Elastic Knits with Different Structures Composed by Using Wrapped Yarns: Function and Comfort Evaluations

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Abstract: In this study, the wrap yarns are made with antibacterial/green charcoal plied yarns as the wrap material and moisture management yarns as the core by using a rotary twisting machine. The wrap yarns and Tetoron® elastic yarns are then combined with different structures in order to form elastic knits. The elastic knits are then evaluated for their functions in terms of their antibacterial properties, far infrared radiation rate, and anion counts, as well as comfort in terms of settling time, wicking performance, water vapor permeability, softness, and air permeability, in order to examine the influences of jersey structure, stripe structures and mesh structures. The test results indicate that the combination of five green charcoal filaments and a mesh structure provides the elastic knits with the maximum functions and comfort, due to a high content of functional fibers per unit area. The optimal FIR emissivity reaches 0.89, maximum anion amount is 673±21.4, and the highest permeability is 63.9±2.6 cm²/cm²/s. As a result, the proposed elastic knits have an adjustable fabric structure that is feasible to meet any requirements and thus has a broad application range.

Keywords: Functional textiles, Comfort, Wrapped yarn, Elastic knits

Introduction

The advances of modern technologies give rise to a high standard of living, and people thus have greater demands for garments and commodities. Many developers have addressed these demands by making improvements with their design concepts for textiles, with having comfort, functions, and fashion as important indicators. Wearing textiles on a long term basis causes perspiration that discomfits wearers as the perspiration between the human body and garments causes moisture, humidity, and cold feelings. The perspiration-soaked textiles in turn become sticky on the skin, and thus hamper the movement of the body, and make people subject to cold illneses. The fast-drying and moisture-wicking performance of the textiles leads to keeping skin dry skin and also pleasant wearing comfort. Related studies on moisture management yarns and fabrics have been conducted in response to these demands [1-3].

In addition, perspiration accumulated in textiles easily results in the growth of bacteria that is ascribed to odor. Bacteria is divided into aureus [4], bacillus [5] and spirillum [6] in terms of their appearance. In recent years, SARS, influenza A virus subtype H1N1, and H7N9 have caused panicked people, and it is worthy of studies on manipulating growth and reproduction of bacteria and eradicating bacteria. Textiles with antibacterial properties are thus important. There is a great variety of antibacterial agents, and the antibacterial yarns in this study that contain ZnO as the antibacterial agent. The Zn ions can damage the cell walls of the bacteria and prevent the respiration of the bacteria that leads to their death, and thereby attaining antibacterial efficacy. Therefore, ZnO [7,8] has a higher application value when it is used in antibacterial fibers, fabrics, films, and coating, as well as biomedical materials [9].

In order to satisfy the consumers’ demands via increasing the added value of functional textiles, this study uses green charcoal filaments to provide textiles with thermal retention and anion release, and thus increasing their healthcare regimen. Bamboo charcoal that has been calcined at 1200 °C until the charcoal emits far infrared rays, after which the anion pulverulent body is added to the charcoal, is then are calcined again in order to form the green charcoal filament.
These filaments have far infrared emissivity and anion release functions. Anions can react with parasympathetic nerves, and expand blood vessels, thus facilitating the blood circulation. Bodies expel a considerable amount of waste when they are filled with anions, and thereby improve katabolic metabolism [11].

Far infrared rays [12] have wavelengths ranging from 4.0 μm to 1000 μm. Specifically, rays with wavelengths of 4.0 μm to 14 μm benefit the human body to the greatest extent, and are thus called fertility light in Japan. Far infrared rays in this particular range closely pertain to the growth of organisms, and accelerate the vibration of water molecules in the organisms to reach a resonance. Water molecules are thus activated, which expedites the metabolism of cells that allows for efficient nutrient transmission and waste disposal, as well as facilitates their gestation of cells. People use normal radioactive far infrared rays to attain thermal retention, and these infrared rays that are between 22 and 26 °C can keep the human body warm via three measures in terms of radioactive heat transfer, osmotic force, and resonance absorption.

Fabrics can attain multiple functions via a multiple processing according to current technology. In order to surpass the limits of multiple processing and finishing, this study uses a rotary twisting machine for the preparation of functional wrap yarns that satisfy consumers’ requirements [13]. Polyester yarns with a cross section are used as the core [14], while the wrap material are the plied yarns that are composed of antibacterial yarns of the zinc oxide series and green charcoal filaments [15,16]. Moreover, the wrap yarns and Tetoron® elastic yarns are fabricated into elastic knits, and the elastic yarns provide knits with elasticity and a next-to-skin feature [17,18].

In the light of the fact that there is few studies developing multiple functional fabrics study is based on our previous studies, where a hollow spindle spinning technique, this used to make multifunctional crisscross-section polyester (CSP)/antibacterial nylon (AN)/stainless steel wire (SSW) metal hybrid yarns. The yarns are then made into composite knitted fabrics using a circular knitting machine, and woven fabrics. The knitted fabrics are tested for functions (i.e. antibacterial, far infrared emissivity, and anion release) and comfort (i.e. wicking property, water vapor transmission rate, softness, and air permeability). The elastic knitted fabrics can be adjusted according to the practical needs, and thus have greater synergic effects and a variety of applications.

**Experimental**

**Materials**

Antibacterial yarns (Tung Ho Textile Co., Ltd., Taiwan) are the zinc oxide series that have 20 % ZnO, and are composed of rayon/cotton ratio of 20/80 and Ne of 30/2. Green charcoal filaments (Hua Mao Co., Ltd., Taiwan) have a specification of 150D/144f. Tetoron® elastic yarns (Ing Ling Enterprises Co., Ltd., Taiwan) have a specification of 75D/32f/2. Polyester yarns (i.e., moisture management yarn, Everest Textile Co. Ltd., Taiwan) have a specification of 75D/72f/2 and a modified cross-section, and thus have moisture management. The specifications of the yarns are shown in Table 1.

| Type of yarn          | Specification | Function                   |
|----------------------|---------------|----------------------------|
| Antibacterial yarns  | 30/2(Ne)      | Antibacterial property     |
| Green charcoal filaments | 150D/144f    | Far infrared emissivity   |
| Tetoron® elastic yarns | 75D/32f/2    | Elasticity                 |
| Polyester yarns      | 75D/72f/2     | Moisture management        |

**Table 1. Specifications of yarns**

![Figure 1](image.png)  
*Figure 1. Illustrations of (a) the manufacturing and (b) the formation of the wrap yarns, and (c) Stereomicroscopic image (20×) of the wrap yarn.*
Sample Preparation

Preparation of Wrap Yarns

Green charcoal filaments and antibacterial yarns are combined into plied yarns. These plied yarns serve as the wrap material and moisture management yarns serve as the core, in order to form wrap yarns via using a rotary twisting machine, as indicated in Figure 1(a). Moisture management yarns are then wrapped in the plied yarns with a T.P.I. of 2 turns/inch, thereby forming the wrap yarns. The formation and stereomicroscopic images of the wrap yarns are indicated in Figure 1(b and b), while their specification is listed in Table 2.

\[ R = T.P.I \times T_1 \times D \]  

where \( R \) is the rotor speed (rpm), T.P.I. is turns per inch, \( T_1 \) is the take-up roller speed (rpm), and \( D \) is the take-up roller diameter (inch.).

Preparation of Elastic Knits

The wrap yarns and Tetoron® elastic yarns are fabricated into elastic knits in the forms of a jersey fabric, a stripe structure, and a mesh structure (Figure 2(a-c)) via a fully computerized, highly efficient, single cylinder hosiery machine (DK-B318, Da Kong Enterprise Co., Ltd., R.O.C.). The resulting three elastic knits are abbreviated as JK, MK, and SK, where the first letter refers to their forms of being:

Table 2. Specifications and parameters of the wrap yarns that are made with 2 turns/inch

| Wrap yarn Specification/Parameter |  |
|-------------------------------|---|
| Denier (D) | 453 |
| Tenacity (g/d) | 2.74±0.06 |
| Elongation (%) | 22.41±1.15 |
| R (rpm) | 5717.70 |
| \( T_1 \) (rpm) | 350 |
| D (inch) | 2.6 |

Figure 2. Knit patterns of a jersey fabric, (b) stripe structure, and (c) a mesh structure. Note. The black part in (a)-(c) is the wrap yarns with 2 turns/inch, while the white part in (b)-(c) is the yarns that are not fed.

Table 3. Specifications of the elastic knits

| Fabric type | Wale density (wale/cm) | Course density (course/cm) | Thickness (mm) | Fabric weight (g/m²) |
|-------------|------------------------|---------------------------|----------------|----------------------|
| JK          | 7.6±0.3                | 13.2±0.2                  | 1.31±0.02      | 365.333±2.810       |
| MK          | 7.6±0.2                | 13.3±0.2                  | 1.22±0.01      | 321.333±9.801       |
| SK          | 7.6±0.2                | 26.3±0.1                  | 1.28±0.04      | 311.245±5.567       |

Figure 3. Stereomicroscopic images (10×) of the front side (the upper row) and the back side (the lower row) of (a) JK, (b) MK, and (c) SK elastic knits.
jersey fabric (J), stripe structure (S), or mesh structure (M), while the second letter K refers to knits. JK is the control group. The specification and stereomicroscopic of the elastic fabrics are respectively shown in Table 3 and Figure 3. In addition, the optimal elastic knit type (MK) is then combined with one to five green charcoal filaments in order to improve the FIR emissivity and anion amounts of the optimal elastic knits. MK is thus further divided into MK-1, MK-2, MK-3, MK-4, and MK-5 according to the number of green charcoal filaments (one to five). The MK series are then tested for FIR emissivity, anion counts, and air permeability.

Test Methods

All elastic knits are stored in a standard atmospheric condition at 20±2 and a relative humidity of 65±5 % for 48 hours, and are then tested according to different test standards.

Quantitative Bacterial Reduction Test

This test follows AATCC 100-2004. The circular samples have a diameter of 48±1 mm. Samples are placed in a flask, and 0.1 mL of Escherichia coli (E. coli) or Staphylococcus aureus (S. aureus) with a concentration of 1.5×10^6 CFU/mL is then added. The flask is then kept in an incubator at 37°C for 24 hours. The bacteria count is examined according to AATCC 100-2004. A total of five samples of each specification are used for the culture in order to have the mean of their bacteria counts. The bacterial reduction is computed via using equation (2).

\[ R\% = \frac{B-A}{B} \times 100\% \]  

where R is the bacterial reduction, B is the bacteria count of the control group, and A is the bacteria counts of the experimental group.

Far Infrared (FIR) Emissivity Measurement

The FIR emissivity of the samples is measured via using a far infrared emissivity tester (TSS-5X, Desunano Co., Ltd., Japan), as specified in FTTS-FA-010. During the measurement, the sensor head (i.e., black body) intensively emits far infrared rays over the sample. The sample reflects part of the energy it receives, after which the sensor head senses the reflected energy and outputs the emissivity. The radiation intensity of the black body is 0.94 \( \varepsilon \). A total of ten samples of each specification are tested for the mean.

Anion Counts Measurement

Samples are placed in a test box that has a size of 300 mm×300 mm where the anion counts is 401±28.33 counts/cm². Samples are trimmed to be 200 mm×150 mm pieces. An anion tester (ITC-201A, Andes Electric Co., Ltd., Japan) is used to measure the anion counts for 15 minutes, as specified in JIS B9929. The test is repeated five times in order to have the mean.

Settling Time

The setting time standard specified in Physical testing of textiles [23] is used for this test. Samples have a size of 30 mm×30 mm. The beaker is filled with 200 mL distilled water, and the sample is then mounted over the water. The length of time that the sample sinks to the bottom of the beaker is recorded as its settling time. A total of ten samples for each specification are used in order to have the mean.

Vertical Wicking Performance

A total of ten samples along the wale direction and the course direction for each specification are used for the test in order to obtain the mean. Samples are trimmed into 200 mm×25 mm strips, and are vertically suspended above the tank with one end of 5 mm dipped in the water. The length of the water that travels upwards for ten minutes via a capillary phenomenon is then recorded.

Transverse Wicking Performance

The transverse wicking method of physical testing of textiles is followed in this test. A total of five samples for each specification are used for this test in order to obtain the mean. Water of 1 mL is dripped over the circular sample with a diameter of 10 cm, and the sample is photographed by using a stereomicroscopy (SMZ-10A, Nikon Instruments Ins., Japan.) The maximum area of the water stain is then computed via using the Motic Images Plus 2.0 software (Motic Group Co., Ltd., US).

Water Vapor Permeability

A water vapor permeability test is performed in order to characterize the fast-drying and moisture-wicking performance of the samples. According to ASTM E96, the environmental temperature is set to be at 25°C and the relative humidity is set to be at 30-35 %. A total of five samples for each specification are used for this test in order to obtain the mean. The circular samples have a diameter of 18 mm. Samples are affixed onto a glass bottle containing 20 mL of water for a length of time of 24 hours, and are then weighed. Their water vapor permeability is computed with equation (3).

\[ \text{WVTR (g/m}^2\text{hr)} = \frac{(W_0-W_t)}{(t*A')} \]  

where \( W_0 \) is the original weight (g) including the glass bottle, water, and the sample, \( W_t \) is the weight (g) after the sample is exposed over the glass bottle for 24 hours and includes the glass bottle, water, and the sample, \( A' \) is the area of samples (m²) that water vapor permeates, and \( t \) means the evaporation time of 24 hours.

Softness Measurement

Samples are trimmed into 150 mm×20 mm, and are tested for softness as specified in ASTM D1388. A sample is placed on a platform, and then is pushed toward a slope. When the sample is completely adhered to the slope, the length (mm) that the sample starts to bend and attach to the slope is recorded. A total of five samples along the wale
Air Permeability Test

An air permeability tester (TEXTEST FX3300, GO-IN International Co., Ltd., Germany) is used to measure the air permeability according to ASTM D737. Samples have a size of 250 mm×250 mm. A total of twenty samples for each specification are used for the test in order to obtain the mean and standard deviation.

Results and Discussion

Effects of Knitting Structures on Functions of Elastic Knits

Quantitative Bacterial Reduction

A satisfactory antibacterial efficacy against gram-positive bacteria of *S. aureus* or gram-negative bacteria of *E. coli* is exemplified in Figure 4 and Table 4. The bacterial reduction of the elastic knits is above 90 % for *S. aureus*, while the bacterial reduction of the elastic knits is above 70 % for *E. coli*. The antibacterial reduction of the elastic knits is ranked by JK, MK, and then SK, due to a higher content of antibacterial yarns. In comparison to SK, MK is composed of more antibacterial yarns per unit area, as indicated in Table 4, and thus has higher antibacterial efficacy. However, JK is made of jersey fabrics, and thus have the highest content of antibacterial yarns. The results are in conformity with the findings in the previous studies, where the knitted fabrics and woven fabrics showed the same trend [19,20].

The antibacterial yarns used in this study are staple-fiber yarns that contain Zn particles. In addition, these yarns are blended yarns that are composed of rayon/cotton fibers of 20/80, and thus they have antibacterial properties and elasticity that contribute to the comfort of the elastic knits. The major part is cotton fibers that have moisture-wicking performance. Perspiration can thus be conducted to the surface of the knits, and thereby obtaining moisture management. Moreover, the commercially available antibacterial materials are made of organic antibacterial agents, inorganic antibacterial agents, and biological antibacterial agents, while the inorganic antibacterial agent is used in this study [24]. Among the antibacterial principles of contact reaction, photocatalytic reaction, and injure DNA of microorganism, such as bacteria, the contact reaction principle applies to this study. Cells consist of phospholipid and have negative charges. When a small amount of Zn ions have contact with cell membranes, they can firmly adhere to cell membranes via the coulombian force due to the opposites attract theory. The breath of cell membranes is thus interfered with, and thereby jeopardizing some of their physiological functions and only leaving their vital force to a certain extent. However, the increasingly concentrated Zn ions penetrate cell membranes, and enter the interior of enchylema, and eventually react with -SH groups that suppress the activity of endoenzyme. The cell albumen is then solidified and stops nutrient transmission that in turn causes the death of the bacteria. This study uses this type of antibacterial agent as it reacts with perspiration

![Figure 4](image-url)
and releases Zn ions, and thereby killing bacteria in order to obtain the antibacterial efficacy.

**FIR Emissivity Rate**

The FIR emissivity of the elastic fabrics is obtained as follows. Atoms at a stable status receive an energy provided by a heat source or the exposure to electromagnetic waves, and the electrons are thus stimulated and then migrate from an orbit of \( i = k \) to \( i = L \). The electrons are then stabilized and are transferred in the orbits in a reverse sequence. During this process, electrons release energy. For some materials, the energy is released in the forms of FIR rays, which in turn cause heat and attain heat insulation. The FIR emissivity with their corresponding elastic knits is 0.87 for JK, 0.85 for MK, and 0.83 for SK. The FIR emissivity depends on the content of green charcoal yarns, and JK has the maximum content of green charcoal yarns per unit area, followed by MK, and eventually SK. However, more green charcoal yarns mean a higher cost of raw materials. The standard deviation of all elastic knits is 0.01, indicating a high manufacturing stability [19,25].

**Anion Counts**

A high anion counts makes organism pleasantly comfortable. The anion counts is about 5000-50000 counts/cm\(^3\) surrounding waterfalls, 500-3000 counts/cm\(^3\) in forests, 0-300 counts/cm\(^3\) in cities, and 0-300 counts/cm\(^3\) in an indoor space [11]. Anion counts decreases as a result of the increasing positive ions. Anions can adsorb pollutants in the air, including dust and odor, and are then absorbed over trees or rocks, or dissolved in water. This self-purification of nature is called Philip Lenard utility. Moreover, anions can also decontaminate blood, regulate autonomic nerves, activate cells, and boost immunity. An anion counts of 401 counts/cm\(^3\) refers to an effective anion release, and is thus anticipated. Anion counts of the elastic knits are ranked by JK, MK, and SK due to their content of green charcoal yarns. JK has the maximum amount of green charcoal yarns per unit area, followed by MK, and then SK. A greater amount of green charcoal yarns benefits the anion release, but also requires a higher production cost.

**Effects of Knitting Structures on Comfort of Elastic Knits**

**Fast-Drying and Moisture-Wicking Performance**

The moisture management of the elastic knits is dependent on their knitting structures, as indicated in Table 7. The settling time, vertical wicking performance, transverse wicking performance, and water vapor permeability of the samples are evaluated to examine the moisture management. In addition, a settling time test and vertical wicking performance respectively show their water absorption rate and water absorption amount. The transverse wicking performance indicates the diffusion rate of water after the elastic knits are in contact with water. A large transverse wicking area indicates that the moisture in knits has a large contact area with the air, allowing for an efficient drainage of water. Moreover, water vapor permeability shows the content of water that can permeate the elastic knits, and therefore, the higher the water vapor permeability, the greater the fast-drying performance.

The settling time of elastic knits are ranked as JK, MK, and SK. The settling time is dependent on the content of the moisture management yarns (i.e., polyester yarns with a cross section). JK has the maximum content of moisture management yarns, followed by MK and then SK. As a result, JK has the shortest setting time, which is ascribed to the maximum content of these yarns. Similarly, JK also has the best vertical and transverse wicking performance, followed by MK, and eventually SK. These results are ascribed to the

| Fabric type | Sedimentation time (s) | Vertical wicking | Transverse wicking | Water vapor permeability (g/m²/24 h) |
|-------------|-----------------------|------------------|--------------------|-----------------------------------|
| JK          | 8.73±0.56             | 12.9±0.17        | 12.8±0.29          | 21.79±1.15                       |
| MK          | 8.90±0.35             | 12.7±0.76        | 12.7±0.10          | 18.13±0.79                       |
| SK          | 11.03±0.01            | 12.2±0.29        | 12.3±0.18          | 13.74±1.89                       |

Table 5. The FIR emissivity of elastic knits as related to different structures

| Fabric type | Far infrared radiation rate (ε) | Standard deviation σ |
|-------------|---------------------------------|----------------------|
| JK          | 0.87                            | 0.01                 |
| MK          | 0.85                            | 0.01                 |
| SK          | 0.83                            | 0.01                 |

Table 6. The anion release of elastic knits as related to different structures

| Fabric type | Anion amount (counts/cm\(^3\)) | Standard deviation σ |
|-------------|-------------------------------|----------------------|
| Control     | 401                           | 28.33                |
| JK          | 658                           | 25.88                |
| MK          | 655                           | 24.49                |
| SK          | 610                           | 20.82                |

Table 7. The moisture management of elastic knits as related to different structures
content of the moisture management yarns. More moisture management yarns have a positive influence on the vertical and transverse wicking performance. The results are in conformity with the findings in the previous study, where the woven fabrics showed the same trend. Namely, more multifunctional hybrid yarns improved the vertical and transverse wicking performance of the woven fabrics [19,20].

In contrast, SK has the maximum water vapor permeability, followed by MK, and then JK. Because SK has a higher knit density, its structure is fluffier with a large size of pores. These characterizations are conducive for water vapor permeability. JK has the lowest air permeability as it has the maximum amount of yarns, which in turn is disadvantageous for the efficient moisture management. As a result, the water vapor permeability of JK is the poorest.

**Softness**

The influential factors to softness of elastic knits include fiber properties, yarn structure, fabric structure, and finishing. This study examines the effect of knitting structures on the softness. The knits are stiff when having a high bending rigidity. Namely, the softness is poor. The thickness of knits is highly correlated with their softness. The fabrics become stiff as a result of the increasing thickness. For knits, a long loop length and a greater stitch both contribute to a higher softness. In particular, the softness along the course direction of SK is the lowest, as indicated in Figure 5. This result is ascribed to the high thickness of SK. The stiffness of SK is increased as a result of a high thickness. However, regardless of the knit types of being SK, MK, or JK, the softness along the wale direction is about 6.0 cm, which is attributed to the consistent density of wale loops (Table 3). The softness of knits is in relation to the comfort of wearers, and a low softness thus decreases the comfort.

**Air Permeability**

The air permeability of elastic knits is correlated with the knitting structures, as exemplified by the results of 70.2±1.0 cm³/cm²/s for SK and 65.0±1.2 cm³/cm²/s for MK. SK has the highest air permeability due to its low fabric density. The air permeability of elastic knits is indicated in Table 8.

**Effects of Numbers of Green Charcoal Filaments on Functions and Comfort of MK Series**

According to previous two sections, MK series have the optimal functions and comfort, and they are thus combined with different numbers of green charcoal filaments, in order to be compared in terms of the FIR emissivity, anion counts, and air permeability.

**FIR Emissivity of MK Series**

Table 9 indicates the FIR emissivity of the elastic knits with a mesh structure as related to the number of the green charcoal filaments. The FIR emissivity of MK series are 0.81 (MK-1), 0.83 (MK-2), 0.85 (MK-3), 0.88 (MK-4), and 0.89 (MK-5). Namely, their FIR emissivity is proportional to the number of constituent green charcoal filaments. More green charcoal filaments refer to a greater amount of green charcoal filaments per unit area, which provides the MK series with higher FIR emissivity. In addition, all standard deviations for FIR emissivity is 0.01, indicating that MK series are made with stabilized manufacturing.

| Fabric type | Far infrared radiation rate (ε) | Standard deviation σ |
|-------------|---------------------------------|----------------------|
| MK-1        | 0.81                            | 0.01                 |
| MK-2        | 0.83                            | 0.01                 |
| MK-3        | 0.85                            | 0.01                 |
| MK-4        | 0.88                            | 0.01                 |
| MK-5        | 0.89                            | 0.01                 |

**Table 10. Anion counts of MK series as related to different number of green charcoal filaments**

| Fabric type | Anion amount (counts/cm³) | Standard deviation σ |
|-------------|---------------------------|----------------------|
| Control     | 418                       | 24.32                |
| MK-1        | 655                       | 22.60                |
| MK-2        | 655                       | 22.10                |
| MK-3        | 661                       | 28.00                |
| MK-4        | 662                       | 29.33                |
| MK-5        | 673                       | 21.40                |
Table 11. Air permeability of the MK series as related to different numbers of green charcoal filaments

| MK Series | Air permeability (cm\(^3\)/cm\(^2\)/s) | Standard deviation (σ) |
|-----------|----------------------------------------|------------------------|
| MK-1      | 66.2                                   | 2.7                    |
| MK-2      | 65.8                                   | 6.5                    |
| MK-3      | 65.6                                   | 4.9                    |
| MK-4      | 64.2                                   | 6.0                    |
| MK-5      | 63.9                                   | 2.6                    |

Anion Counts of MK Series

An anion counts of 418 counts/cm\(^3\) is expected for this test. Table 10 indicates the anion counts of MK series. The higher the number of the green charcoal filaments, the greater the anion counts. A high number of green charcoal filaments results in a greater amount of them per unit area, and thereby improving the anion counts of the MK elastic knits.

Air Permeability of MK Series

Table 11 shows the air permeability of MK series as related to different numbers of green charcoal filaments, which are 66.2±2.7 cm\(^3\)/cm\(^2\)/s for MK-1, 65.8±6.5 cm\(^3\)/cm\(^2\)/s for MK-2, 65.6±4.9 cm\(^3\)/cm\(^2\)/s for MK-3, 64.2±6.0 cm\(^3\)/cm\(^2\)/s for MK-4, and 63.9±2.6 cm\(^3\)/cm\(^2\)/s for MK-5. The high number of green charcoal filaments is adverse to the air permeability of the MK series. When more green charcoal filaments are added, there are more green charcoal filaments per unit area, which causes the porosity of the elastic knits to decrease. These elastic knits are thus not efficiently ventilated, and as such decreases the air permeability of the MK series.

Conclusion

This study successfully combines diverse functional wrap yarns and develops elastic knits with different knitting structures. The test results indicate that MK-5 has the optimal functions and comfort because MK has more functional yarns per unit area, in comparison to SK. MK-5 thus has the optimal FIR emissivity of 0.89, anion amount of 673±21.4, and air permeability of 63.9±2.6 cm\(^3\)/cm\(^2\)/s. This manufacturing technique can replace some not eco-friendly manufacturing for products that are made with coating. In addition, the manufacturing allows for the combination of diverse functional yarns, and thereby attaining environmentally protective purposes and multiple functions of the elastic knits. The proposed elastic knits are suitable for their application to healthcare clothing that activates cells of the wearers. Moreover, they are flexible and comfortable and are free from disadvantages caused by the accumulated perspiration. The resulting healthcare clothing thus have antibacterial efficacy and does not generate odor due to the presence of residual bacteria.

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