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Influences of the Fibre Hygroscopicity of Connecting Yarn on the Liquid Water Transfer Property of Knitted Double-Layer Fabric

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Abstract
Functional knitted fabric is developing fast, claiming moisture management, quick drying and so on through post finishing and treatment, the fabric texture design, and fiber selection. The present study focuses on the role played by connecting yarn, which bridges the two layers of knitted double-layer fabric, in the fabric liquid water transfer and distribution performance, investigating the effects of the hygroscopicity of connecting yarn in three dimensions. It was found that, compared with ordinary cotton yarn, cotton and polyester blended yarn, as connecting yarn, can significantly increase the moisture management ability of the fabric; compared with ordinary polyester yarn, modified polyester, with higher hygroscopicity, can improve the liquid water transfer ability of the fabric.

Key words: *connecting yarn, hygroscopicity, liquid water transfer, knitted double-layer fabric.*

Introduction

Functional knitted fabric is widely used in sports activities, claiming moisture management [1, 2], quick drying [3] and so on, to meet the requirements of the wearer, like heat and moisture transfer, and dissipation. Normally a knitted double-layer construction is selected to realise a functional fabric design because of its flexibility of fiber selection and properties. In these fabric structures, the connecting yarn acts as a bridge between the two layers of the fabric. Some studies have focused on the selection of two layer yarn to create a capillary drive for liquid transfer [4, 5]. Some researchers have studied the liquid water transfer properties of improved polyester [6].

Fiber hygroscopicity is the property that a fiber possesses to readily take up and retain moisture from the air [7]. It is well known that generally cotton fiber has a higher hygroscopicity than polyester fiber. Fiber hygroscopicity influences fabric liquid water absorbency and the transfer capacity significantly, as observed by a previous research work, Liu et al. [8], reporting that cotton fiber has an extraordinary wicking ability compared with polyester, indicating that fiber hygroscopicity has a significant influence on fabric liquid water transfer.

All this information indicates that the hygroscopicity of the connecting yarn of knitted double-layer fabric may have some influence on the liquid water transfer properties of the fabric. The present study investigated how the hygroscopicity of connecting yarn in knitted double-layer fabrics of the same kind of structure influences their liquid water transfer ability and suggests how to select connecting yarn in order to enhance the liquid water transfer ability of the fabric in accordance with the results.

Experimental

Fabric Preparation

In our study, four kinds of fabric were prepared, the yarns of which are shown in ***Table 1***. Yarns of the top and bottom layers of the four kinds of fabrics are the same, respectively. The top layer of the fabric was close to the skin when worn, whereas the bottom layer was exposed to the surrounding environment. For all four fabrics, hydrophobically treated 30tex cotton yarn was used to form the top layer. The bottom layer of the fabric was placed downside when being tested and was close to the surrounding environment. The bottom yarns were ordinary 30tex cotton yarn. The connecting yarns were different, as shown in ***Table 1***.

The physical properties of the fabrics are shown in ***Table 2***. The moisture regain of the fabrics was determined by ASTM D 2654. Fabric a, with 30tex cotton yarn as the connecting yarn, had the highest moisture regain, Fabric b, with 30tex Blend yarn as the connecting yarn – the second highest moisture regain, Fabric c, with 30tex Modified Polyester yarn – the second lowest moisture regain, and fabric d, with 30tex Polyester yarn as the connecting yarn, had the lowest moisture regain. The fabric moisture regain indicates the hygroscopicity of the fabric – the higher the moisture regain, the higher the hygroscopicity. In our study, the different moisture regains of the fabrics show that they were affected by the hygroscopicity of the connecting yarn.

Table 1. *Fabric Yarn Matching.*

Fabric No.	Top layer	Bottom layer	Connecting yarn
A	30tex Cotton	30tex Cotton	30tex Cotton yarn
B	30tex Cotton	30tex Cotton	30tex Blend yarn (50%cotton, 50%polyester)
c	30tex Cotton	30tex Cotton	30tex Modified Polyester yarn
d	30tex Cotton	30tex Cotton	30tex Polyester yarn

Table 2. *Fabric Physical Properties.*

Fabric No.	Thickness,mm	Weight, g×100cm^2	Moisture Regain
a	1.47±0.010	56.7±0.17	7.2±0.03%
b	1.45±0.023	59.5±0.23	4.5±0.04%
c	1.45±0.018	56.3±0.17	2.3±0.03%
d	1.38±0.018	55.6±0.13	2.0±0.02%

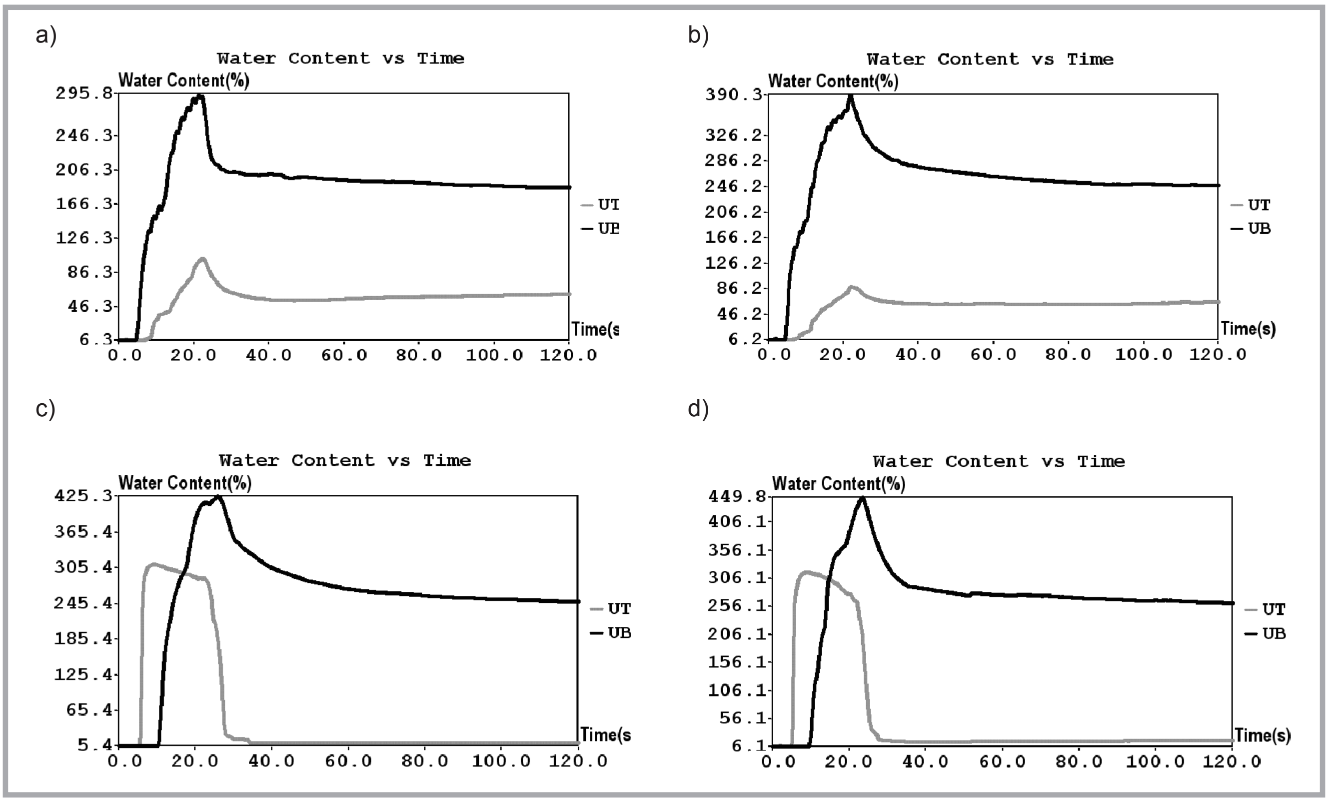

***Figure 1.** Typical MMT curves of the fabrics.*

Experiment

To reduce the influence of environmental factors on measurement results, 5 specimens were cut with a size of 90´90 mm for each kind of fabric. Then they were put in a conditioning room controlled at 21 ± 1°C and RH 65 ± 2% (Ref: ASTM D1776) for at least 24 hours to achieve "equilibrium regain".

The liquid water transfer and distribution in the fabrics was tested according to AATCC 195-2009 using a moisture management tester (MMT, a commercial testing product of SDL Atlas). The MMT is composed of an upper set and lower set of concentric moisture sensors, between which the fabric was placed [10]. The top layer was placed upside when being tested. A predefined amount of test solution (synthetic sweat) was introduced to the top side of the fabric by a pump, and the test solution was then transferred to the fabric in three directions: spreading it on the top layer of the fabric, transferring it from the top layer to the bottom layer, and spreading it on the bottom layer of the fabric. The change in water content in the top and bottom layer would then be detected by the sensors and recorded by the computer connected [2, 9].

Statistical method

One-way ANOVA was used to determine whether the connecting yarn's hygroscopiciy had made a significant difference to each MMT index for the four fabrics, and the paired t-test was used to assess the difference between each of the two sets of data. A *P – Value* less than 0.05 was considered statistically significant.

Results

MMT curves

Figure 1 shows typical relative water content curves vs. time for each kind of fabric. During the first 30 seconds, the tester was pumping to inject liquid water into the top surface of the fabric, and it could be observed that the water content increased sharply in this period. At the 20th second, with the water injection having stopped, the water content began to decrease sharply and then gradually to equilibrium.

It is clear that fabric a, with 30tex ordinary cotton yarn as the connecting yarn, and fabric b, 30tex blend yarn of 50% cotton and 50% of ordinary polyester as the connecting yarn, are of the same pattern. Meanwhile, fabric c, with 30tex modified polyester yarn as the connecting yarn, and fabric d, with 30tex ordinary polyester yarn as the connecting yarn, are of the same pattern in the MMT curve. For fabrics a and b, the water content of the bottom layer was significantly higher than that of the top layer as soon as the fabrics were wetted by liquid water, indicating that the liquid water was transferred quickly to the bottom layer from the top layer by the connecting yarn. For fabrics c and d, the water content of the top layer was higher than that of the bottom layer, lasting for seconds in the duration of pumping; it then decreased dramatically, with the water content of the bottom layer evidently increasing, which exceeded that of the top layer, followed by a significant, gradual decrease to equilibrium after reaching a peak at about the 26th second, while the content of water in the top layer decreased to a very low level, lasting to the end of the test. This indicates that the liquid water accumulated at the top surface of the fabric for a while after being injected by a pump through a needle and was then suddenly transferred to the bottom layer; it is notable that for fabrics c and d most of the liquid water was transferred and distributed in the bottom layer.

Top and bottom surface liquid water spreading properties

The definitions of the MMT indexes are as follows [9]: The wetting time of the

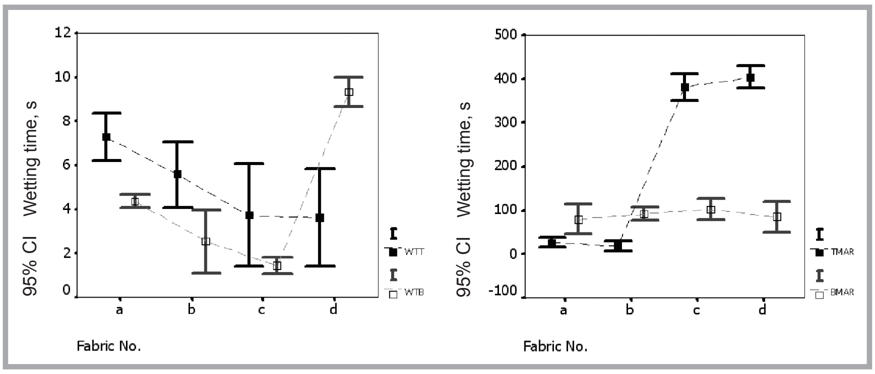

Figure 2. Comparison of the WTT and WTB (left) and TMAR and BMAR (right) of the fabrics.

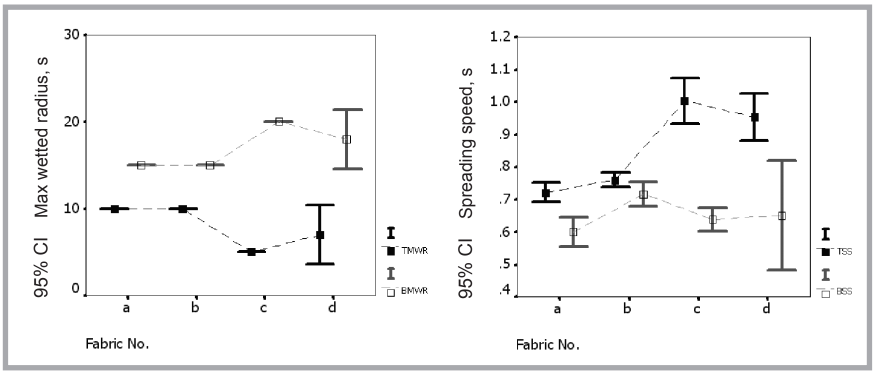

Figure 3. Comparison of the fabrics with respect to the TMWR and BMWR (left), and TSS and BSS (right).

Table 3. *ANOVA results with hygroscopicity as the fixed factor.*

Quantity	Sum of Squares	df	Mean Square	F	Sig.
WTT	44.7	3	14.90	6.69	0.00
WTB	182.1	3	60.71	137.18	0.00
TMAR	688293.5	3	229431.15	791.97	0.00
BMAR	1525.4	3	508.47	0.98	*
TMWR	90.0	3	30.00	16.00	0.00
BMWR	90.0	3	30.00	16.00	0.00
TSS	0.3	3	0.10	51.04	0.00
BSS	0.0	3	0.01	2.18	*
OWTC	12286.3	3	4095.43	20.52	0.00

* – $p > 0.05$

top surface (WTT) and wetting time of the bottom surface (WTB) (seconds) are the time periods in which the top and bottom surfaces of the fabric just start to be wetted, respectively, after the test commences, defined as the time in seconds [11] when the slope of the total water contents on the top and bottom surfaces become greater than tan (15°). The top max absorption rate (TMAR) and bottom max absorption rate (BMAR) are the maximum moisture absorption rates of the fabric's top and bottom surfaces, which are the positive maxima of the slopes of the water contents. The top max wetted radius (TMWR) and bottom max wetted radius (BMWR) are defined as the maximum wetted ring radius at the top and bottom surface, respectively, where the slopes of water contents become greater than tan (15°). The top spreading speed (TSS) and bottom spreading speed (BSS) are those of the moisture spreading on the top and bottom fabric surfaces to reach the maximum wetted radius.

A comparison of the wetting time of the top surface (WTT) and that of the bottom surface (WTB) for the four kinds of fabric is given in ***Figure 2*** (left), showing that the WTT of fabrics a, b, c was significantly higher than the corresponding WTB, indicating that the liquid water took a very short time to be transferred to the bottom layer after having been injected into the surface of the top layer, which was then sensed and recorded by the bottom sensor. However, for fabric d, the WTT is smaller than the WTB, suggesting that it took longer for the liquid water to be transferred to the bottom layer. It is notable that fabric c has the smallest mean WTB, followed by b, a and d , demonstrating that fabric b has a better liquid water transfer ability from the top to the bottom layer than fabric a in the thickness direction of the fabric, and fabric c was much better than fabric d.

Figure 2 (right) shows a comparison of the top max absorption rate (TMAR) and bottom max absorption rate (BMAR) for the four kinds of fabrics. Fabrics c and d have an extraordinarily higher TMAR than fabrics a and b, which may be because of the liquid water accumulating on the top layer surface for a very short while, causing an obvious increase in the water content of the top surface (see ***Figure 1 c** & **d***). Another reason being that the TMAR was the positive maximum of the slopes of the water contents of the top surface, hence fabrics c and d caused a significantly higher TMAR than fabrics a and b. The influence of the hygroscopicity of connecting yarn on the BMAR was not significant (p > 0.05).

The influence of the hygroscopicity of connecting yarn on the WTT, WTB and TMAR was significant ($p < 0.01$), as shown by the one-way ANOVA statistical results in ***Table 3***.

Figure 3 (left) shows a comparison of the top max wetted radius (TMWR) and bottom max wetted radius (BMWR) of the four kinds of fabrics. In general, the TMWR is lower than its corresponding BMWR for the same kind of fabric, suggesting that all the four kinds of fabric had transferred and distributed more liquid water in bottom layer than the top layer, indicating that all four fabrics had a moisture management ability. Fabrics a and b almost have the same TMWA and BMWR, lower than fabrics c and d, while fabric c has a clearly lower mean TMWR and higher mean BMWR than fabric d. The results show that fabric c has the largest bottom wetted area and the smallest top wetted area, showing that the modification of polyester yarn as connecting yarn can increase the liquid moisture spreading capacity of the bot-

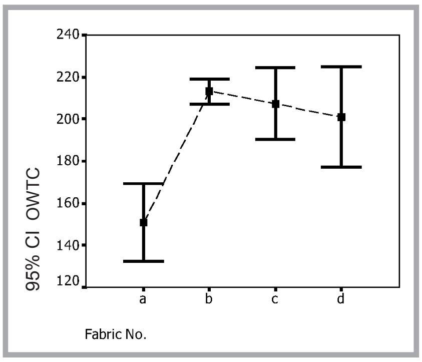

Figure 4. Comparison of the fabrics with respect to the OWTC.

tom layer. Regarding the hygroscopicity of the connecting yarn, there was no significant difference between fabrics a and b, and c and d ($p > 0.05$), but there was a significant difference between all four fabrics with respect to both the TMWR and BMWR (shown in ***Table 3***).

Figure 3 right shows a comparison of the top spreading speed (TSS) and bottom spreading speed (BSS) of the fabrics. It is obvious that fabric has the highest mean BSS and the second lowest mean TSS, whereas fabrics c and d have a higher TSS, which may be due to the sudden transfer of liquid water to the bottom layer at about the 26th second. With blend connecting yarn, the BSS was greatly improved compared with fabric a, with pure cotton connecting yarn. The hygroscopiciy of connecting yarn has a significant ($p < 0.01$) influence on the TSS but not on the BSS ($p > 0.05$).

Inter layer transfer and distribution

The cumulative one-way transport capacity (OWTC) is the difference in the cumulative moisture content between the two surfaces of the fabric in the unit testing time period.

A comparison of the cumulative one-way transport capacity (OWTC) of the four kinds of fabric is shown in ***Figure 4***, showing that the OWTC of fabric a was dramatically lower than that of the other three fabrics. The results indicate that with respect to the liquid water transfer speed and water content, fabrics b, c and d have higher differences between the two layers and a better moisture management ability, while fabric a, with 30tex ordinary cotton as connecting yarn, has the poorest OWTC. The connecting yarn's hygroscopicity has a significant influence on the OWTC ($p < 0.01$).

Discussion

In the present paper, four kinds of knitted double-layer fabric with the same fabric structure, top layer yarn and bottom layer yarn were investigated to explore the influence of the hygroscopicity of connecting yarn on fabric liquid water transfer and the distribution capacity.

For fabrics a and b, the bottom layer was generally wetted earlier than the top layer, as tested and recorded by MMT, shown in ***Figures 1*** & ***2*** (left). This may be due to the higher hygroscopicity of connecting yarn in fabrics a and b, which can be wetted quickly and, in turn, introduce the liquid water into the bottom layer , which had good liquid water absorbency. These results can be verified by Liu et al.'s study [8], namely that cotton fiber, which is has higher hygroscopicity, begins to wick earlier than polyester due to greater fiber onset surface energy. After two layers were wetted, the top layer of fabrics a and b had a higher water content than that of fabrics c and d. This is probably a result of the well known fact that [12] cotton fiber is characterised by a higher water retention ability than polyester. Moreover cotton fiber swells after absorbing liquid water, inhibiting the liquid water from being transferred from the top layer to the bottom layer. After being wetted, the liquid water transfer ability of cotton fabric decreased compared with polyester fabric.

For fabric c, the bottom layer was generally wetted earlier than the top layer, while for fabric d the bottom layer was generally wetted later than the top layer, indicating that the modification of polyester fiber increased the yarn's liquid water transfer ability, which was faster than normal polyester yarn. For fabrics c and d, the absorption ability of the connecting yarn was very limited, but the bottom layer, made of cotton, had a great absorption ability, hence the connecting yarn acted mainly as a bridge for liquid water transfer. This can be further verified by the results shown in ***Figure 3*** (left): fabrics c and d had a larger BMWR than a and b. Due to the different liquid water transfer characters of connecting yarn, as described above, fabric c has the highest BMWR and the lowest TMWR, indicating that most liquid water was distributed in the bottom layer of the fabric. It can be seen that the connecting yarn's hygroscopicity has a significant influence on the liquid water transfer and distribution in knitted double-layer fabrics in three dimensions of the thickness and horizontal directions.

Conclusion

The results strongly suggest that the hygroscopicity of connecting yarn has a significant influence on the liquid water transfer and distribution ability of fabric. Different mechanisms of liquid water absorption and the transfer properties of cotton and polyester fiber may lead differences. The modification of polyester connecting yarn has a significant influence on liquid water transfer and the distribution ability by increasing the fiber surface energy.

To enhance the liquid water transfer capacity of knitted double-layer fabric, it is better to choose cotton and polyester blend yarn and modified polyester as connecting yarn.

Acknowledgement

Thank Key Laboratory of Textile Science & Technology, Ministry of Education, Donghua University for supporting this research project.

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Received 23.03.2007 Reviewed 17.04.2010