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Comfort and Functional Properties of Far-Infrared/Anion-Releasing Warp-Knitted Elastic Composite Fabrics Using Bamboo Charcoal, Copper, and Phase Change Materials

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Abstract: Elastic warp-knitted composite fabrics with far-infrared emissivity and an anion-releasing property were prepared using bamboo charcoal (BC), copper (Cu), and phase-change material (PCM). The functional composite fabric, which was composed of self-made complex yarns with various twisting degrees and material composition, were created using a rotor twister and ring-spinning technique. The fabric structure was diversified by the feeding modes of weft yarn into a crochet-knitting machine. The twist number of complex yarns was optimized by tensile tenacity, twist contraction, and hairiness, and analysis showed that twisting at 12 twists per inch produced the highest tensile tenacity and appropriate twist contraction and hairiness. Comfort evaluation showed that the elastic composite fabrics with BC weft yarns exhibited higher water–vapor transmission rate and air permeability, reaching 876 $g/m^2\cdot$ day and 73.2 $cm^3/s/cm^2$, respectively. Three structures of composite fabric with various weft yarns had >0.85 ε far-infrared emissivity and 350–420 $counts/cm^3$ anion amount. The prepared elastic warp-knitted fabrics can provide a comfortable, dry, and breathable environment to the wearer and can thus be applied as health-care textiles in the future.

Keywords: composite fabric; warp knitted; far infrared; anion; water transmission; air permeability

1. Introduction

Industrial textiles, apart from apparel textiles and decoration textiles, are divided into medical, traffic, industry, building, agricultural–fishery–mining, sport, and special-clothing textiles, as well as packaging materials and geotextiles [1]. Textiles refer to fibers, yarns, and fabrics comprising fiber materials, semi-finished products (lap, silver, yarn, and fabric) and final products [2]. Fabrics are composed of yarn spun by staple fibers or continuous filaments. Staple spinning including ring spinning, open-end spinning, and air-jet spinning strengthens yarn by twisting [3]. Ring spinning is one of the most common spinning methods suitable for spinning high-quality yarns, including conventional yarns and special yarns [4–6]. Ring-spun yarns used for knitted and woven fabrics account for 80% of the entire commercial market.

Textile properties can be changed by selecting fiber material and spinning method. The structure of fabrics can be designed by varying process parameters, and fabric properties can be given by material composition. Stanković *et al.* indicated that yarn density, twist number, and hairiness affected the fabric structure [7]. Schwarz *et al.* prepared complex yarns using rubber, polyamide yarn, polyester, and metal fibers (stainless steel, copper, and silver), and showed that complex yarns had high tenacity and elongation [8]. Majumdar *et al.* fabricated three structures of knitted fabrics by blend spinning using cotton fibers and bamboo fibers. They showed that yarn constitution and fabric structure affected air permeability [9]. Lin *et al.* also showed that knitted fabrics composed of bamboo charcoal/stainless-steel complex yarns have a far-infrared function [10]. Stainless steel wire woven with other materials such as recycled polypropylene nonwoven or TPU yarn gives electromagnetic-shielding properties to the resulting composites [11,12]. Compared with metal plates, these composite fabrics have better flexibility and comfort after blending with natural and man-made fibers [13–16].

In the present study, bamboo charcoal/copper/phase change complex yarns were fabricated using a rotor twister combined with ring-spinning techniques. Bamboo charcoal can release far-infrared rays at wavelengths of 4–14 μm [17], resonating with human molecules, accelerating blood circulation, and strengthening metabolism and immunity [18,19]. Phase-change materials (PCM) can regulate temperature and preserve heat. Copper has greater conductivity and higher electromagnetic shielding effectiveness than stainless steel. Different compositions of complex yarns are prepared into various constitutions of elastic warp-knitted fabric using a crochet-knitting machine. The constitution of composite fabric was changed by a feeding mode of weft yarns. The comfort and functional properties of composite fabrics with various structures comprising various compositions of weft yarns were evaluated afterwards.

2. Experimental Section

2.1. Materials

Bamboo-charcoal/nylon (BC/N) roving (Desiccant Technology Co., Ltd., Taoyuan, Taiwan) comprising 70% rayon fiber and 30% bamboo charcoal fiber had a fineness of 70 denier (D)/36f. Bamboo-charcoal roving (Tung Ho Spinning Weaving & Dyeing Co., Ltd., Taipei, Taiwan) had a bamboo-charcoal content of 3%. Copper (Cu) fiber (Yeou Chuen Wire Co., Ltd., Taoyuan, Taiwan) had a diameter of 0.08 mm. PCM roving (San Wu Rubber Mfg. Co., Ltd., Changhua, Taiwan) was composed of 50% combed cotton silver (San Wu Rubber Mfg. Co., Ltd.) and 50% PCM (Toyobo Co., Ltd., Osaka, Japan). Polyester (PET) filament (Yi Jinn Industrial Co., Ltd., Changhua, Taiwan) had a fineness of 150D/48f. Rubber thread (Ta Yi Co., Ltd., Taichung, Taiwan) had a diameter of 0.65 mm.

2.2. Preparation of Complex Yarn and Elastic Warp-Knitted Fabrics

2.2.1. Preparation of Ring-Spun Complex Yarn

Core materials of the ring-spun complex yarn, *i.e.*, BC/N/Cu wrap yarn, were prepared as in our previous study [20] with BC/N yarn and Cu fibers using a self-made rotor twister machine (Feng Chia University, Taichung, Taiwan). The twist number of core material was set as 10 twists per inch (TPI), which shows the number of turns of spiral yarn in each inch of length after twisting process. The structure diagram of BC/N/Cu wrap yarn is shown in Figure 1.

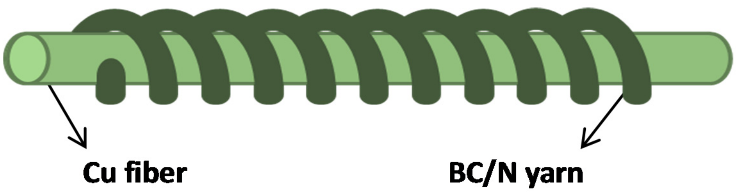


Figure 1. Schematic diagram of Bamboo-charcoal/nylon/Copper (BC/N/Cu) wrap yarn.

BC or PCM roving or both as the sheath were encompassed by the core (BC/N/Cu wrap yarn) to prepare a ring-spun complex yarn using a ring-spinning frame (SM06, Sun Mien Mechanical Co., Ltd., Taipei, Taiwan). Figure 2 shows the principle of producing ring-spun complex yarn. BC or PCM roving or both (sheath material) were fed from the back roller and passed by the middle roller, and BC/N/Cu wrap yarn (core material) was brought together at the nip point of the front roller. During spinning, one of the ends was held by the front roller, and the other ends were rotated along the yarn axis, forming a "V-shape" twisting zone. The sheath was wrapped around the core yarn, forming twisted ring-spun complex yarns wound the spindles. Three different kinds of ring-spun complex yarns were prepared and named as follows: 1-ply BC roving feeding as the sheath fabricated into BC/Cu ring-spun complex yarn, abbreviated as BC; when 1-ply PCM roving was fed into the back roller, PCM/Cu ring-spun complex yarn was made, shortened as PC; and both 1-ply BC roving and 1-ply PCM roving feeding from the back roller can be prepared into BC/N/Cu complex yarn, denoted as BPC. Twist number can be changed using the gear ratio of the front and winding rollers and varied as 9, 12, 15, 18, and 21 TPI. Table 1 shows the physical properties of 15 groups of ring-spun complex yarns. The optimal twist number was determined by tensile tenacity, twist contraction, and hairiness of complex yarns for the subsequent fabrication of warp-knitted fabrics.

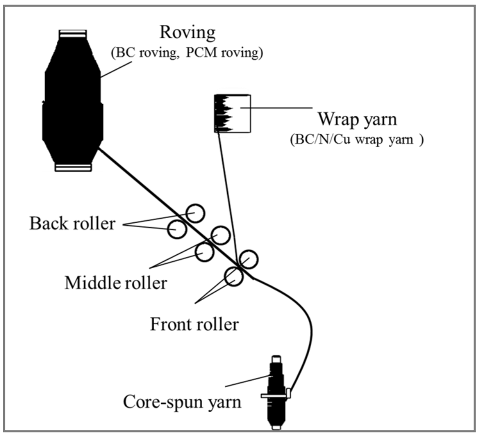


Figure 2. Configuration of ring spinning frame.

Table 1. Physical properties of ring-spun complex yarn.

Sample Code	Twist Number	Sheath	Fineness (D)	Elongation (%)
Y1	9	1-ply BC roving	836.9	14.22 ± 0.82
Y2	9	1-ply PCM roving	855.2	18.36 ± 1.12
Y3	9	1-ply BC roving and 1-ply PCM roving	1277.2	16.35 ± 1.21
Y4	12	1-ply BC roving	857.5	15.40 ± 0.92
Y5	12	1-ply PCM roving	870.3	20.18 ± 1.30
Y6	12	1-ply BC roving and 1-ply PCM roving	1305.7	16.91 ± 0.94

Table 1. *Cont.*

Sample Code	Twist Number	Sheath	Fineness (D)	Elongation (%)
Y7	15	1-ply BC roving	896.0	16.57 ± 1.10
Y8	15	1-ply PCM roving	913.1	20.76 ± 2.15
Y9	15	1-ply BC roving and 1-ply PCM roving	1441.3	19.42 ± 1.19
Y10	18	1-ply BC roving	908.3	17.92 ± 0.81
Y11	18	1-ply PCM roving	938.2	17.13 ± 3.97
Y12	18	1-ply BC roving and 1-ply PCM roving	1597.9	18.83 ± 2.70
Y13	21	1-ply BC roving	991.7	18.73 ± 1.76
Y14	21	1-ply PCM roving	1025.9	19.38 ± 1.84
Y15	21	1-ply BC roving and 1-ply PCM roving	1870.6	23.64 ± 2.83

D = denier; Y = yarn; BC = bamboo charcoal; PCM = Phase change materials.

2.2.2. Preparation of Elastic Warp-Knitted Fabric

BC, PC, or BPC complex yarns with the optimal twist number as the weft yarn, as well as PET filaments and rubber threads as warp yarn, were fabricated into BC, PC, and PCM warp-knitted fabrics using a crocheting machine (DH608-L, Dah Heer Industrial Co., Ltd., Changhua, Taiwan). Three different structures of composite fabrics were changed by the feeding mode of weft yarns. Figure 3 shows the principle of preparation of warp-knitted fabrics with different structures. Weft yarns fed from front-weft and/or rear-weft guide tubes knitted with PET filament and rubber threads formed elastic warp-knitted fabrics. When 1-ply complex yarn was fed from the front-weft and rear-weft guide tubes, a double-faced elastic warp-knitted fabric was prepared and named Fabric A. When 1-ply complex yarn was introduced only into the front-weft guide tube, a single-faced warp-knitted fabric was prepared and named Fabric B. However, when feeding from the rear-weft guide tube, single-faced warp-knitted fabric (Fabric C) was made.

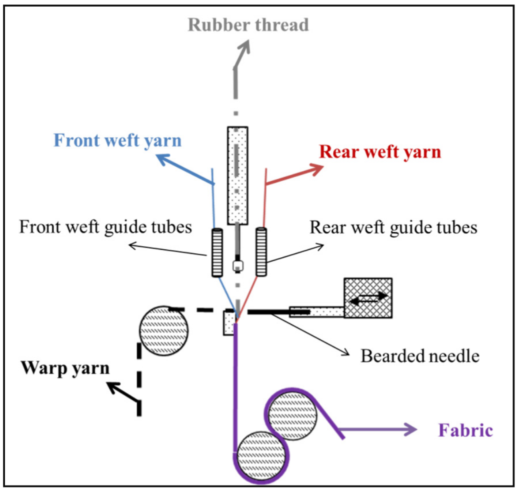


Figure 3. Principle of producing warp-knitted fabrics using a crochet knitting machine.

2.3. *Testings*

2.3.1. Tensile Test of the Yarn

Tensile tenacity and elongation of 15 groups of BC, PC and BPC complex yarns (Y1–Y15) were measured using Automatic Yarn Tester (FPA M, Textechno H. Stein GmbH & Co., Mönchengladbach, Germany) according to ASTM D2256. Tensile speed was 300 mm/min, and gauge length was 250 mm. Each yarn was tested 10 times.

2.3.2. Twist Contraction Test of the Yarn

Twist contraction of 15 groups of BC, PC, and BPC ring-spun complex yarns (Y1–Y15) was measured with Motor Twist Counter (HT-8639A, Hung Ta Instrument Co., Ltd., Taichung, Taiwan) according to CNS 11263L3216. The tested yarn length was 10 inches. The clamped distance was 250 mm. After testing, the twist contraction of yarn was calculated as in Equation (1).

$$\text{Twist contraction } (\%) = (L' - L)/L \times 100 \tag{1}$$

where L is the original yarn length, and L' is the untwisted yarn length.

2.3.3. Hairiness Test of Yarn

The hairiness of 15 groups of BC, PC, and BPC ring-spun complex yarns (Y1–Y15) was measured using Zweigle Hairiness Testwer (G565, Uster Technologies AG, Reutlingen, Germany) according to ASTM D5647. The length of testing yarn was 1000 mm, and testing speed was 30 m/min.

2.3.4. Stereomicroscopic Observation

The yarn structures of BC, PC, and BPC complex yarns (Y1–Y15) were observed using a stereomicroscopic microscope (SMZ-10A, Nikon Instech Co., Ltd., Tokyo, Japan) attached with Motic Images Plus 2.0 Software (Motic Group Co., Ltd., San Antonio, TX, USA).

2.3.5. Water–Vapor Transmission Rate Test of the Fabric

The water–vapor transmission rate (WVTR) of warp-knitted composite fabrics was measured at room temperature of 25 °C and relative humidity of 30%–35% as specified in ASTM E96. The circular sample with a diameter of 18 mm was placed on the opening of the glass bottle containing 20 mL of water and weighed every hour in the subsequent 24 h. The number of samples was five. A precision balance measured the decrease in amount of water in the bottle, and all detected values were calculated using Equation (2):

$$WVTR\,(\text{g/m}^2\,\text{Day}) = (W_0 - W_t)/(A' \times t) \tag{2}$$

where W_0 is the original weight (g) including bottle, water, and fabric; W_t is the weight (g) of bottle, fabric, and water that evaporates in time t; A' is the area (m^2) in which water vapor permeates; and t is the evaporation duration (h).

2.3.6. Air Permeability Test of the Fabric

The air permeability of elastic warp-knitted fabrics was tested using TEXTEST FX3300 Air permeability Tester (TEXTEST AG, Schwerzenbach, Schwitzerland) according to ASTM D737. Air penetrated the fabrics via a nozzle at a constant pressure of 125 Pa. Air permeability was expressed as air amount at per cubic centimeter per second per square centimeter fabric. The mean of twenty positions per fabric was obtained.

2.3.7. Far Infrared Emissivity Test of the Fabric

The far-infrared emissivity of elastic warp-knitted fabrics was tested using a far-infrared emissivity tester (TSS-5X, Desunnano Co., Ltd., Tokyo, Japan) according to FTTS-FA-010. Ten positions per fabric were tested. Far-infrared emissivity was defined as the thermal radiation of each fabric compared with that of black body (0.94 ε).

2.3.8. Anion Amounts Test of the Fabric

The anion amount of elastic warp-knitted fabrics was measured using an Anion Tester (ITC-201A, Andes Electric Co., Ltd., Aomori, Japan) according to JIS B9929. Relative humidity was 65% ± 5%, and temperature was 25 ± 2 °C. The size of sample was 300 mm × 200 mm. Each fabric was tested for 15 min. Each fabric was tested five times, and the mean value was obtained.

3. Results and Discussion

3.1. Properties of Ring-Spun Complex Yarn

3.1.1. Tensile Tenacity and Twist Contraction

Figure 4 shows the effect of twist number on the tensile tenacity and twist contraction of complex yarns. Twisting gives yarn mechanical strength. Figure 4a shows that with increase of the twist number, tensile tenacity increased to a certain value and then decreased. BC and PC complex yarn twisted at 12 TPI had the highest tensile tenacity. For BPC yarn, tensile tenacity slightly decreased from 9 to 12 TPI and then continued to decrease largely with twist number. With the increase in twists per inch, the outer layer of fiber gradually pushed into the interspace of inner yarn, and the cohesive force between fibers evidently increased and led to yarn compactness and higher tenacity [21]. However, when the twist number exceeded 12 TPI, the inner yarn did not have sufficient space to hold more fibers, and the outer yarn appeared to fracture, which reduced tensile tenacity [21]. The tensile tendency of BPC yarns to twist number differed from those of the BC and PC complex yarns. This finding was due to the fact that BC and PC shell yarn generated higher compression to the core yarn, and the cohesive force between outer and inner yarn was non-uniformly distributed and easily produced stress concentration, which resulted in decreased tensile tenacity at a lower twist number.

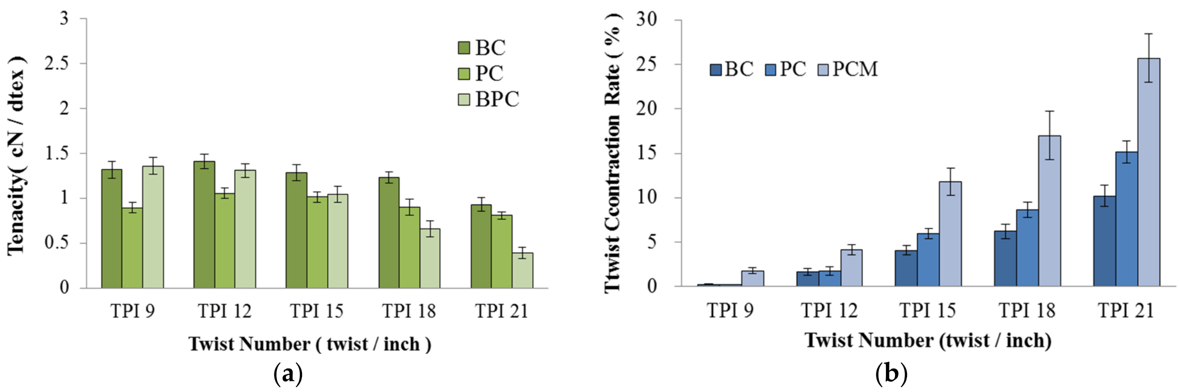


Figure 4. Tensile tenacity (**a**) and twist contraction ratio (**b**) of ring-spun yarns with different twist number (9, 12, 15, 18, and 21 per inch (TPI)).

Figure 4b shows that the twist contraction increases continuously with the twist number. The relation between the twist contraction and the twist number was consistent with Equation (3) as derived by Besset [22]. When the twist number increased, the angle *(θ)* formed by the spirals with yarn axis increased and the twist contraction ratio *(C)* also increased.

$$C = 100(1 - \frac{1}{\sqrt{1 + tan^2\theta}}) \quad (3)$$

Moreover, at the same twist number, the BPC complex yarn had much higher twist contraction ratio than others (BC, and PC yarn). This finding can be explained by Equation (4) based on the correlations of angle (θ) between the diameter (d_t) and twist number (T) of yarns [22].

$$tan\theta = \pi d_t T \quad (4)$$

Table 1 shows that BPC yarn has a higher fineness than BC and PC yarns. Even with the same twist number, the spiral angles with the yarn axis was higher; thus, the twist contraction ratio of BPC yarn was the largest. Twisting angle is one of the concepts to characterize the degree of twisting. Because of inconvenient to measure it, twist coefficient is also used to compare the degree of twisting between yarns. Twist coefficient α_{tex} is expressed as Equation (5).

$$\alpha_{tex} = \frac{10T}{2.54}\sqrt{N_{tex}} \quad (5)$$

where N_{tex} shows the yarn count in tex-system, T shows twists per inch.

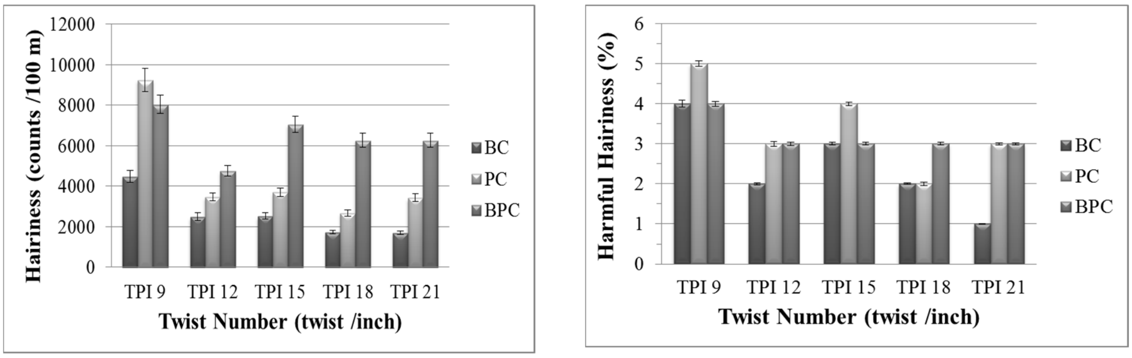
Comparing the contraction ratio with the same twist coefficient, no difference was found among BC, PC, and BPC yarns. Therefore, twist contraction ratio depended on the twist number and the yarn count.

3.1.2. Hairiness of Yarn

Table 2 shows the hair length and its distribution of ring-spun complex yarns. The total hairiness and harmful hairiness of complex yarns are shown in Figure 5a,b. Except for yarns twisted at 9 TPI, the hairiness of the BPC ring-spun yarn was much higher than those of BC and PC yarns; moreover, with increase of the twist number, overall hairiness gradually decreased. The former was due the fact that higher content of staple fiber was used as the outer layer of yarns during spinning and more hairs were exposed. The latter was due to the fact that twisting caused the outer staple fibers to be wrapped into the inner, the number of fiber ends decreased and the original hair length was shortened [23].

Table 2. Hairiness length and number distribution of BC, PC and BPC complex yarns.

Sample Code	Number of Hairs in the Length Zones						
	1 mm	**2 mm**	**3 mm**	**4 mm**	**6 mm**	**8 mm**	**⩾3 mm**
Y1	4096	249	158	4	30	-	355
Y2	8273	615	383	9	113	1	506
Y3	7373	434	268	11	55	-	334
Y4	2358	148	41	0	1	-	42
Y5	3220	206	80	1	11	-	92
Y6	4430	250	111	5	6	-	122
Y7	2321	186	59	4	8	-	71
Y8	3398	195	116	4	29	-	149
Y9	6563	364	183	8	39	-	230
Y10	1619	100	28	0	1	-	29
Y11	2508	134	48	3	1	-	52
Y12	5826	374	138	9	21	-	168
Y13	1631	94	19	1	5	-	25
Y14	3189	173	75	4	9	-	88
Y15	5825	315	134	9	21	-	164



(**a**) (**b**)

Figure 5. Total hairiness (**a**) and harmful hairiness (**b**) of BC, PC and BPC ring-spun complex yarns with different twist number (9, 12, 15, 18, and 21 TPI).

The number of hairs affects the weaving efficiency, fabric handfeel and product quality [24]. Hairs ⩾3 mm long are harmful because they cause pilling and shed-clinging problems [25,26]. Figure 5b shows that the harmful hairs of three ring-spun complex yarns accounted for 1%–5% of the total number of hairs. Therefore, Figure 6 displays that the surface of yarns was generally smooth because of its spiral winking and compact structure.

Figure 6. Stereomicroscopic observations of BC (**a**); PC (**b**) and BPC (**c**) ring-spun complex yarns.

Based on the aforementioned properties of yarn, three kinds of complex yarns at 12 TPI had the highest tensile tenacity and appropriate twist contraction as well as suitable hairiness. The following subsections discuss warp-knitted fabrics made by 12 TPI weft yarns.

3.2. Comfort Evaluation of Elastic Warp-Knitted Fabrics

Human skin has many micropores penetrating not merely sweating but also air. Therefore, WVTR and air permeability are critical factors for evaluating comfort performance which is related to physiological sensation to fabrics [23]. Figures 7 and 8 show the WVTR and air permeability of elastic warp-knitted fabrics. Comparing Figure 7a,b, Fabric A had lower WVTR than Fabric B even with the same weft yarns, which is equivalent to Figure 8a,b that air permeability of Fabric B is higher than Fabric A. Moreover, regardless of the fabric structure, the warp-knitted fabrics made by PC ring-spun complex yarns possessed the lowest WVTR values (Figure 7) because of the highest remaining water ratio of cotton fibers in the PC yarns as explained by the fact that cotton fibers had cellulosic groups and thus easily bonds with water molecules through hydrogen bonds [27].

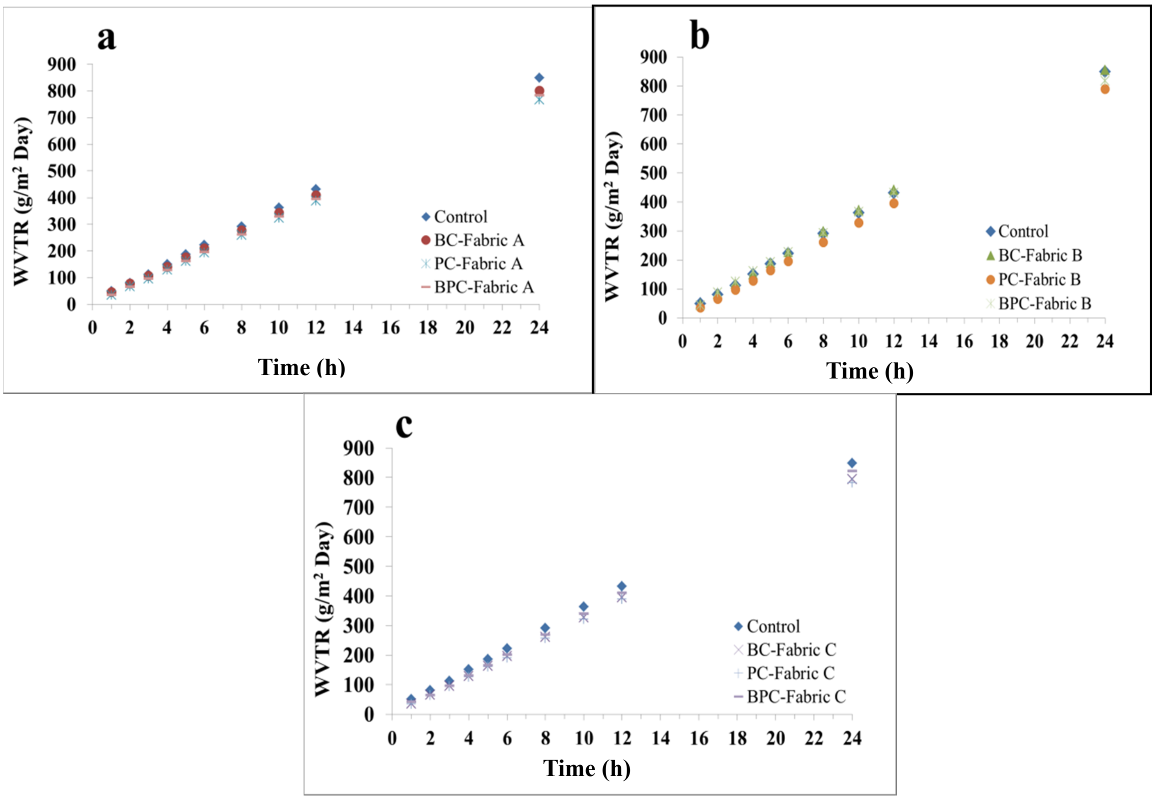


Figure 7. Far-infrared emissivity of elastic warp-knitted fabrics (Fabrics A (**a**); B (**b**) and C (**c**)) made by ring-spun complex yarns (BC, PC and BPC).

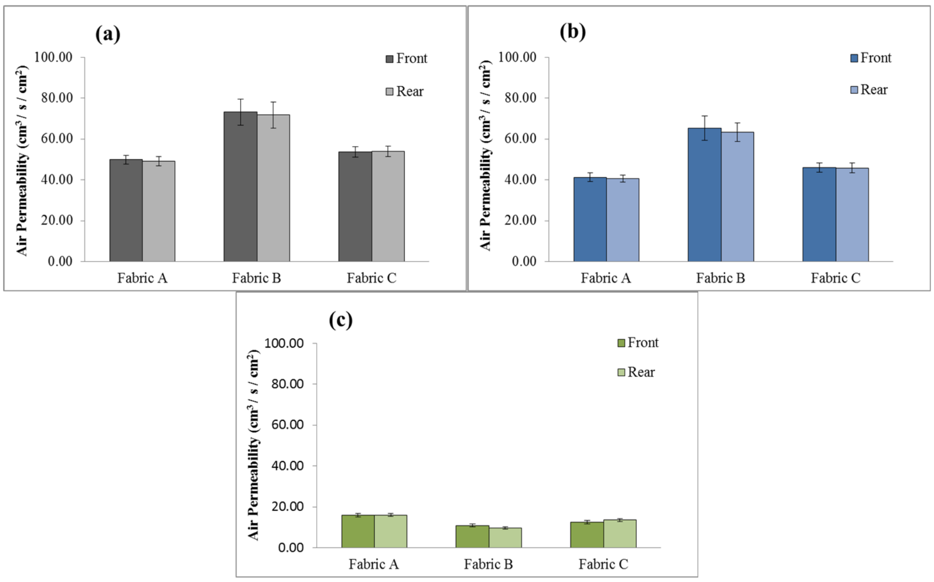


Figure 8. Air permeability of elastic warp-knitted fabrics (Fabrics A, B, and C) made by BC (**a**); PC (**b**) and BPC (**c**) ring-spun complex yarns.

Figure 8 shows that Fabric B made by BC or PC weft yarns had the highest air permeability, and Fabrics composed of BPC weft yarns generated the lowest air permeability. This finding indicated that BPC fabrics had higher density than the others because of the coarser yarn (Table 1). This finding has been confirmed by Xu *et al.* [28], who showed that air permeability was correlated with the diameters of weft and warp yarns and fabric density. Figure 8 also suggests that air permeability depended on the feeding methods of weft yarns and diameter of the feeding yarns. The compactness of fabrics was variable even with the same feeding methods of weft yarns.

Based on the above, the value of WVTR of all fabrics reached 699–876 g/m^2 day. According to literature, the WVTR of human skin under dry condition was 215 g/m^2·Day, but that of skin under wet condition reached 350 g/m^2·Day [29,30]. Therefore, the elastic fabrics showed two times higher value of WVTR than wet human skin. The air permeability of Fabric B composed of BC and PC yarns achieved 73.2 cm^3/s/cm^2, four times higher than that of plain woven fabrics made by filaments based on ASTM D737. As aforementioned, the warp-knitted fabrics fabricated in this study can provide a comfortable, drying and breathable microclimate environment to wearers.

3.3. Far Infrared Emissivity and Anion Amounts of Elastic Warp-Knitted Fabrics

Warp-knitted fabrics contain bamboo charcoal powders. When fabric is heated, bamboo charcoal releases far-infrared radiation with a wavelength of 8–14 μm. In accordance with radiation laws of Kirchhoff and Wien's displacement, the far infrared wavelength coordinated with that released by the human body, thereby easily absorbed by the body and was thus effective to physical therapy and health care [19,31].

Figure 9 shows the far-infrared emissivity of three kinds of fabrics made by BC, PC and BPC ring-spun yarns. The far-infrared emissivity of fabrics made by BC yarns was slightly higher than that of PC yarns but slightly lower than that of BPC yarns. This finding can be explained by the fact that fiber assembles plied in a more compact manner had better far-infrared emissivity than those plied in a fluffier manner [32]. Combined by Figure 8, the BPC fabrics had more compact structure and higher far-infrared emissivity than the others. In addition, the front and rear faces of Fabric A had no significant difference because of the similar structure between two faces. The far-infrared emissivity of elastic warp-knitted fabrics reached >0.9 ε, which was the level of far infrared health-care effects [33].

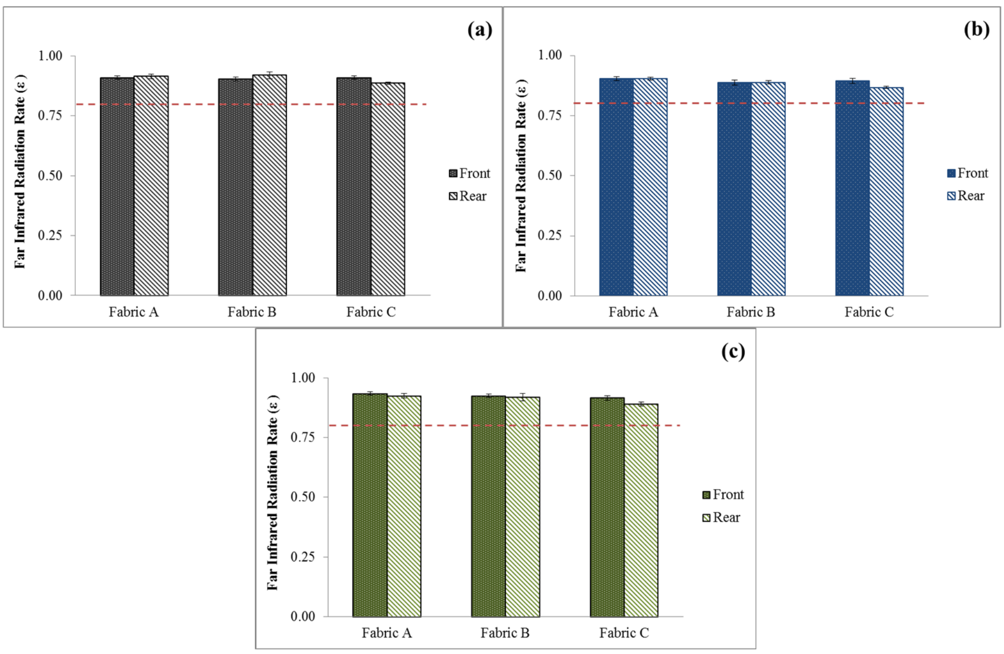


Figure 9. Far-infrared emissivity of elastic warp-knitted fabrics (Fabrics A, B, and C) made by BC (**a**); PC (**b**) and BPC (**c**) ring-spun complex yarns.

Bamboo charcoal fibers were formed by the addition of bamboo charcoal powders during spinning. Bamboo charcoal had a graphite structure in which each carbon atom formed three covalent bonds with other carbon atoms and retained one free electron to transfer charge. Therefore, it had high electronic conductivity and provided a strong electric field energy to ionize the polar groups of water molecules into anions (OH^-) [34].

Figure 10 shows the anion amounts of elastic warp-knitted fabrics with different compositions of complex yarns and feeding methods of weft yarns. The control group showed the anion amount in the detecting environment. Single-faced Fabric C made by BC complex yarns had the highest anion amounts, *i.e.*, up to 380–420 counts/cm^3, which was at least 80 counts/cm^3 higher than that of control group. This finding was due to the fact that Fabric C had a more compact structure than others, and closer bamboo charcoal easily accumulated higher electric energy to separate the polar groups from water. The anion amounts of the resulting warp-knitted fabric reached the level of metropolitan park [35], which benefits the physical and spiritual health to humans.

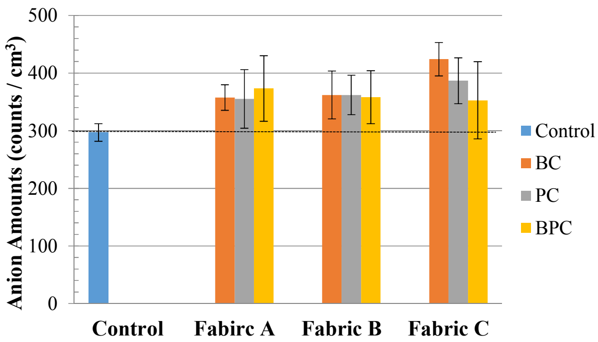


Figure 10. Anion amounts of elastic warp-knitted fabrics (Fabrics A, B, and C) made by BC, PC and BPC ring-spun complex yarns.

4. Conclusions

This study prepared different structures of elastic warp-knitted fabrics by changing the feeding mode of weft yarns, which had far-infrared emissivity and anion-releasing property. The composite fabrics were made of different compositions of ring-spun complex yarns (BC, PC, and BPC) using crochet-knitting machine. The complex yarns were composed of copper fibers, bamboo-charcoal roving, and phase change materials, and made with different twist number by rotor twister machine and ring-spinning frame.

Yarn analysis also showed that the tensile tenacity of BC and PC complex yarns initially increased and then decreased with the twist number. Twist contraction presented a reciprocal relation to twist contraction. When complex yarns were twisted at 12 TPI, the harmful hairiness accounted for only <3% of the total hairiness of 5000 counts/100 m, which was suitable for the fabrication of warp-knitted fabrics.

The comfort and functional properties of elastic composite fabric showed that when weft yarn fed from the rear-weft guide tube, single-faced Fabric C made by BC weft yarns had the highest WVTR of 876 g/m^2 Day, far-infrared emissivity of 0.9 ε, and anion amount of 420 counts/cm^3. Fabric B made by BC and PC weft yarns possessed the highest air permeability of 73.2 cm^3/s/cm^2, which was four times higher than that of woven fabrics made by filaments. The far-infrared emissivity and anion amount of all fabricated warp-knitted fabrics reached above 0.85 ε and 350–420 counts/cm^3, respectively, surpassing the level of healthcare effect of far-infrared emission and anion release. Therefore, elastic warp-knitted fabrics had excellent water vapor and air transmission, as well as far-infrared and anion-releasing effects. This comfortable and functional fabric can be good alternative to maternity belts for pregnant woman in the future.

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