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The Study of Thermal-wet Comfort of Women's Sock

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To investigate the thermal-wet comfort of women's sock, 5 kinds of common women's socks on the market were selected as research objects, which were made of different materials and weaved with different blending ratio. The warmth retention property, air permeability, moisture permeability and moisture absorption performance were tested and analyzed. The results showed that the thickness, fiber composition, density and blending ratio of women's socks all have a certain impact on the thermal-wet comfort of women's socks. Approximate optimal comprehensive judgment method was used to make a comprehensive evaluation of the thermal-wet comfort of women's socks, and sort the thermal-wet comfort of women's socks, which provided theoretical reference for the study of thermal-wet comfort of women's socks.

1. Introduction

In recent years, with the development of clothing industry and the continuous improvement of people's living standard, people has higher requirement for clothing comfort, and clothing comfort has become one of the most important features to evaluate garment. The research scopes of clothing comfort include pressure comfort, touch comfort and thermal-wet comfort mainly (Meng and Zhang (2006)). About thermal-wet comfort, many researches focused on the thermal comfort of all kinds of industries (Cannistraro et al (2015), Seth et al (2015), Hassan (2015)). As one of the commonest close-fitting clothing, at present, the existed researches about socks mainly focused on the pressure comfort of the top part of sock at home and abroad, and the study of thermal-wet comfort of sock was relatively less, therefore, it was necessary to study the thermal-wet comfort of sock(Dan et al (2011)). Through market research, the commonest several women's socks on the market were selected as research objects in this study and the thermal-wet comfort of women's sock was evaluated. The results provided references for the design and development of women's sock and consumers' purchase, which has important significance.

2. Experiment

2.1 Experimental materials

At present, most of the common women's socks on the market were weft plain. In this research, the commonest 5 women's socks on the market were selected as research objects, whose raw materials and blended ratio were different. The specification parameter of samples selected was listed in table 1.

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Table 1: The specification parameter of samples

Sample number	Material composition	Blended ratio	Horizontal density /(coil number .(5cm)-1)	Longitudinal density /(coil number.(5cm)-1)	Thicknes s /(mm)	Surface density /(g.m-2)
1#	Cotton/polyester/ spandex	82.5%/15.7%/ 1.8%	45	65	1.34	268.75
2#	Cotton/polyester/ spandex	72.4%/24.6%/ 3%	57	78	1.63	262.5
3#	Cotton/polyester/ spandex	68.9%/27.9%/ 3.2%	58	81	1.46	237.5
4#	Cotton/polyester/ spandex / Nylon/latex	63.5%/23%/2 %/7.5%/4%	55	70	1.42	225
5#	Cotton/polyester/ spandex / bamboo	45.5%/19%/3 %/32.5%	59	77	1.33	216.8

2.2 Experimental apparatus and methods

2.2.1 Warmth retention property testing

YG606 textile thermal (wet) resistance tester was used to measure the warmth retention property of women's sock. The testing conditions whose temperature was (20 + 2) ℃, relative humidity was (65 + 2) %, and the temperature of instrument testing board, protection board and floor board was all 36 ℃. With reference to the national standard GB11048-89, the testing method of warmth retention property of textile, the thermal conductivity of women's sock was measured to reflect the warmth retention property of women's sock.

2.2.2 Air permeability testing

YG641 air permeability tester was used to measure the air permeability of women's sock. With reference to the national standard GB /T5453-1997, the testing method of air permeability of textile, the gas flow through vertically a given area in a certain period of time was tested when there was a pressure difference on both sides of women's sock.

2.2.3 Moisture permeability testing

With reference to the national standard GB /T12704- 91, the testing method of moisture permeability of textile, YG601 digital fabric moisture tester was used to measure the moisture permeability of women's sock. And the moisture permeability of women's sock in a certain period of time was measured.

2.2.4 Moisture absorption performance testing

With reference to the national standard GB/T 9995-1997, the testing method of moisture content and moisture regain of textile, YG777 automatic ventilated constant temperature oven was used to measure the moisture regain of women's sock.

3. Experimental results and analysis

3.1 Warmth retention property of women's sock

The testing result of warmth retention property of women's sock was shown in figure 1.

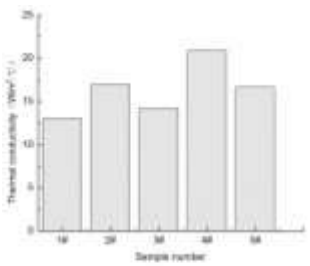

Figure 1: The testing result of warmth retention property of women's sock

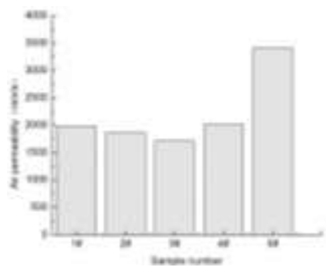

Figure 2: The testing result of air permeability of women's sock

It could be seen from figure 1 that the thermal conductivity of 1# women's sock was the least, so the warmth retention property of 1# women's socks was the best. And the thermal conductivity of 4# women's sock was the biggest, so its warmth retention property was the worst. The warmth retention property in the middle of the list was 2 #, 3 # and 5 # women's socks. This phenomenon was mainly caused by the fiber composition and thickness of women's socks. The proportion of cotton fiber of 1 # women's sock was the highest and the content of cotton fiber of 1 # women's sock was much more than that of other women's socks. The warmth retention property of cotton fiber was good was the main reason that the warmth retention property of 1# women's sock was the best. The thermal conductivity of 4# women's sock was the biggest because 4# women's sock contained nylon fiber whose warmth retention property was bad. The thickness of women's sock was also one of the factors which caused the difference of thermal conductivity of women's socks. The thicker fabric is, the better warmth retention property is. The thinner fabric is, the worse warmth retention property is. Usually, the thickness of fabric has a good linear relationship with the warmth retention property of fabric. The composition of fiber of 2# and 3# women's socks was the same, and the proportion of fiber was similar, so the main reason which caused the thermal conductivity of 2# women's sock was greater than that of 3# women's sock was 2# women's sock was thicker than 3# women's sock.

3.2 Air permeability of women's sock

The testing result of air permeability of women's sock was shown in figure 2.

The air permeability of fabric has a great relevance to the fiber composition and organization structure of fabric. It could be seen from figure 2 that the air permeability of 5# women's sock was the best, 5# women's sock contained higher proportion of bamboo fiber, the cross section of bamboo fiber is uneven, the fiber is hollow and has a lot of pore, which make the fiber has good air permeability. In addition, the thickness is also an important factor to influence on the air permeability of women's sock. so although the fiber composition, fiber content, and organization structure of 1#, 2# and 3# women's socks were all similar, 1# women's sock was thinner than 2# and 3# women's socks, the channel through which gas penetrated 1 # women's sock was short, in the process, the resistance was less, the air permeability of 1 # women's sock was better than that of 2# and 3# women's socks.

3.3 Moisture permeability of women's sock

The testing result of moisture permeability of women's sock was shown in figure 3.

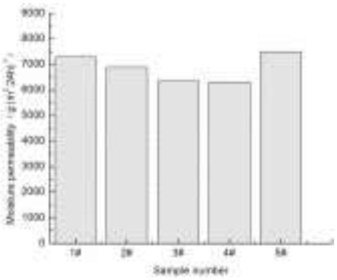

Figure 3: The testing result of moisture permeability of women's sock

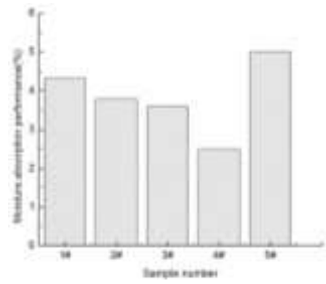

Figure 4: The testing result of moisture absorption performance of women's sock

The moisture permeability of women's sock mainly depends on the space between fiber and fiber, yarn and yarn, and the space was regarded as the channel of the movement of water vapor, so the moisture permeability of women's sock has a bigger relevance with the density of women's sock. It could be seen from table 1 that the horizontal density and longitudinal density of 1# women's sock was the lowest, which was an important reason of the good moisture permeability of 1# women's sock. In addition, the moisture permeability of women's sock has a lot of relevance with the fiber and air permeability of women's sock. It could be seen from figure 3 that the moisture permeability of 5# women's sock was the best, the proportion of cotton fiber of 1# women's sock was higher, but the moisture permeability was worse than that of 5# women's sock. 5# women's sock contained bamboo fiber, because the surface of bamboo fiber has grooves, cracks, lumen and gap, which has better capillary effect and make bamboo fiber have good moisture permeability. Although cotton fiber contains a large number of hydrophilic groups, the specific surface area of wet permeability groove which is caused by the natural turn of cotton fiber and is advantageous to capillary transmission is small, so its moisture permeability is lower. The good air permeability of 5# women's sock was also a factor leading to its good moisture permeability, because good air permeability could transmit the moisture of women's sock to the outside, and made 5# women's sock have better moisture permeability. (Shen et al. (2007)).

3.4 Moisture absorption performance of women's sock

The testing result of moisture absorption performance of women's sock was shown in figure 4.

It could be seen from figure 4 that the order of moisture absorption performance of women's sock was 5#>1#>2#>3#>4#. This phenomenon was mainly caused by the fiber composition and fiber content of women's sock. 5# women's sock contained higher proportion of cotton fiber and bamboo fiber, the moisture absorption performance of the two was good, especially bamboo fiber. The cross section of bamboo fiber is concave and convex and is full of elliptic pore, which makes bamboo fiber highly hollow and have strong capillary effect and can absorb lots of moisture instantly. Cotton fiber also contains a large number of hydrophilic groups and has good moisture absorption performance. The fiber composition of 1#, 2# and 3# women's socks was the same. And the proportion of cotton fiber of 1# women's sock was the highest, so the moisture absorption performance was better. The proportion of cotton fiber of 4# women's sock was the lowest, and the other fiber was the fiber whose moisture absorption performance was bad, such as polyester, spandex, nylon, etc. Therefore, the moisture absorption performance of 4# women's sock was the worst.

It could be seen from the above analysis that the performances of different women's socks both had advantages and disadvantages, so we couldn't evaluate the thermal-wet comfort of women's socks directly. It was necessary to establish a scientific analysis and evaluation method to evaluate the thermal-wet comfort of women's socks quantitatively.

Along with the development of the times and the progress of scientific method, people realize that the gray phenomenon of objective world has universality. For people, objective things are all grey system. On evaluating the thermal-wet comfort of women's sock, it was very difficult to determine the mapping relationship between different factors or between the thermal-wet comfort of women's sock and factors. Therefore, the evaluation of the thermal-wet comfort of women's sock belongs to an evaluation question of grey system (Loganathan and Sivapoornapriya (2015), Singh (2015)).

3.5 The approximate optimal judgment of the thermal-wet comfort of women's sock

For the women's sock used in above experiment, according to the given index (the index of thermal-wet comfort measured in the experiment), approximate optimal comprehensive judgment method could be used to decide the thermal-wet comfort of women's sock. And basic idea was to establish mathematical model to solve first, then sort to find the optimal value (Zheng et al (2007), Huang et al (2009), Kong and Yan (2007)).

3.5.1 The determination of approximate optimal grey element model

In grey system theory, the element whose information is incomplete or whose connotation is hard to end is referred to as grey element (Wu and Yu (2008)). If you have $F_j(j=1,2,\cdots,m)$ women's socks, $C_i(i=1,2,\cdots,n)$ d indexes and corresponding whitening grey measures value $\overline{\otimes}_{ji}$, then the composite grey element having m kinds of women's socks and n d indexes is referred to as $\overline{\otimes}R_{m\times n}$, namely,

$$\overline{\otimes}R_{m\times n}=\begin{array}{c|c} & \begin{matrix} F_1 & F_2 & \cdots & F_m \end{matrix} \\ \begin{matrix} C_1 \\ C_2 \\ \vdots \\ C_n \end{matrix} & \begin{bmatrix} \overline{\otimes}_{11} & \overline{\otimes}_{21} & \cdots & \overline{\otimes}_{m1} \\ \overline{\otimes}_{12} & \overline{\otimes}_{22} & \cdots & \overline{\otimes}_{m2} \\ \vdots & \vdots & \vdots & \vdots \\ \overline{\otimes}_{1n} & \overline{\otimes}_{2n} & \cdots & \overline{\otimes}_{mn} \end{bmatrix} \end{array} \tag{1}$$

The whitening grey measures value in equation (1) was processed in measureless steel and to be mapped to [0, 1] area, converted into approximate optimal whitening grey measures value $\overline{\otimes}'_{ji}$, then m kinds of women's socks and n d approximate optimal composite grey element was referred to as $\overline{\otimes}'R_{m\times n}$, thus there are,

$$\overline{\otimes}'R_{m\times n}=\begin{array}{c|c} & \begin{matrix} F_1 & F_2 & \cdots & F_m \end{matrix} \\ \begin{matrix} C_1 \\ C_2 \\ \vdots \\ C_n \end{matrix} & \begin{bmatrix} \overline{\otimes}'_{11} & \overline{\otimes}'_{21} & \cdots & \overline{\otimes}'_{m1} \\ \overline{\otimes}'_{12} & \overline{\otimes}'_{22} & \cdots & \overline{\otimes}'_{m2} \\ \vdots & \vdots & \vdots & \vdots \\ \overline{\otimes}'_{1n} & \overline{\otimes}'_{2n} & \cdots & \overline{\otimes}'_{mn} \end{bmatrix} \end{array} \tag{2}$$

In equation (2) $\overline{\otimes}'_{ji}\ (j=1,2,\cdots,m; i=1,2,\cdots,n)$ expressed the approximate optimal whitening grey measures value of the i_{th} index of the j_{th} kind of women's sock. And its determination method could be processed according to the following method, namely,

①The bigger index that is better

$$\overline{\otimes}'_{ji}=\overline{\otimes}_{ji}/\max\{\overline{\otimes}_{ji},u_{\max}\} \tag{3}$$

②The smaller index that is better

$$\overline{\otimes}'_{ji}=\min\{\overline{\otimes}_{ji},u_{\min}\}/\overline{\otimes}_{ji} \tag{4}$$

③The moderate index that is better

$$\overline{\otimes}'_{ji} = \min\{\overline{\otimes}_{ji}, u_0\} / \max\{\overline{\otimes}_{ji}, u_0\} \tag{5}$$

In equations, $\max\overline{\otimes}_{ji} = \max\{\overline{\otimes}_{j1}, \overline{\otimes}_{j2}, \cdots, \overline{\otimes}_{ji}\}$, $\min\overline{\otimes}_{ji} = \min\{\overline{\otimes}_{j1}, \overline{\otimes}_{j2}, \cdots, \overline{\otimes}_{ji}\}$, $u_{\max}$ was the specified larger value, $u_{\min}$ was the specified smaller value, u_0 was the specified moderate value.

3.5.2 The solve and sorting of approximate optimal degree

The approximate optimal whitening grey measures value in equation (2) was a decentralized approximate optimal comparison, which couldn't be used to compare women's socks on the whole. Therefore, we could convert the approximate optimal whitening grey measures value into approximate optimal degree, it referred to the metrics that was used to measure the approaching degree between all kinds of women's socks and comparison standards. s_j was selected to express the approximate optimal degree of the j_{th} kind of women's sock. Thereby, the approximate optimal whitening grey measures value was processed and converted into approximate optimal degree composite grey element $\overline{\otimes}R_s$, there was,

$$\overline{\otimes}R_s = S_j \begin{array}{c} \begin{array}{cccc} F_1 & F_2 & \cdots & F_m \end{array} \\ [S_1 \quad S_2 \quad \cdots \quad S_m] \end{array} = S_j \begin{array}{c} \begin{array}{cccc} F_1 & F_2 & \cdots & F_m \end{array} \\ \left[1/n\sum_{i=1}^{n}\overline{\otimes}'_{i1} \quad 1/n\sum_{i=1}^{n}\overline{\otimes}'_{i2} \quad \cdots \quad 1/n\sum_{i=1}^{n}\overline{\otimes}'_{im}\right] \end{array} \tag{6}$$

Sorting the approximate optimal degree of all kinds of women's socks calculated according to equation (6), and the rank of the women's socks could be determined. The approximate optimal degree of women's sock was more close to 1, indicating that the thermal-wet comfort of the women's sock was better.

3.5.3 Approximate optimal decision and discussion

In the case of the 5 kinds of women's socks in this research, the 4 indexes corresponding with the thermal-wet comfort of women's socks was used to establish the composite grey element that contained 5 kinds of women's socks and 4 indexes, namely,

$$\overline{\otimes}R_{5\times4} = \begin{array}{r} \\ \text{Thermal conductivity} \\ \text{Air permeability} \\ \text{Moisture permeability} \\ \text{Moisture absorption performance} \end{array} \begin{array}{c} \begin{array}{ccccc} F_1 & F_2 & F_3 & F_4 & F_5 \end{array} \\ \begin{bmatrix} 13.05 & 16.98 & 14.23 & 20.89 & 16.66 \\ 1986 & 1867 & 1715 & 2019 & 3413 \\ 7284.92 & 6875.58 & 6345.93 & 6311.68 & 7501.66 \\ 4.31 & 3.78 & 3.59 & 2.48 & 4.99 \end{bmatrix} \end{array} \tag{7}$$

The approximate optimal composite grey element $\overline{\otimes}'R_{5\times4}$ was obtained by using approximate optimal conversion to process equation (7) in accordance with equations (3)~(5).

$$\overline{\otimes}'R_{5\times4} = \begin{array}{r} \\ \text{Thermal conductivity} \\ \text{Air permeability} \\ \text{Moisture permeability} \\ \text{Moisture absorption performance} \end{array} \begin{array}{c} \begin{array}{ccccc} F_1 & F_2 & F_3 & F_4 & F_5 \end{array} \\ \begin{bmatrix} 1 & 0.7686 & 0.9171 & 0.6247 & 0.7833 \\ 0.5819 & 0.547 & 0.5025 & 0.5916 & 1 \\ 0.9711 & 0.9165 & 0.8459 & 0.8414 & 1 \\ 0.8618 & 0.7563 & 0.7188 & 0.4962 & 1 \end{bmatrix} \end{array} \tag{8}$$

The approximate optimal degree was calculated in accordance with equation (6),

$$\overline{\otimes}R_s = S_j \begin{array}{c} \begin{array}{ccccc} F_1 & F_2 & F_3 & F_4 & F_5 \end{array} \\ [0.8537 \quad 0.7471 \quad 0.7461 \quad 0.6385 \quad 0.9458] \end{array} \tag{9}$$

Namely, $S_5 > S_1 > S_2 > S_3 > S_4$

There is, $F_5 > F_1 > F_2 > F_3 > F_4$

It could be seen from the evaluation results that the comprehensive evaluation of the thermal-wet comfort of 5# women's sock was the best in the experiment. And the sorting of the thermal-wet comfort of women's socks from priority to inferiority was 5# >1# >2# >3# >4#.

4. Conclusions

Approximate optimal comprehensive judgment method was used to solve the evaluation problem of the thermal-wet comfort of women's sock, and the thermal-wet comfort of women's sock from priority to inferiority was ranked, which gave a theory basis to the comprehensive evaluation of the thermal-wet comfort of women's sock. The research results pointed out that the thermal-wet comfort of women's sock which contained higher proportion of bamboo fiber and cotton fiber was better. And the research results could provide a certain theoretical guidance for the production and manufacture of women's sock and the choice of goods.

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