Research and Application of Biomimetic Textile Materials in Fashion Design

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Abstract. Bio-simulation textile materials have been widely used in clothing, especially in sports and leisure clothing, especially water-absorbing and moisture-conducting bio-release fabrics have entered the clothing market. To this end, the biomimetic characteristics of the internal water transport network structure of plants in nature are studied. It is of great significance to study the design of absorbent garments with strong water-absorbent and quick-drying fabrics. To this end, the paper opened the research of biomimetic fabric materials around this research background, hoping to provide new ideas for fashion design.

1. Introduction

When the temperature is high in summer or during intense exercise, the human body will sweat a lot. Through sweating and evaporation of water vapor, the human body can dissipate heat. Currently, the wet transfer performance of the garment is an important factor for maintaining the heat balance of the human body and making people feel comfortable or not [1]. If the body's sweat and sweat cannot smoothly pass through the fabric, resulting in increased humidity in the microclimate between the human skin and the clothing and moisture on the surface of the human skin, affecting the body's evaporation and heat dissipation, the human body will have a stuffy feeling; as the skin contacts the garment The increase in area, if the sweat is filled in the fabric, the air in the gap between the fiber and the yarn is squeezed out, on the one hand, the human body feels more stuffy, and at the same time, the adhesion of the skin and the clothing further increases the uncomfortable feeling of the human body; At some point, this situation causes a decrease in the air inside the garment, which causes the warmth to decrease, and the human body has a cold feeling [2]. Therefore, the moisture permeability and moisture permeability of the garment play an important role in wearing comfort.

At present, the development and research of moisture-conducting and quick-drying fabrics has become one of the research hotspots. The moisture permeability and moisture permeability of the garment is always manifested during the wearing process, especially after the body sweats a lot, the inner side of the garment directly contacting the skin (the reverse side of the fabric) absorbs sweat, so that the sweat can spread along the surface and thickness direction of the fabric. It is conducted to the front of the fabric and is dampened to the atmosphere on the front side of the fabric. This is a complex dynamic process [3]. To improve the moisture permeability of the fabric, it is necessary to combine the entire moisture absorption and wetting process to analyse each step, and use more effective principles to improve the process in order to develop a better moisture-conducting fabric. Structure. From the
perspective of bionics, this paper simulates the structure of organisms with excellent water transport mechanism in nature, and develops and designs knitted fabrics.

2. Research background of biological biomimetic performance of moisture-permeable quick-drying fabric

2.1. Evaporation mechanism of moisture in fabric
Under heat balance conditions, the main way of water vapor transmission is through the voids of the fabric. Therefore, the main influencing factors of water vapor transmission in the fabric are the structure of the fabric, such as the thickness and porosity of the fabric. The paper analyzes the relationship between fabric thickness (T), whole diameter (d) and unit area porosity (β) and wet resistance by simulating fabric experiments:

\[ R = \frac{T}{\beta} + 0.71d \left( \frac{1}{\beta} - \frac{1}{\sqrt{\beta}} \right) \] (1)

It can be seen from the equation that the larger the thickness and the diameter of the fabric, the larger the moisture resistance of the fabric and the worse the moisture permeability; however, the more the void per unit area, the smaller the moisture resistance of the fabric and the better the moisture permeability. When the void ratio is between 20% and 29%, the thickness of the fabric is linear with the wet resistance [4].

The thickness of the fabric is an important factor affecting the moisture permeability of the fabric. The thicker the fabric, the greater the wet resistance and the poorer the moisture permeability. At the same time, factors such as the void ratio of the fabric and the type of yarn are also important factors.

2.2. Liquid water transmission mechanism in knitted fabric structure
The energy of the capillary phenomenon is derived from the interfacial energy. When the liquid infiltrates the wall of the thin tube, the liquid surface will bend, causing the liquid surface to pull and produce a slight pressure difference ΔP. The Laplace equation is used to indicate that the pressure difference is:

\[ \Delta P = \frac{2\gamma \cos \theta}{R_c} \] (2)

Where: \( R_c \) represents the radius of curvature of the curved surface.

When the contact angle is 0°-90°, \( \cos \theta \) is positive and \( \Delta P \) is also positive. At this time, capillary wicking continues to occur, and the liquid water transfer of the fabric is also continuously performed. The wicking rate is an important indicator of the moisture permeability of a fabric structure. It is affected not only by the surface tension and wettability of the fabric, but also by the radius of curvature R and the viscosity of the fluid. The wicking rate of a liquid can be expressed by the Washburn-Lucus equation:

\[ \frac{dl}{dt} = \frac{r \gamma \cos \theta}{4\eta l} \] (3)

Where, the height at which the liquid climbs in the capillary during time t.

The capillary phenomenon is affected by the surface morphology of the fiber and by the shape of the fiber. Because the shape of the fiber affects its own capillary space, it also affects the shape of the gap between the fiber and the fiber, thus affecting the wicking rate. In order to more clearly analyze the
transport shape of liquid in the fiber, the paper presents a model for simulating moisture wicking, as shown in Figure 1.

![Figure 1. Horizontal wicking test device structure](image)

2.3. Heat conduction mechanism of knitted fabrics

The sensible heat transfer between the skin and the outermost surface of the body is quite complex, including internal convection between the under-air layer space and the radiation process between the layers of clothing, as well as thermal conduction through the layer of clothing material itself. However, the layers of the garment are very close to each other, the temperature gradient is small, and the radiation heat is negligible [5]; when the air in the air layer under the clothes is in a quiet state, it can be regarded as still air, and the heat conduction amount is also small. Therefore, the heat transfer in a multi-layer garment system is primarily the conduction of the garment fiber material itself. This article mainly discusses the structure of summer apparel fabrics, while summer garments are generally single-layered. The heat conductivity of a single garment layer can be calculated according to Fourier's law of heat conduction:

$$Q = \frac{0.382 \lambda AT \Delta t}{d}$$  \hspace{1cm} (4)

Where: \(Q\) represents the thermal conductivity of the garment, J; \(\lambda\) represents the thermal conductivity, W/(m·°C); \(A\) represents the heat transfer area of the garment, m²; \(T\) represents time, h; \(\Delta t\) represents the temperature difference between the inner and outer surfaces of the garment, °C; \(d\) represents the thickness of the garment, m; in order to find the heat obtained per unit area of the garment layer per unit time, the above formula can be rewritten as:

$$\frac{Q}{ST} = \frac{0.382}{d \lambda} \Delta t$$  \hspace{1cm} (5)

Where \(\frac{Q}{ST}\) represents the heat flux, W/m², which represents the heat per unit area of the fabric layer per unit time; \(d / \lambda\) represents the thermal resistance \(R\), °C·m²/W. At the same time, it can be seen from the above formula 5 that the thermal resistance \(R\) of the garment is the ratio of the temperature difference between the two sides of the garment layer to the heat flow rate per unit area passing through the garment. Thermal resistance reflects the insulation and warmth of clothing and its materials, sometimes referred to as insulation or warmth.
3. Hygroscopic bio-synthesis textile material design

3.1. Structural design
Depending on the thermal wet comfort mechanism of the fabric, the type of yarn or fiber is one of the main factors affecting the thermal and moisture barrier properties of the fabric. Therefore, this paper chooses a kind of moisture-conducting and quick-drying raw materials to design different wetted structures. The selected fabric material was a 16.7 tax/96f polyester filament, and Figure 2 is a fiber cross-sectional shape photographed by an electron microscope. As can be seen from the figure, the cross-sectional shape is a cross (+). The surface of the profiled cross-section fibers can produce fine grooves, so that the channels formed between the fibers during weaving produce capillary phenomenon, and the sweat of the human body is wicked and diffused to the outer surface of the fabric to evaporate.

![Figure 2. Electron micrograph of the fiber](image)

3.2. Sample pretreatment
The back surface of the fabric is dusty, oily, etc. In order to reduce the error caused by these factors on the experimental test, the experimental fabric is first pretreated. According to the washing standard, the fabric was placed in the washing machine together with a certain proportion of detergent, and all the samples were washed at the same time. After washing, the fabric was soaked in clean water, and a hydrophilic agent having a weight ratio of 1:20 to the fabric was added, and the fabric was subjected to hydrophilic finishing, and the soaking time was six hours [6].

3.3. Performance test
(1) Wicking test. The wicking characteristics were obtained by vertical wicking experiments according to the B5342-24 standard. The lower end of the fabric to be tested was vertically infiltrated in the dyeing solution (containing 50 g of dye in 100 mL of water), and the time required for the longitudinal direction of the fabric to reach a certain wicking height was observed, and the average value was calculated.

(2) Drying rate. The fast-drying properties of the fabric were measured according to the standard ASTM D4935 - 99.

(3) Water vapor permeability. After the sample was conditioned, it was tested in a standard atmospheric laboratory [temperature (20±2) °C, relative humidity (65 ± 5) %]. The rate at which water vapor diffuses through the fabric is measured using a single disc test like ASTM E96-80. The water gas loss rate (MVTR) is calculated in units of g/ (m²·24h).

(4) Water diffusion test. The water absorption of the fabric was tested according to the AATCC 79:2000 standard.

4. Results analysis

4.1. Wicking behavior
Figure 3 (a, b) shows the wicking properties of the biomimetic knit fabric in the longitudinal and transverse directions, respectively. As can be seen from Fig. 3 (a, b), as the composition of the Tencel
in the blend increases, the wicking speed also increases. The hydrophilic component of the fiber affects the transfer of liquid moisture from the capillary in the yarn and is therefore a determining factor for wicking. In addition, the fast wicking speed is also related to the decrease in the contact angle and the increase in the number of pores.

4.2. Dyeing rate

Figure 4 is a dyeing rate based on a biomimetic fiber knit fabric at room temperature. As can be seen from the results, the rate order is: 100% PET > Tence VPET (15/85) > Tencel/PET (30/70) > Tence VPET (50/50) > Tencel/PET (70/30) > Tencel/PET (85/15) > 100% Tencel. After analyzing the characteristics at room temperature, it was found that the RWR under skin conditions was low because the heat in the environment caused the volatilization to be fast. An inflection point appeared at 30 min in Figure 3, indicating that the volatilization became slower. The first part of the curve has a higher rate, indicating that the moisture is emitted through the fabric, and the second slope of the line is smaller, indicating that the moisture is emitted from the inside of the fiber.
4.3. Water vapor transfer

Figure 5 shows the water vapor permeability of a biomimetic fiber knit. Sanjoy S. Chaudhari believes that the smaller the fiber diameter, the greater the surface energy, and the more the tendency of water to flow through the fabric. The surface energy and hydrophilicity of bionic fiber knits make water flow faster than in hydrophobic fibers.

![Figure 5. Water vapor permeability of fiber knitted fabric](image)

4.4. Water diffusion

The more water-staining fibers in the knitted fabric, the greater the water diffusion rate. It is believed that the contact angle of the surface of the fabric with water is reduced, and the number of holes in the fiber and the inside of the yarn is increased, which makes the diffusion of water easy to occur. It is also believed that the hydrophilic groups increase the diffusion, which may be related to the greater moisture diffusion rate of the fiber fabric.

5. Conclusion

Functional fabrics are the main direction for textile development and apparel fabric procurement, especially for sports and leisure apparel, and are constantly developing new materials and structures to meet the needs of clothing for specific functions. Simulating the tree-like branch structure to develop the knitted fabric wetted fabric is only a preliminary study of bionics for the development of knitted fabric structure. In-depth study can design a tree structure of "three-level branch" or "multi-level branch", or through the fabric the different proportions of the circle in the opposite direction directly reach the effect of the tree branch. The moisture-conducting functional fabric is the first choice for summer clothing, and it is necessary to improve the moisture guiding performance of the fabric from different aspects.

References

[1] Rajan, T. P., Ramakrishnan, G., Sundaresan, S., & Kandhavadivu, P. The influence of fabric parameter on low-stress mechanical properties of polyester warp-knitted spacer fabric.
International Journal of Fashion Design Technology & Education, Vol. 1 (2016) No.10, p. 37 - 45.

[2] Haque, A. N. M. A., Hannan, M. A., & Rana, M. M. Compatibility analysis of reactive dyes by exhaustion-fixation and adsorption isotherm on knitted cotton fabric. Fashion & Textiles, Vol. 1 (2015) No.2, p. 3 - 6.

[3] Poincloux, S., Adda-Bedia, M., & Lechenault, F. Geometry and elasticity of a knitted fabric. Physical Review X, Vol. 2 (2018) No.8, p. 021075 - 021082.

[4] Kumar K.V., Sampath V. R., & Prakash, C. Investigation of stretch on air permeability of knitted fabric part i: effect of spinning system. International Journal of Clothing Science & Technology, Vol. 6 (2017) No.29, p. 754 - 767.

[5] Karthikeyan, G., Nalankilli, G., Shanmugasundaram, O. L., & Prakash, C. Thermal comfort properties of bamboo tencel knitted fabrics. International Journal of Clothing Science & Technology, Vol. 4 (2016) No.28, p. 420 - 428.

[6] Mozafary, V., & Payvandy, P. Mass spring parameters identification for knitted fabric simulation based on fast testing and particle swarm optimization. Fibers & Polymers, Vol. 10 (2016) No17, p. 1715 - 1725