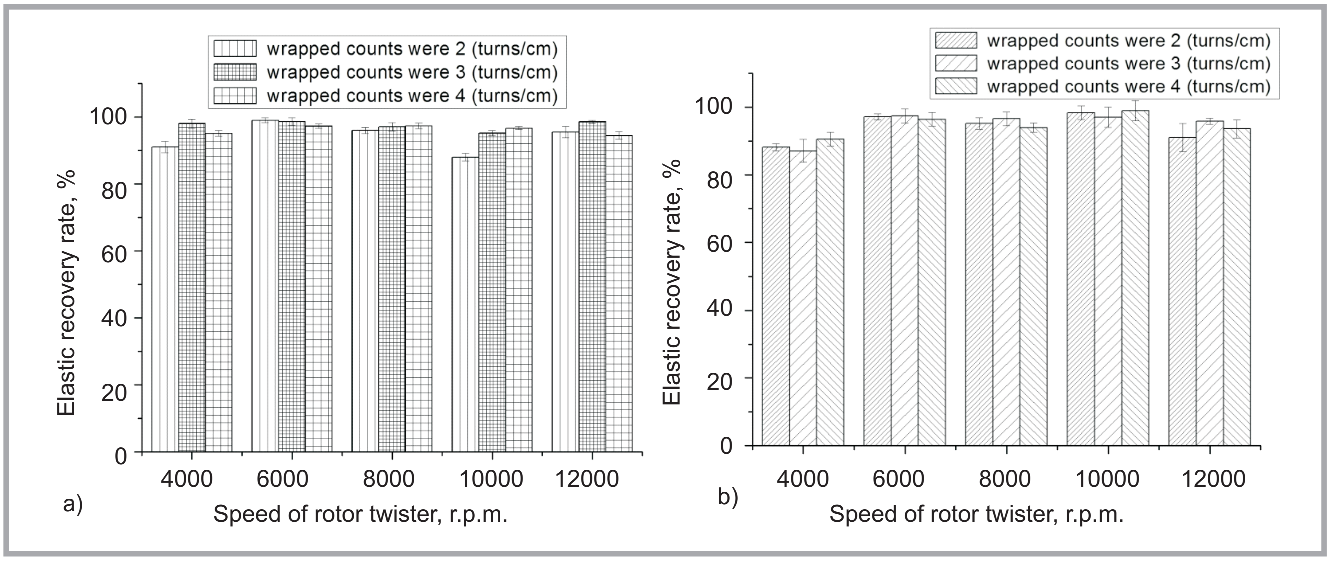

Figure 3. *Elastic recovery rate of BC/S complex yarns whose core yarn is (a) 44.0 dtex and (b)76.9 dtex spandex.*

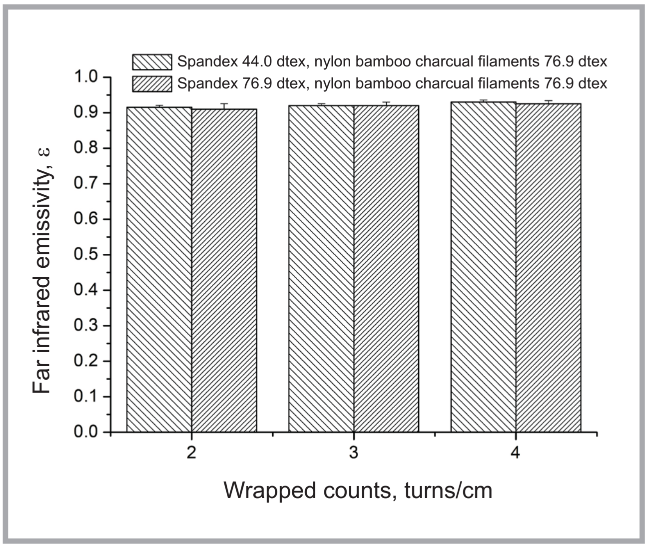

Figure 4. *Far infrared emissivity of the BC/S complex knitted fabrics.*

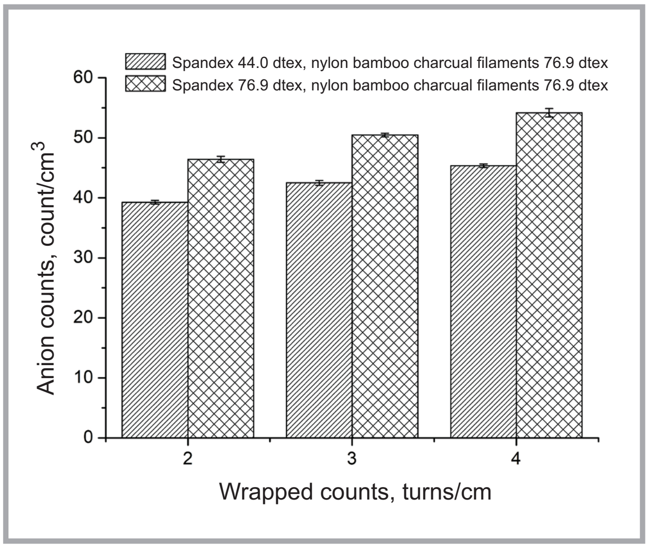

Figure 5. *Anion density of the BC/S complex knitted fabrics.*

much. However, if the wrap number was 4 turns/cm, the tenacity of the yarn declined, which is due to the fact that when the wrap angle of the yarn was enlarged, stress was not imposed on the yarn in an axial direction, and the yarn consequently had worse morphological stability.

We therefore surmised that high-speed manufacturing caused the instability and affected the tenacity of the yarn. In particular, when the wrap number was 2 turns/cm and the rotor speed 4000 or 10000 r.p.m, the yarn containing 76.9 dtex spandex displayed higher tenacity. The spandex was evenly wrapped at a lower rotor speed; thus, when the yarn received stress, it evenly dispersed it, enhancing the tenacity.

Tables 2.a and ***2.b*** demonstrate that the elongation of the complex yarn increases with the wrap number. In ***Table 2.a***, the core yarn is 44.0 dtex spandex, and in ***Table 2.b*** it is 70 dtex spandex. When the rotor speed was 4000 r.p.m, the elongation of the 44.0 dtex spandex yarn decreased with a reduction in the wrap number. When the wrap number decreased, the angle between the wrap yarn and core yarn shrank. When a force was imposed on the yarn, the wrap yarn took the stress directly and broke earlier. When the rotor speed was 4000 r.p.m and the wrap number 3 or 4 turns/cm, the rotor speed did not have a distinct influence on the yarn's elongation. If the rotor speed exceeded 6000 r.p.m., the centrifugal force increased, and the wrapping yarn wrapped the spandex more tightly, limiting its expansion. An increase in the wrap number enhanced the cohesion force; therefore, the stress was dispersed effectively, and the wrapping yarn or core yarn did not have to bear the stress alone.

Influence of the rotor speed and wrap number on the elastic recovery rate of the BC/S complex yarn

Figures 3.a and ***3.b*** give the elastic recovery of the BC/S complex yarn. In ***Figure 4***, the core yarn is 44.0 dtex spandex, and in ***Figure 5*** it is 76.9 dtex spandex. ***Figure 4*** illustrates that when the rotor speed is 8000 or 10000 r.p.m., the elastic recovery rate of the 44.0 dtex spandex yarn increases slightly to 99%, following a rise in the wrap number. Due to the increase in the wrap number, the spandex was wrapped more tightly by the bamboo charcoal yarn, preventing the BC/S yarn from warping under stress.

Figure 3.b shows, however, that the elastic recovery rate of the BC/S yarn is unaffected by the rotor speed. During the fabrication process, the rotor speed did not affect the spandex much. ***Figure 3.b*** also reveals that the yarn's elastic recovery rate does not change much with the wrap number. Because 76.9 dtex spandex is thick, it can be exposed to a higher amount of stress and will not stretch out of shape.

Influence of the wrap number and conformation of the BC/S complex fabrics on the far infrared emissivity

Figure 4 (see page 49) reveals that BC/S complex fabrics display a stable trend of far infrared emissivity when the fabrics contain spandex with different finenesses. This was probably because the spandex was not a mineral material and hence not capable of heightening the far infrared emissivity. In addition, the far infrared emissivity of the BC/S fabrics rose slightly with an increase in the wrap number. A possible explanation was that when the wrap number increased, the content of bamboo charcoal nylon textured yarn also rose. As the bamboo charcoal texture yarn was capable of emitting far infrared rays, it heightened the far infrared emissivity of the knitted fabrics accordingly. If the far infrared emissivity of an object is over 0.8 (i.e., $\varepsilon > 0.8$), the object is capable of emitting far infrared rays. Thus the knitted fabrics reached an optimum far infrared emissivity of 0.92.

Influence of the wrap number and conformation of the BC/S fabrics on the anion density

Figure 5 (see page 49) illustrates that the knitted fabrics had a higher anion density when the wrap number increased, due to the fact that when the wrap number rose, there was more yarn, therefore increasing the fabric's bamboo charcoal content and, thus, its anion density. Bamboo charcoal could release far infrared rays with a certain wavelength, making the gas in the air negatively ionised .

The BC/S fabric containing 76.9 dtex spandex had a higher anion density than that containing 44.0 dtex spandex. Because 76.9 dtex spandex is thicker than 44.0 dtex spandex, it can be wrapped with more bamboo charcoal nylon textured yarn, and therefore it has more anions to release. Due to the higher contractility of 76.9 dtex spandex, the resulting knitted fabrics contained a higher amount of bamboo charcoal than that of 44.0 dtex spandex within the same area.

Conclusions

In this research, we successfully manufactured BC/S complex yarn and knitted fabric using a novel rotor twister machine. The BC/S yarn displayed an optimum elastic recovery rate of 98.89% when the rotor speed was 10 000 r.p.m. and the wrap number 4 turns/cm. The wrap number and spandex type had stability with respect to far infrared emissivity. The BC/S fabric reached an optimum far infrared emissivity of 0.92 under two conditions: 1) the wrap number was 2 or 3 turns/cm and the spandex 44.0 dtex, or 2) the wrap number was 4 turns/cm and the spandex 76.9 dtex. It also had a far infrared emissivity of over 0.80 (i.e., $\varepsilon > 0.8$), and thus was proved to be able to emit far infrared rays.

The anion density of the BC/S complex knitted fabrics increased with the wrap number of the yarn. When the wrap number was 4 turns/ cm and the core yarn 76.9 dtex spandex, the fabric displayed an optimum anion density of 54 anions/cc, which is 15% higher than when the wrap number was 2 turns/cm. Nevertheless, the BC/S fabrics possess superior elastic recovery rates and far infrared emissions, thus they are ideal materials to be used for diverse textile products like sportswear, lace, stockings and corsets.

References

1. *An, T. C., Chiu, C. H., Lin, C. A., Lai, W. J., The Gas Removal Effect of Bamboo Charcoal/Nylon 6 Blended Fibers., Polymer-Plastics Technology and Engineering, 2010*; *49*, 14: *1395-1398.*
2. An TC, Lin CA, Chiu CH, Liu CH, Hu PT. Thermal Retention Performance and Gas Removal Effect of Bamboo Charcoal/PET Blended Fibers, *Polymer-Plastics Technology and Engineering* 2008; 47, 9: 895-901.
3. Lou CW, Lin CW, Lei CH, Su KH, Hsu CH, Liu ZH, Lin J H. PET/PP blend with bamboo charcoal to produce functional composites. *Journal of Materials Processing Technology* 2007; 192–193: 428–433.
4. Lin CA,; An T C, Hsu YH. Study on the Far Infrared Ray Emission Property and Adsorption Performance of Bamboo Charcoal/Polyvinyl Alcohol Fiber *Polymer-Plastics Technology and Engineering* 2007; 46, 11: 1073-1078.
5. Lin CM, Huang C C, Lou C W, Chen AP, Liou SE, Lin JH. Evaluation of a Manufacturing Technique of Polyamide Bamboo Charcoal/ Polyurethane Complex Yarns and Knitted Fabrics and Assessment of their Electric Surface Resistivity, *Polymer-Plastics Technology and Engineering* 2011; 19, 2: 28-32.
6. Lou CW, Lin CW, Lei C H, Su KH, Hsu CH, Liu Z H, Lin JH. PET/PP Blend with Bamboo Charcoal to Produce Functional Composites. *Journal of Materials Processing Technology* 2007; 192-193: 428-433.
7. Chen AP, Lin CM, Hsieh CT, Yang YC, Lou CW, Lin JH. Mechanical Evaluation of the Production of Bamboo Charcoal/ Stainless Steel Complex Yarns and Knitted Fabrics. *Advanced Materials Research* 2010; 97-101: 1786-1789.
8. Lou CW, Lin CM, Chen A P, Yang YC, Chen C P, Lin JH. Manufacturing Technique and Physical Property of Metal Wires/ PP Nonwoven Selvedges Complex Ply Yarns and Knitted Fabrics. *Advanced Materials Research* 2010; 97-101: 1797-1800.
9. Lin CW, Lin JH. Manufacture and Application of High-Performance Geogrids with PP/PET Composite Covered Yarn. *Textile Research Journal* 2005; 75, 6: 453-457.
10. Chen AP, Lin CM, Lin CW, Hsieh CT, Lou CW, Young YH, Lin JH. Electromagnetic Shielding Effectiveness and Manufacture Technique of Functional Bamboo Charcoal/Metal Composite Woven. *Advanced Materials Research* 2010; 123-125: 967-970.
11. Lin JH, Chang CW, Hsing WH, Lou CW. Production of a Highly Elastic Complex Yarn with Spandex Using a Novel Rotor Twister. *Journal of Advanced Materials* 2007; 39, 3: 54-58.
12. Lin JH, Chang CW, Lou CW, Hsing WH. Mechanical Properties of Highly Elastic Complex Yarn with Spandex Made by a Novel Rotor Twister. *Textile Research Journal* 2004; 74, 6: 480-484.

Received 13.07.2011 Reviewed 14.11.2011