A BIOMIMIC THERMAL FABRIC WITH HIGH MOISTURE PERMEABILITY

by

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Moisture comfort is an essential factor for functional property of thermal cloth, especially for thick thermal cloth, since thick cloth may hinder effective moisture permeation, and high moisture concentration in the micro-climate between skin and fabric would cause cold feeling. Here, we report a biomimic thermal fabric with excellent warm retention and moisture management properties. In this fabric, the warp yarn system constructs many tree-shaped channel nets in the thickness direction of the fabric. Experimental result indicates that the special hierarchic configuration of warp yarns endows the biomimic thermal fabric with a better warm retention and water vapor management properties compared with the traditional fabrics.

Key words: *biomimic fabric, warm retention, water management, fabric texture design*

Introduction

Warm retention and moisture management properties are two important factors for clothing comfortability. For a thick clothing worn in cold weather, positive moisture transport of the clothing is critical in keeping the skin dry and promoting the comfort of clothing. Considerable research work has been carried out to improve the moisture management property of fabric. Bagherzadeh *et al.* [1] found that by using profiled fibers such as Coolmax fiber, moisture management properties of spacer fabrics can be improved. Research work by Xu *et al.* [2] suggested that abnormal degree of profiled fiber has an obvious effect on the moisture management property of fabric.

Structure of fabric and the assembly of fibers and yarns in the fabric are significant for warm retention property and moisture management property of a comfort fabric, as well [3, 4]. Bedek *et al.* [5] concluded that the relative porosity of a fabric would affect the first thermal contact feeling. Majumdar *et al.* [6] reported that fabric texture has an influence on the thermal resistance of fabric. Ozdil *et al.* [7] found that while the yarn twist and yarn count increase, the thermal resistance values decrease and the water vapor permeability values increase.

For a thick multilayer fabric, connectivity of pores and micro capillary tubes between yarns and fibers is crucial to liquid and water vapor transportation. Fan *et al.* [8] devel-

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oped a brand new textile woven fabric with hierarchic inner structure by imitating the configuration of plant, and the novel fabric exhibit an improved liquid water transport property.

In the present study, we constructed a biomimic multilayer thermal cloth with excellent moisture permeability by modify the fabric texture of the biomimic fabric by Fan. The new thermal fabric is softer and warmer with better moisture management property.

Weave design

Figure 1 demonstrates the movement rule of one group of the three groups of warp yarns in the biomimic triple-layer thermal cloth. In the biomimic fabric, the warp yarns move back and forth between the top layer and the bottom layer providing a continuous path for moisture transportation. The warp yarns in the bottom layer of fabric combine together simulating the trunk of the tree. In the middle layer, the combined warp yarns split into pairs forming a 2/2 matt weave and the separated pairs of warp yarns emulate the central branch of the tree. In the top layer, the coupled yarns further separate into single yarn forming a 1/1 plain weave which means the central branch splits into smaller secondary branch. To some extent, the warp yarns construct many tree-shaped branch channel nets in the vertical cross-section of the biomimic fabric.

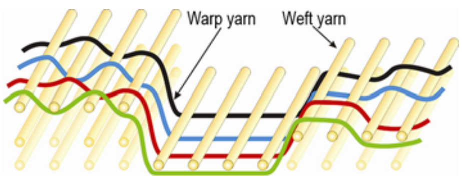

Figure 1. Schematic diagram of biomimic thermal fabric structure

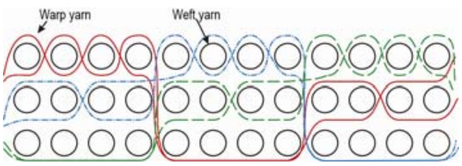

Figure 2. Exchange laws of the three groups of warp yarns in the cross-section of biomimic thermal fabric

The difference between the novel thermal fabric and the fabric developed by Fan is that we choose the warp yarn system but not the weft yarn system as the continuous path for moisture transportation. By variation of the fabric texture, the number of warp yarns in a fabric constructional unit is reduced from 24 yarns to 12 yarns. This modification greatly simplifies the weave process. Thus, the new thermal fabric can be manufactured in general loom with 12 heald frames. Meanwhile, the number of weft yarns in a fabric constructional unit is reduced from 72 yarns to 36 yarns. This made the direct length of the warp yarn from the bottom layer to the top layer of fabric decreased by half. In addition, the bottom of the fabric is completely covered with short pattern threads of warp yarns, which doubles the surface area for moisture absorption.

Figure 2 illustrates the exchange law of the three groups of warp yarns in different layers of the triple-layer fabric. Each group of warp yarns at different layer has the same movement rule as demonstrated in fig. 1, just staggered along the horizontal direction.

Fabric preparation

We prepared 4 triple-layer biomimic thermal fabrics. The samples were made of 25 tex × 2 wool yarns. In order to enlarge the advantages of the biomimic thermal fabrics, fleece finish treatment was applied to the fabrics to make tiny fluff on the surface of fabric in mimicking the root and leaf of natural plant. Three of the four samples were subject to the fleece finish treatment, among which one fabric was teased at the top surface, another was teased at the bottom surface. The other one was teased at the bottom surface, and the third one was teased at both side of the fabric surface.

To demonstrate the excellent moisture management and warm retention property of the biomimic thermal fabrics, we prepared three triple-layer stitched plain weave fabrics as control samples. The three triple-layer stitched plain weave fabrics are made of wool fiber as well, among which one fabric was teased at one surface and another one was teased at both side of the fabric surface leaving the third one without fleece finish.

Result and discussion

Fabric structural parameter

The weft yarn density, mass, thickness, and porosity of the fabric samples are tested and listed in tab. 1. The weft yarn density of biomimic thermal fabric is about 300 pich/10 cm, while that of the stitched plain weave fabrics is around 245 pich/10 cm. The low weft yarn density of the stitched plain weave fabrics is due to its high density of weaving point. The mass of the biomimic thermal fabric is about 440 g/m^2, which is larger than that of the stitched plain weave fabric 410 g/m^2. The thickness of fabrics is measured under the pressure of 2 gf/cm^2. The biomimic thermal fabric is 3.4 mm thick, while the stitched plain weave fabric is about 2.6 mm thick.

The porosity of the fabrics is calculated using the equation:

$$P = \left(1 - \frac{m}{\rho h}\right)100 \tag{1}$$

where P is the porosity, m – the fabric weight [gm^{-2}], ρ – the fiber density [gcm^{-3}], and h – the fabric thickness [mm]. The density of wool fiber is 1.31 g/cm^3.

Table 1 shows that the porosity of the biomimic thermal fabrics is about 90%, while that of stitched plain weave fabrics is around 88%.

Table 1. Structural parameter and test result of fabric samples

Sample*	Fleece finish	Weft yarn density [pichs 10^{-1} cm]	Mass [gm^{-2}]	Thickness [mm at 2gf cm^{-2}]	Porosity [%]	Thermal conductivity [Wm^{-1}K^{-1}]		Water vapor conductivity [Wm^{-1}Pa^{-1}]	
						Face up	Bottom up	Face up	Bottom up
Thermal fabrics	–	304	445.13	3.257	89.57	30.38813	28.88948	0.171	0.407
Thermal fabrics	Top face	300	441.56	3.384	90.04	29.93895	28.21411	0.164	0.520
Thermal fabrics	Bottom face	298	442.42	3.384	90.02	29.58559	28.65368	0.225	0.439
Thermal fabrics	Double face	306	441.01	3.488	90.35	28.40854	27.54699	0.221	0.491
Stitched fabrics	–	240	415.98	2.437	86.97	34.94408		0.103	
Stitched fabrics	Top face	244	414.27	2.673	88.17	36.8995	35.71619	0.095	0.347
Stitched fabrics	Double face	248	412.14	2.835	88.90	34.68314		0.124	

* Warp yarns and weft yarns are pure wool yarns; warp yarn density is 450 picks/10 cm.

Fabric thermal resistance

Thermal resistance of the fabric samples were tested using the SDL sweating guarded hotplate. Considering that the thickness of fabric samples is an inevitable factor to intrinsic thermal property of fabric samples, thermal conductivity of the samples was calculated according to eq. (2):

$$\lambda = \frac{h}{R_{ct}} \tag{2}$$

where λ is the thermal conductivity of fabric samples and h – the thickness of fabric samples.

Table 1 shows that the thermal conductivity value of the biomimic thermal fabric is smaller than that of the stitched plain weave fabrics, indicating that the biomimic thermal fabric has a better warm retention property. This is due to two reasons: on the one hand, the bulky structure of the biomimic thermal fabric, is beneficial to retain more static air, on the other hand, the tiny static air trapped in different layer of the biomimic thermal fabric has different size. The static air connected to presents a hierarchic distribution in the thickness direction of the biomimic thermal fabric which may provide a better warm retention property for the biomimic fabric.

For non-fleece finished biomimic thermal fabric, the thermal conductivity value of fabric is different when the fabric is tested face up or bottom up. A smaller thermal conductivity value was obtained when the fabric was tested bottom up, while a larger thermal conductivity value is obtained when the fabric was tested face up. That is because when the fabric was tested bottom up, the top layer of the fabric contacted with the test board. Since the top layer of the fabric has a compact structure, more tiny static air is traped in the top layer of fabric, thus the tested thermal conductivity value is small. On the contrary, when the fabric was tested face up, the bottom layer of the fabric contacted with the test board. As the bottom layer is covered by short pattern thread with less weaving points, the hole between warp yarns are relatively large, which is not beneficial for keeping tiny static air, thus the thermal conductivity of fabric is relatively large.

Results in tab. 1 also indicated that fleece finish can improve the thermal resistant of all fabric samples. For biomimic thermal fabric, no matter the fabric is tested face up or bottom up, fleece finish on the fabric surface which contact with the test board is more efficient to increase the warm retention property of the fabric. In contrast, fleece finish on the fabric surface which does not contact with the test board makes less increase in the warn retention property of the fabric. That is because even though the fleece finish is efficient to increase the tiny static air content, only the tiny static air close to skin, does it perform better warm retention property. Fleece finish on double layer of fabric achieves the largest thermal resistance and the smallest thermal conductivity of fabric samples.

Fabric water vapor permeation

Water vapor resistance of the fabric samples were tested using the SDL sweating guarded hotplate. To explain the intrinsic water vapor transfer characteristic of the fabric samples, moisture conductivity was calculated by eq. (3):

$$q = \frac{h}{R_{et}} \tag{3}$$

where q is the water vapor conductivity of fabric samples and h – the thickness of fabric samples.

The calculated water vapor conductivity value in tab. 1 suggests that the water vapor transport efficiency of the biomimic thermal fabric is higher than that of the stitched plain weave fabric. That is attributed to the warp yarns which provide a continuous moisture transport path between the top layer and bottom layer in the biomimic thermal fabric.

Result in tab. 1 also indicates that there is a slight difference between the water vapor conductivity values of fabric when the biomimic thermal fabric is tested face up on the man-made skin film and when the fabric is tested bottom up on the film. The face-up fabric has relatively larger water vapor conductivity. That is because in the former case the bottom layer of the biomimic thermal fabric contacts with the skin film, as the bottom layer of the biomimic thermal fabric is covered with short pattern thread of warp yarn, it provides a maximum contact area for wet absorption, which is beneficial for efficient moisture transportation. In addition, the warp yarns exhibit many upright branching trees in the thickness direction of the fabric in this case. This structure serves a maximum surface area for moisture evaporation, which is beneficial for efficient moisture transportation, as well. However, when the fabric is tested bottom-up, there would be many inverted branching tree by warp yarns in the thickness direction of the fabric. Even though the separated warp yarns at the top layer of fabric provide a large moisture absorption area, the evaporation of moisture at the bottom is inhibited, since the warp yarns gather step by step to form yarn bundle at the bottom layer. Thus, the moisture conductivity of the bottom-up fabric is smaller.

Fleece finish of fabric can further enlarge the better moisture transport property of biomimic fabric. When the fleece finish conducted on the fabric surfaces which direct contacts with the testing man-made skin film, the tiny fluff on the fabric surface provides an even larger specific surface area for moisture absorption through mimicking the plant root, thus, the moisture resistance further decreases comparing with the fabric without fleece finish treatment. In the same way, the fleece finish on the fabric surface faced to the atmosphere would increase the moisture evaporation area, and is beneficial to improve the moisture transport efficiency. However, the bulky fluff layer on the fabric surface away from skin may in turn hinder the diffusion of moisture on the other hand. The obtained result reveals that the latter factor is predominant. Fleece finish on the fabric surface faced to the atmosphere would decrease the moisture transport property of the biomimic thermal fabric.

Conclusions

In summary, a novel biomimic thermal fabric through mimicking the plant channel net structure was promoted in the presentation. In the new biomimic thermal fabric, warp yarns continuously move back and forth between the top layer and the bottom layer in the thickness direction of the triple-layer fabric, constructing a hierarchic branching channel net configuration. It is the special hierarchic structure of the biomimic structure which endows the biomimic thermal fabric with better warm retention and moisture management properties comparing with the traditional stitched plain weave fabrics. Moreover, fleece finish in the inner surface of fabric can be applied to assist regulate the warm retention and moisture management property of the biomimic thermal fabric.

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