EFFECT OF FIBER MATERIALS ON THE THERMAL AND MOISTURE COMFORT PROPERTIES OF SOCKS

by

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In this study, the influence of fiber materials on socks' thermal and moisture comfort properties is explored. The main factor affecting the properties are obtained experimentally and evaluated by the gray relation analysis. Fibrilia fabric is the best candidate for sock's material due to its high air permeability and good moisture absorption.

Key words: *socks, fiber materials, thermal and moisture comfort, capillary effect grey relation analysis*

Introduction

Thermal and moisture comfort of garments next to the skin has caught increasing attention. Socks are an important part of foot wearing, which work together with foot and the environment of shoe cavity, and affect greatly the thermal and moisture comfort of foot [1]. Socks with good thermal and moisture comfort can keep the skin of foot dry for a long time and allow the skin to breathe freely. Otherwise, epidermal sweat cannot be transmitted in time, which is not conducive to foot health and comfort. The thermal and moisture comfort of socks is largely related to fiber materials [2]. Currently, socks sold in the market are mainly composed of cotton or polyamide, and also contain a small amount of elastic yarns to make the socks fit snugly [3]. In this study, different material combinations will be used to design mixed knitting socks, through quantitative testing to explore the influence of fiber types on the thermal and moisture comfort of socks.

Experimental

Materials

The socks were prepared by a 6 F WEIHUAN computer hosiery machine of 144 latch needles at the same settings, and flat knit was used for all fabrics. The combinations are shown in tab. 1.

During the knitting process, Yarn 1, Yarn 2, and spandex elastic yarn were fed simultaneously. In order to study the effect of elastic yarn type on the thermal and moisture comfort of socks, 6# sample socks were knitted with bare spandex filament.

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Table 1. Combinations of sock materials

Number	Material combination		
	Yarn 1	Yarn 2	Yarn 3
1#	Ramie yarn	Ramie yarn	Single cover lycra
2#	Cotton yarn	Ramie yarn	Single cover lycra
3#	Cotton yarn	Cotton/hemp blend Yarn 1	Single cover lycra
4#	Cotton yarn	Cotton/hemp blend Yarn 2	Single cover lycra
5#	Cotton yarn	Cotton yarn	Single cover lycra
6#	Cotton yarn	Cotton yarn	Bare spandex filament
7#	Cotton yarn	Fine denier polyamide	Single cover lycra

Evaluation of the physical performance of the fabric

The factors influencing the thermal and moisture comfort of socks are quite different from other garments. The hot and humid environment is more stable in the shoes than other garments, and it is not easy for socks to transfer heat to outside [2]. In this study, the thermal comfort indexes such as thermal resistance were not considered, while air permeability, wicking height [4], moisture absorption and quick-drying of these seven samples were measured and other fabric structural parameters such as stitch density, mass per unit area, and thickness which indirectly affect the thermal and moisture comfort of socks were valued as well [5].

Evaluation of thermal and moisture comfort

Thermal and moisture comfort is reflected by human's satisfaction with the clothing's thermal and humid environment. The factors involved vary from person to person and show strong ambiguity. Given the small amount of data, it was difficult to find the correlation between various indicators and comfort and the degree of influence. Therefore, Gray Relation Analysis (GRA) tool was used to process and analyze the physical performance results of the test, and the thermal and moisture comfort of socks was quantitatively characterized by the relation calculation to achieve comprehensive evaluation of comfort of these samples [6].

Results and discussion

Fabric structure parameters

As shown in tab. 2, the thickness of the sample socks ranges between 0.94-1.39 mm, and the weight per unit area ranges between 268-455 g/m^2. There is no significant difference in the thickness and weight among these sample socks except for 6# sample sock, which indicate that fabric structure is influenced by the type of elastic yarn. The sample 1# is the sock with the smallest course stich density, which can be explained by the high rigidity value of ramie fiber. Due to high rigidity value, the needle loop is pushed to both sides and wale spacing becomes larger after stitch formation. The sample 1# is the sock with the smallest course stich density, which can be explained by the high rigidity value of ramie fiber. Due to high rigidity value, the needle loop is pushed to both sides and wale spacing becomes larger after stitch formation.

Table 2. Fabric specifications and structural parameters of sample sock

Number	Stitch density		Thickness [mm]	Mass per unit area [gm^{-2}]
	Wales per 5 cm	Courses per 5 cm		
1#	35	62	1.09	292
2#	40	63	1.11	308
3#	41	56	0.98	273
4#	44	62	1.08	282
5#	45	62	1.06	268
6#	48	88	1.39	455
7#	47	64	0.94	268

Thermal and moisture comfort of the fabric

Air permeability and wicking

Air permeability is affected by thickness and stich density [6]. Wicking refers to the ability of liquid to transport on the course and wale surface of textiles, which is related to the stich density negatively. Moreover, the air permeability index was standardized as the average of ratio (air permeability: thickness and air permeability: stich density), the wicking height is normalized to the ratio of the product of the course and wale wicking heights to stich density, thereby allowing these two properties comparison between the fabrics of different thicknesses and stich densities.

There are differences in the air permeability on both sides of the socks, tab. 3. The position of feeding makes the elastic yarn be arranged in the reverse, so the inner layer structure is tight, and the air permeability is poorer than the outer. The fibrilia has high rigidity, the yarn is not easy to bend during knitting, so the socks containing fibrilia have good air permeability, and the air permeability increases with the increasing of the content. While the air permeability of the 6# sample containing bare spandex filament is the worst, because the fine and high-elastic yarn is passively fed during knitting, there is almost no pores on the fabric surface.

Table 3. Fabric air permeability and wicking height of sample sock

Number	FAP [mms^{-1}]	RAP [mms^{-1}]	CWH [mm per 30 minutes]	WWH [mm per 30 minutes]	SAP	SWH
1#	1717.0	1588.0	113.0	147.0	760.93	7.65
2#	1297.0	1174.0	104.0	108.0	556.78	4.46
3#	750.1	703.3	125.0	121.0	370.92	6.59
4#	1021.0	1021.0	77.0	68.0	472.87	1.92
5#	931.9	904.4	93.0	95.0	433.25	3.17
6#	309.3	288.5	50.0	53.0	107.55	0.63
7#	860.1	857.9	100.0	121.0	457.06	4.02

FAP – face air permeability (the permeability of the gas from the outer layer of the fabric to the inner layer), RAP – reverse air permeability (the permeability of the gas from the inner layer of the fabric to the outer layer), CWH – course wicking height, WWH – Wale wicking height, SAP – standardized air permeability, SWH – standardized wicking height

The wicking height is intuitively reflected by the quality of the fabric's moisture absorption and conductivity. It can be seen from tab. 3 that it is the highest wicking height of sample 1# since fibrilia has natural moisture absorption and conductivity, and the ultra-fine micro pores inside the ramie fibers are conducive to the formation of capillary effects to accelerate the diffusion of moisture [7-13]. While the wicking height of compact sample 6# without voids of the fabric and capillary effect is the lowest. For cotton/fibrilia mixed socks, the wicking height of 3# cotton/hemp mixed fabric is higher than that of cotton/ramie mixed fabric, which can be explained by the larger cavity on the center of hemp fiber. The capillary effect of sample 5# is not obvious because the cotton fiber absorbs moisture but not transfers. There is a high wicking height for sample 7#, because ultra-fine fibers can form a dense fabric, the small distance between the fibers make a capillary effect be formed.

Fabric moisture management capability

Unidirectional moisture-transfer ability is greatly affected by the thickness since moisture needs to be transferred from one side to the other in the thickness direction [13]. In this study, one way transport capability is standardized as the ratio of unidirectional moisture capacity to thickness.

Table 4. Fabric moisture management capability of sample sock

No.	Wetting time [s]		Absorption rate [% s^{-1}]		Max wetted radius [mm]		Spreading Speed [mms^{-1}]		OWTC	
	Top	Bottom	Top	Bottom	Top	Bot-tom	Top	Bottom	Unstandardized	Standardized
1#	18.66	14.34	5.34	6.88	0.0	0.0	0.00	0.00	28.4991	26.1460
2#	5.81	4.31	16.03	23.03	20.0	15.0	2.83	3.29	1016.6793	915.9273
3#	4.69	4.69	30.81	39.45	20.0	15.0	2.82	2.61	732.7640	747.7184
4#	14.53	7.59	59.49	212.03	15.0	15.0	1.13	4.35	1031.3502	954.9539
5#	5.16	4.50	29.01	42.40	20.0	15.0	2.71	2.65	849.6951	801.5992
6#	6.56	6.84	218.53	36.89	15.0	10.0	1.62	1.90	185.6639	133.5712
7#	9.66	7.88	52.54	69.73	30.0	30.0	3.16	5.52	502.3137	534.3763

Top – immersion surface, Bottom – penetration surface, OWTI – one way transport index

According to the rating standard of GB/T 21655.2-2009, each index of fabric moisture management capability, tab. 4, is divided into five levels. The higher the level, the better the performance.

There is an excellent unidirectional moisture-transfer performance for samples 2#, 3#, 4# and 7#, fig. 1, indicating that these socks meet the technical requirements of moisture absorption and perspiration [14]. In the controlled sample, fibrilia sock showed poor unidirectional moisture-transfer ability, while cotton sock showed excellent. It is believed that the fiber configuration in the fabric is the main influencing factor [15]. Wetting is the premise of penetration. The low wetting time and absorption rate of sample 1# on the immersion surface hinder the transmission of liquid to the outer penetration surface. Meanwhile, it is found that the inner layers of fibrilia fabric are hydrophobic elastic yarn. Hence, the moisture surface of the sample is not easy to wet. For the pure cotton fabric, due to similar rigidity in cotton and elastic yarn, the cotton content on the immersion surface is higher. The 6# sample with poor wicking performance showed good unidirectional moisture guidance, which indicates that the moisture transmission of the fabric surface is affected more than the transmission perpendicular to the fabric surface by the stich density.

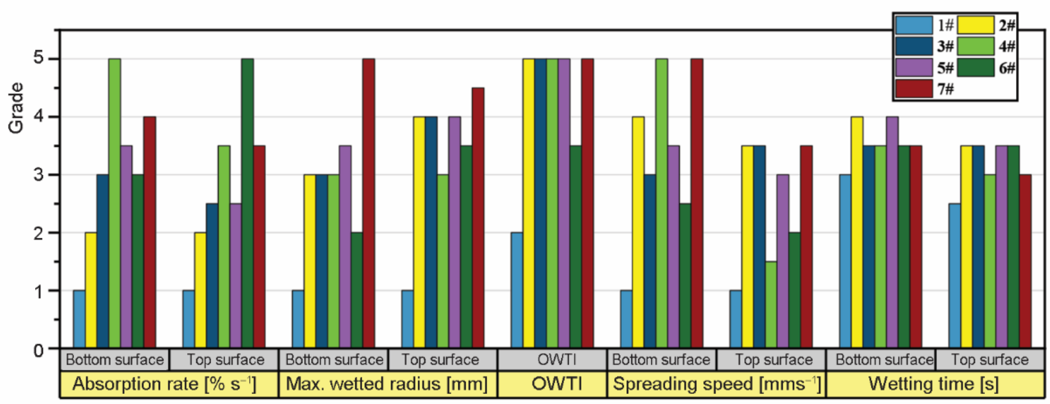

Figure 1. Finger print of moisture management properties

Grey relation analysis

The standardized air permeability, wicking height, and one way transport capability are taken as the thermal and moisture comfort performance indexes, and the optimal value of each performance index is selected to constitute the reference sequence [$X'_0(K)$ = = (760.93 7.65 954.9539)]. The sequence composed of the thermal and moisture performance indexes of the seven sample socks is used as the comparison sequence recorded as $X'_i(K)$, where i is the sample number and K is a certain character, tab. 5. There are big differences in the dimension, so a new variable [$X_i(K) = X'_i(K)/X'_0(K)$] was introduced to initialize the data.

Table 5. Initialized data

Number	K_1	K_2	K_3
X_0	1.0000	1.0000	1.0000
X_1	1.0000	1.0000	0.0274
X_2	0.7317	0.5826	0.9591
X_3	0.4875	0.8611	0.7830
X_4	0.6214	0.2509	1.0000
X_5	0.5694	0.4139	0.8394
X_6	0.1413	0.0820	0.1399
X_7	0.6007	0.5258	0.5596

K_1 – air permeability, K_2 – wicking height, K_3 – one way transport capability

The correlation coefficient [$\varepsilon_i(K)$] is calculated:

$$\varepsilon_i(K) = \frac{\min\limits_i \min\limits_k |X_0(K) - X_i(K)| + \delta \max\limits_i \max\limits_k |X_0(K) - X_i(K)|}{|X_0(K) - X_i(K)| + \delta \max\limits_i \max\limits_k |X_0(K) - X_i(K)|} \tag{1}$$

Here, δ is identification coefficient (δ = 0.6). Let $|X_0(K) - X_i(K)|$ be the absolute difference [$\Delta i(K)$].

From tab. 6, we can get the following equations:

$$\min_i \min_k \left|X_0(K) - X_i(K)\right| = 0 \tag{2}$$

$$\max_i \max_k \left|X_0(K) - X_i(K)\right| = 0.9726 \tag{3}$$

Hence, eq. (1) becomes:

$$\varepsilon_i(K) = \frac{0 + 0.6 \times 0.9726}{\Delta_i(K) + 0.6 \times 0.9726} = \frac{0.5836}{\Delta_i(K) + 0.5836} \tag{4}$$

So, the correlation coefficient can be calculated easily, tab. 7.

Table 6. The absolute difference

Number	K_1	K_2	K_3
Δ_1	0.0000	0.0000	0.9726
Δ_2	0.2683	0.4174	0.0409
Δ_3	0.5125	0.1389	0.2170
Δ_4	0.3786	0.7491	0.0000
Δ_5	0.4306	0.5861	0.1606
Δ_6	0.8587	0.9180	0.8601
Δ_7	0.3993	0.4742	0.4404

Table 7. The correlation coefficient

Number	K_1	K_2	K_3
ε_1	1.0000	1.0000	0.3750
ε_2	0.6851	0.5830	0.9346
ε_3	0.5324	0.8078	0.7289
ε_4	0.6066	0.4379	1.0000
ε_5	0.5754	0.4989	0.7842
ε_6	0.4046	0.3887	0.4042
ε_7	0.5937	0.5517	0.5699

The transmission of liquid through the fabric can be divided into two categories: wicking and unidirectional moisture-transfer. Because the sweat on the skin diffuses through the thickness of fabric, unidirectional moisture-transfer is more important than wicking for thermal and moisture comfort [16]. Therefore, the weight relation grade, r_i, is calculated according to eq. (5):

$$r_i = 0.4\varepsilon_i(K_1) + 0.2\varepsilon_i(K_2) + 0.4\varepsilon_i(K_3) \tag{5}$$

Table 8. The weight relation grade and rank

Number	Weight relation grade	Weight relation rank
X_1	0.7500	2
X_2	0.7645	1
X_3	0.6661	4
X_4	0.7302	3
X_5	0.6436	5
X_6	0.4013	7
X_7	0.5759	6

The thermal and moisture comfort performance of 2# sock among the seven samples is the best, followed by 1#, 4#, 3# sock, and then 5# sock, 6# sock, and the cotton sock containing bare spandex filament is the worst among the seven samples, tab. 8. It is thought that thermal and moisture comfort differences may be sourced from fiber material variations of the fabrics. The thermal and moisture comfort performance of fibrilia is better than that of cotton fiber and fine denier chemical fiber.

Conclusions

Thermal and moisture comfort properties of different material socks were compared and analyzed. The conclusions are as follows.

- The speed of air circulation in the shoe cavity is slow, and heat and moisture cannot be transferred quickly outward. Compared to fabric permeability, moisture absorption and perspiration are more critical to thermal and moisture comfort. Therefore, the thermal and moisture comfort properties of socks are influenced more by the material.
- Socks made of any single fiber material cannot meet people's requirements for high moisture absorption, air permeability, antibacterial properties and skin-friendliness. Using the principle of 1 + 1 > 2, combining different materials is a means to develop comfort of socks.
- There is good thermal and moisture comfort for the socks prepared by interlacing fine denier polyamide and cotton as well, while the bare spandex filament is not suitable for producing socks. In addition, compared to synthetic fiber socks, natural fiber socks are more ecological and environmentally friendly and more in line with the needs of social development.

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