Performance Test of Clothing Materials and the Prediction Model of Clothing Thermal-Wet Comfort

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Abstract: This research focuses on the performance test of clothing materials and analyzes the relationship between the performances of knitting fabric and clothing comfort. In the field of clothing thermal-wet comfort studying, this paper is proposed that "Fiber - Yarn - Fabrics - Clothing" can be made as the research system for the first time. According to the experiments, it analyzes that these three variables— "fibers", “yarn properties” and “fabric performance”— influence clothing thermal-wet comfort. The testing includes basic performance, style, comfort and clothing comfort. By methods of math-statistics, it has set up a prediction model of clothing thermal-wet comfort.

Keywords: Clothing Materials, Thermal-wet Comfort, Fibers, Yarn Properties, Fabric Performance, Manikin

1. Introduction
Clothing materials play a significant role to contribute to clothing comfort. Performance and feature of fiber is the key factor, which affects fabric and clothing’s appreciation of the beauty, physiology comfort, wear durableness and maintenance performance. The feature of knitting fabric depends on these aspects, such as the categories of fiber raw material composed to it, yarn, fabric organization structure, and after processing technology. It should select knitting fabric corresponding and according to the performance requirement in terms of wearing purposes and functional requirement. The measure of comfort is the comprehensive balance of biothermodynamics among human, clothing and circumstance. And this balance mainly includes satisfactory thermal equilibrium and moisture equilibrium, as a result of integrated coordinat- ing with situation of surroundings, activity level of hu- man body and property of clothing.

This essay proposes a research system, which is “fib- ers-yarn-fabric-clothing” and can analysis lengthways the relationship between systems, and find out the relev- ance about yarn properties and fabric performance influencing clothing thermal-wet comfort.

2. Experiment
2.1. Experimental arrangement and introduction to specimen
There are 12 fabric specimens in these three groups (fab- ric specimens ID 1～12), and yarn specimens corre- sponding to the fabric ones(yarn specimens ID a～e). Fabric parameter design divides the experiment specimen into three groups according to three variables: fiber raw material, fineness of yarn and fabric organization structure. With the clothing parameter design, both the cloth- ing style structure design and clothing size are consistent, and the whole design unify male knit T shirt with long sleeve (clothing specimens ID 1～12 ). Subject and intro- duction to fabric specimens are shown in below table 1.

2.2. Experiment testing
The testing includes basic performance, styles, fabric comfort and clothing comfort test. Fabric comfort test: heat preservation test by flat fabric heat retention tester, water vapour transmission test by M261 revolving cup water vapor transmission tester, thermal insulation and evaporative resistance test, which is tested by self-designed instrument, called clothing thermal-wet comfort tester, air permeability test by gurley permeameter, and performance of stickiness to skin, which is tested by self-designed fabric stickiness tester. And clothing comfort test, which is tested by Walter, through testing the thermal insulation and evaporative resistance, and can figure out Water vapour permeability index, as the index to evaluate clothing thermal-wet comfort (Water vapour permeability index, im, as the evaluation index of measuring whether the clothing is comfortable or not in thermal environment). In the testing, manikin is worn T shirt specimens on upper body and the same sport pants, when the microclimate between skin and clothing regard as iden tical, therefore, this factor of influence is constant. In the situation of experiment 20 (±1)˚C and 65(±5)%RH, skin temperature is controlled constantly at 35˚C, and it takes the mean value of three independent test results of thermal insulation and mois- ture resistance as the final outcome.

2.3. Experiment result and analysis
By means of the method of one-way ANOVA, it can be gained that fiber raw material is of great influence in
clothing thermal insulation and exerts little influence on moisture resistance; So is fineness of yarn; Fabric organization structure exerts little influence on both clothing thermal insulation and moisture resistance. It illustrates there is a notable difference among these diverse fabric of fiber raw material selected in this essay; similarly, the selection of fineness of yarn is reasonable, and specimens differ markedly; but there no significant difference among fabrics with diverse fabric organization structure.

Table 1. Subject & Introduction to fabric specimens

<table>
<thead>
<tr>
<th>Subject fiber raw material</th>
<th>fineness of yarn</th>
<th>fabric organization structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specimens ID</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Fabric content</td>
<td>100% cotton</td>
<td>95% cotton 5% spandex</td>
</tr>
<tr>
<td>Fineness of yarn</td>
<td>14.6tex</td>
<td>14.6tex</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>0.823</td>
<td>1.024</td>
</tr>
<tr>
<td>Density h/z (cycles/100cm²)</td>
<td>154×218.5</td>
<td>189.5×255</td>
</tr>
<tr>
<td>Loop length (cm)</td>
<td>0.256</td>
<td>0.2914</td>
</tr>
<tr>
<td>Weight per square meter (g/m²)</td>
<td>109.84</td>
<td>183.76</td>
</tr>
<tr>
<td>Yarn specimens ID</td>
<td>a</td>
<td>a</td>
</tr>
<tr>
<td>Corresponding yarn specimen</td>
<td>14.6tex Combed Cotton</td>
<td>14.6tex Combed Cotton</td>
</tr>
</tbody>
</table>

2. To establish the prediction model of clothing thermal-wet comfort of yarn-fabric-clothing system [12, 13]

2.1. To analyze the yarn property and get the prediction model of yarn

To analyze four properties of these five yarns by principal component analysis method, with 9 indexes. Based on factor analysis, by method of calculating the weighted total score, it can be gained the prediction model of yarn:

$$S_{yarn} = \sum W_{fi} S_{fi}$$

Where, $S_{yarn}$ is clothing thermal-wet comfort of yarn, $W_{fi}$ is the contributing rate of factor, $S_{fi}$ is factor. On the basis of the situation of Rotation Sums of Squared Loadings, contribution of variance is substituted into:

$$S_{yarn} = 42.301\% \times \text{yarn primary factor} + 28.343\% \times \text{yarn primary factor 2} + 25.125\% \times \text{yarn primary factor 3}$$

$$= 0.39744 \times \text{mean twist} + 0.38367 \times \text{sliver unevenness} - 0.35998 \times \text{actual fineness} + 0.353636 \times \text{nubs number} + 0.305836 \times \text{coefficient of twist} + 0.273227 \times \text{hairiness index} - 0.24885 \times \text{twist CVRI} + 0.24924 \times \text{fine end} + 0.248738 \times \text{nepi number}$$
2.2. To analyze the physical performance and fabric appearance and to get the prediction model of fabric

To analyze five properties of these twelve fabrics by principal component analysis method, 18 indexes in all. On the basis of the situation of Rotation Sums of Squared Loadings, it can be got calculation formula of principal variables. After simplifying, contribution of principal variables is analyzed:

\[
S_\text{surface} = 31.358\% \times \text{appearance properties primary factor 1} \\
+ 23.656\% \times \text{appearance properties primary factor 2} \\
+ 14.782\% \times \text{appearance properties primary factor 3} \\
\] (4)

\[
\times (0.898 \times \text{hysteretic force } 5^\circ + 0.891 \times \text{shearing rigidity } + 0.822 \times \text{specific compression work } - 0.796 \times \text{compress thickness } + 0.714 \times \text{drape coefficient } + 0.606 \times \text{friction coefficient mean deviation } - 0.578 \times \text{dynamical friction mean coefficient } + 0.538 \times \text{surface roughness}) + \\
23.656\% \times (0.851 \times \text{bending stiffness } - 0.816 \times \text{lengthways number of stitches } - 0.807 \times \text{crosswise Loop course } + 0.774 \times \text{hysteretic moment}) + \\
14.782\% \times (0.938 \times \text{gram weight per unit area } + 0.816 \times \text{apparent thickness } + 0.667 \times \text{steady thickness}) \\
\] (5)

2.3. To analyze comfort ability of fabric and clothing and to get the prediction model of fabric comfort

To analyze seven properties of these twelve fabrics by principal component analysis method, 12 indexes in all. In a similar way, we can get the prediction model of fabric comfort:

\[
S_\text{comfort} = 32.216\% \times \text{comfort primary factor 1} \\
+ 27.124\% \times \text{comfort primary factor 2} \\
+ 15.030\% \times \text{comfort primary factor 3} \\
+ 11.374\% \times \text{comfort primary factor 4} \\
= 32.216\% \times (0.973 \times \text{vapour transmission } + 0.973 \times \text{moisture transmission } + 0.782 \times \text{coefficient of heat transfer } - 0.755 \times \text{preservation rate}) + 27.124\% \times (0.948 \times \text{horizontal stickiness force per unit gram weight } + 0.866 \times \text{thermal insulation of clothing } + 0.741 \times \text{permeability rating of air } - 0.755 \times \text{hymetric force } 5^\circ + 0.938 \times \text{gram weight per unit area } + 0.816 \times \text{apparent thickness } + 0.667 \times \text{steady thickness}) \\
\] (6)

\[
\times (\text{predicted value of yarn property section } - \text{predicted value of fabric appearance section } + \text{Predicted value of fabric and clothing comfort section}) \\
\] (7)

3. To build model making use of regression analysis [13]

In terms of the primary - composition analysis calculation formula, the calculated value of primary factor of yarn-fabric-clothing system can be gat, and clothing thermal-wet comfort value of yarn property section, fabric appearance section and comfort ability section can be figure out. This essay made “Water vapour permeability index” tested by Thermal manikin method and calculated as the index for evaluating clothing comfort, and the water vapour permeability index of every kind of clothing specimen wearing can be shown in table 4, where Y (Water vapour permeability index of clothing), X1 (Predicted value of yarn property section), X2 (Predicted value of fabric appearance section), X3 (Predicted value of fabric and clothing comfort section) indicate signs in the regression equation.

<table>
<thead>
<tr>
<th>Table 2. Coefficientsa</th>
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<tbody>
<tr>
<td><strong>Model</strong></td>
</tr>
<tr>
<td><strong>B</strong></td>
</tr>
<tr>
<td>(Constant)</td>
</tr>
<tr>
<td>X1</td>
</tr>
<tr>
<td>X2</td>
</tr>
<tr>
<td>X3</td>
</tr>
</tbody>
</table>

a. Dependent Variable: Y

3.1 To build regression equation

Regression equation is built by analyzing:

\[
Y=0.002 \times X1 - 0.003 \times X2 + 0.0011 \times X3 - 0.441 \\
\] (8)

It means:

\[
\text{Clothing thermal-wet comfort} = 0.002 \times \text{S}_\text{yarn} - 0.003 \times \text{S}_\text{surface} + 0.0011 \times \text{S}_\text{comfort} - 0.441 \\
[ R=0.992, R_{adj} = 0.968 ] \\
\] (9)

It means: Clothing thermal-wet comfort=0.002×(predicted value of yarn property section) -0.003×(predicted value of fabric appearance section) +0.0011×(Predicted value of fabric and clothing comfort section) -0.441 (constant)

Factors of every section are substituted into equation (9), and equation (3), (5), (7) also are substituted into equation (9). After simplifying the form of this equation by calculating, the same coefficients are combined, and the final prediction model equation can be got:

\[
Y=0.8 \times (\text{mean twist } + \text{silverunevenness } - \text{hysteretic force } 5^\circ \times \text{shearing rigidity } - \text{hysteretic force } 0.5^\circ \times \text{specific compression work } + 0.7 \times (\text{-actual fineness } + \text{nubs number } + \text{compress thickness } - \text{drape coefficient}) \\
\]
+0.6×(coefficient of twist - dynamical friction mean coefficient -bending stiffness+ lengthways number of stitches + crosswise Loop course - hysteretic moment) +0.5×(hairiness index - rate of twist irregularity + fine end + nep number + dynamical friction mean coefficient - surface roughness) +0.4×(-gram weight per unit area - apparent thickness) +0.3(-steady thickness + moisture transmission + vapour transmission + coefficient of heat transfer - heat preservation rate + horizontal stickiness force per unit gram weight + thermal insulation of clothing) +0.2×(permeability rating of air + moisture vapor resistance of clothing) +0.1×(moisture vapor resistance of fabric + moisture regain) \times 10^{-3} - 0.441
\[ R=0.992, \ R_{adj} = 0.968 \]

(10)

3.2 To test the regression model

The score and sort predicted and calculated by this model of total clothing thermal-wet comfort is: 1 > 6 > 12 > 10 > 9 > 2 > 11 > 4 > 3 > 5. This sort is comprehensive forecast result of total clothing thermal-wet comfort according with yarn-fabric-clothing system, showing a sort order from low to high principle of comfort. Note: No.1 and No.7 fabrics are same, so comfort property of them is shown the very same value; fabric content, fineness of yarn and fabric organization structure of No.6 and No.8 fabrics are same, except color, so comfort property of them is similar, therefore, No.7 and No.8 fabrics are not in the sort order.

This result of the sort corresponded to the marketing survey results of knitted underwear and underlines: products made of 14.6tex 100% cotton plain knit fabric are excellent, because soft and flexibility, air permeability and glossiness of them are: preferably, moreover, no pilling and fluffing after washing, no broken wires and wire drawing for extended wear.

4. Conclusions

The prediction model of clothing thermal-wet comfort of “yarn-fabric-clothing system” is established using principal component analysis and regression analysis method. Step 1: To find out the main influencing factors affecting clothing thermal-wet comfort from these various factors which are yarn property, the physical performance, fabric appearance and comfort ability of fabric and clothing, using principal component analysis method. On the basis of factors pick-up from data, the prediction models of yarn, fabric appearance and fabric comfort section are respectively built up. Step 2: The water vapour permeability indexes tested by thermal manikin and calculated are used as evaluation indexes of clothing thermal-wet comfort; and predicted values are calculated by prediction models of all the sections. Both of them are analyzed by linear regression analysis method, and total forecasting regression model can be set up. The results of scores of total clothing thermal-wet comfort calculated by this model corresponded to the marketing survey results of knitted underwear and underlines; consequently, it has certain practicability and applicability.

References