Thermal Comfort Properties of Compact and Ring Yarn Woven Fabrics

Najwa Ali Abu Nassif

Fashion Design Department, Design and Art College, King Abdul Aziz University, Jeddah, Saudi Arabia

Abstract: This study focuses on a comparison between ring and compact yarn fabrics in relation to their thermal comfort properties. The effect of spinning technique, twist factor and yarn count on thermal comfort properties were studied. The air permeability, thermal conductivity and thermal resistance are the most parameters concerning thermal comfort that have been investigated in this study. It was noticed that there is a remarkable difference between compact and ring yarn fabrics with respect to their thermal comfort parameters. Also it was revealed that yarn count and twist factors have a remarkable influence on thermal comfort properties.

Keywords: Ring spinning, compact spinning, fabric properties, thermal comfort, air permeability, thermal conductivity.

1. INTRODUCTION

Good comfort, handle, low cost and high quality are what the mankind needs when wearing clothes. Choosing appropriate clothing to wear requires other parameters than handling, touching and seeing, what the textile experts called fabric comfort [1]. One of the most significant factors affecting the knitted or woven fabrics performance is their comfort. It can be divided into physiological and psychological comfort, which lie in fabric warmness, roughness, coolness movement facility and breath ability [2, 3].

Numerous research studies were conducted to investigate performance, handle and comfort of woven and knitted fabrics [4-16]. Thermal comfort characteristics of single jersey blended fabrics knitted from cotton and bamboo fibers was investigated. The findings of this study revealed that the blended fabrics’ thermal conductivity was reduced with the bamboo fiber content. It was also found that water vapor and air permeability have increased with the increase in bamboo fiber content [5, 7]. As a possible material for a ballistic vest, Kevlar/wool woven blended fabrics’ thermal comfort was examined. Compared to Kevlar fabrics only, this study showed that the blended fabrics woven from Kevlar and wool fibers have better moisture management properties [8].

For ready made garment, as one of the most important parameters which reflects the thermal comfort, the air permeability was investigated in the case of fabrics woven from combed wool yarns. The findings of this study revealed that yarn fineness and weave structure type are the main parameters influencing woven fabric air permeability [9].

The influence of polyester fabrics weave pattern and the cross sectional shape of their fibers on thermal comfort was studied [10]. The hollow, round and trilobal cross sectional shapes of polyester fibers along with plain and twill weaves and their impact on thermal comfort were examined. It was found that fabrics woven from hollow polyester fibers exhibited lower thermal resistance, lower air permeability, higher thermal conductivity and absorption compared to the other polyester fibers. Also, it was noticed that the lowest thermal conductivity and absorption were associated with twill fabrics woven from trilobal fiber shape has

Cotton/khadi and cotton/polyester khadi blended knitted fabrics were compared regarding their mechanical and comfort properties. Cotton/khadi knitted fabrics were found to be more comfortable then cotton/polyester/khadi knitted fabrics. The polyester fibers in the blended fabrics enhanced their tensile and bursting strength [12].

Since various researches [4, 11, 13-16] worked on the comparison between compact and ring spinning techniques in relation to mechanical and physical properties of their spun yarns and woven fabrics; this research study focuses on a comparison among thermal comfort characteristics of the fabrics woven from the both. The effects of spinning method twist factor and weave structure on the thermal comfort properties of woven fabrics were studied.
2. MATERIALS AND METHODS

Throughout this study, twelve woven cotton fabrics were investigated. The half of them was produced from compact spun yarns and the left were woven from ring spun yarns. All fabric samples differ in their weft yarn linear density and their twist factors. The warp yarns count and density, weft density and warp yarn twist factor were remained constant for all types of fabrics. All fabric samples were woven with a twill 2/2 weave structure with the following characteristics:

- Warp yarn count: 50 Ne,
- Warp yarn density: 74 ends/inch,
- Warp yarn twist factor: 4,
- Weft yarn count: 40 Ne, 50 Ne and 60 Ne,
- Weft yarn density: 74 ends/inch,
- Weft yarn twist factor: 3.8, and 4.1,
- Fabric width: 165 cm,
- No. of harness frame: 4,
- Weaving machine: Rapier weaving machine with model --
- Running speed of the weaving machine: 470 ppm.

Before measuring, all fabrics samples were left in the standard atmosphere, i.e. 20 °C±2 temperature and 65%±2 relative humidity all full day long. Each property was measured ten times and the average value of each was calculated.

TEXTEST FX 3300 air permeability tester was used to measure air permeability of compact and ring yarn fabrics according to ASTM D737 [17]. Thermal conductivity and resistance of the woven fabrics under study were measured using Alambeta instrument in accordance with ISO 11092 [18].

3. STATISTICAL ANALYSIS

To disclose the influences of independent variables, namely spinning method, twist factor and weave structure on woven fabrics’ thermal comfort properties, a 2 × 3 ×3 mixed factorial design was implemented. This factorial design was analyzed using Analysis of Variance (ANOV) at significance level 0.05 ≤ α ≤ 0.01. Also, the contribution of each independent variable in the effect on thermal comfort characteristics was determined.

A regression analysis was also used to deduce a multiple linear regression models which correlate both of weft yarn count and twist factor with woven fabrics’ thermal comfort. The regression relationships have the following linear model:

\[ Z = a + b \times X + c \times Y \]

Where,

\[ Z \] thermal comfort characteristics, namely, air permeability, thermal conductivity or thermal resistance.

\[ X \] = weft yarn count (Ne),

\[ Y \] = weft yarn twist factor,

\[ a \] = constant, and,

\[ b \] and \[ c \] = regression coefficients.

4. RESULTS AND DISCUSSION

4.1. Effects on Thermal Resistance

From the thermal insulation view point, thermal resistance is considered an important aspect and it is related to fabric type and structure. For the space of body insulated by the woven fabric, the higher is the thermal insulation; the lower is the heat loss. The values of thermal resistance of ring and compact spun yarn fabrics versus weft yarn count and weft yarn twist factor were depicted in figures 1 and 2 respectively. The results of ANOVA are listed in tables 1 and 2.
It was noticed that weft yarn count and twist factor have a significant impact on thermal resistance of compact and yarn fabrics at 0.05 significance level. From figures 1 and 2, it can be observed that as the both variables levels increases, the thermal resistance decreases. That is the effects of both variables have the same trend on thermal resistance for compact and ring yarn woven fabrics.

Table 1: ANOV Results of the Effects of Yarn Count and Twist Factor of Weft Yarn on Thermal Resistance of Ring Yarn Fabric

<table>
<thead>
<tr>
<th>Source - Variation</th>
<th>Sum-square</th>
<th>Degree-freedom</th>
<th>Mean-squares</th>
<th>Calculate-F</th>
<th>Significance level</th>
<th>Critical-F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twist factor</td>
<td>600</td>
<td>1</td>
<td>600</td>
<td>24.4898</td>
<td>0.038491</td>
<td>18.51276</td>
</tr>
<tr>
<td>Yarn count</td>
<td>1123</td>
<td>2</td>
<td>561.5</td>
<td>22.91837</td>
<td>0.041809</td>
<td>19.0000</td>
</tr>
<tr>
<td>Error</td>
<td>49</td>
<td>2</td>
<td>24.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1772</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: ANOV Results of the Effects of Yarn Count and Twist Factor of Weft Yarn on Thermal Resistance of Compact Yarn Fabric

<table>
<thead>
<tr>
<th>Source - Variation</th>
<th>Sum-square</th>
<th>Degree-freedom</th>
<th>Mean-squares</th>
<th>Calculate-F</th>
<th>Significance level</th>
<th>Critical-F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twist factor</td>
<td>352.6667</td>
<td>1</td>
<td>352.6667</td>
<td>34.68852</td>
<td>0.027638</td>
<td>18.51276</td>
</tr>
<tr>
<td>Yarn count</td>
<td>1430.333</td>
<td>2</td>
<td>715.1667</td>
<td>70.34426</td>
<td>0.014017</td>
<td>19.0000</td>
</tr>
<tr>
<td>Error</td>
<td>20.33333</td>
<td>2</td>
<td>10.16667</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1803.333</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It was noticed that weft yarn count and twist factor have a significant impact on thermal resistance of compact and yarn fabrics at 0.05 significance level. From figures 1 and 2, it can be observed that as the both variables levels increases, the thermal resistance decreases. That is the effects of both variables have the same trend on thermal resistance for compact and ring yarn woven fabrics.

In general, ring yarn fabrics exhibited higher thermal resistance than compact yarn fabrics. This means that compact yarn fabrics give a feeling of coldness greater than their corresponding made from ring spun yarns. This is because the yarn hairiness and fabric bulkiness associated with ring yarn fabrics are higher than compact fabrics. It was also determined that increasing the weft yarn count from 40 Ne to 60 Ne results in a reduction in the thermal resistance by about 26% and 37 % for ring and compact yarn fabrics respectively. While increasing the weft yarn twist factor reduced the thermal resistance of both fabrics by approximately 16%.

The linear regression models which correlate thermal resistance of both fabrics with twist factor and yarn count have the following linear forms:

Thermal resistance ( m²K/W ) --- ring fabric = 456.0833-1.675*X -66.6667*Y

Thermal resistance ( m²K/W ) --- compact fabric = 378.3056-1.875*X-51.1111*Y

Figure 2: Response surface of the effects of filling yarn count and twist factor on thermal resistance of compact yarn fabrics.

The weft yarn count was found to have a more pronounced influence on thermal resistance than the twist factor. Also the effects on thermal resistance are more pronounced in compact spinning than in the case of ring spinning. It was proved that the weft yarn count accounted for 60% and 78% of the effects on thermal resistance for ring and yarn fabrics respectively, while twist factor accounted for 32% and 18% for ring and yarn fabrics respectively.
The $R^2$ values of these models were 0.98 and 0.97 for both types of woven fabrics.

### 4.2. Effects on Thermal Conductivity

The woven fabric competence to conduct heat, via a radiation or convection, from skin to surrounding atmosphere is called the thermal conductivity. It is one of the intrinsic aspects of fabric’s thermal comfort. This property can be calculated as the energy per unit area divided by the product of unit time and the temperature gradient.

![Figure 3](image1.png)  
**Figure 3:** Response surface of the effects of filling yarn count and twist factor on thermal conductivity of ring yarn fabrics.

![Figure 4](image2.png)  
**Figure 4:** Response surface of the effects of filling yarn count and twist factor on thermal conductivity of compact yarn fabrics.

From these figures, it can be observed that both variables have a positive influence on thermal conductivity. The values of thermal conductivity against twist factor and count of weft yarns for ring and compact yarn fabrics are plotted in figures 3 and 4. As shown in Tables 3 and 4, the statistical analysis proved that weft yarn count and twist factor have a significant impact on thermal conductivity of both types of fabrics at 0.05 significance level.

### Table 3: ANOV Results of the Effects of Yarn Count and Twist Factor of Weft Yarn on Thermal Conductivity of Ring Yarn Fabric

<table>
<thead>
<tr>
<th>Source - Variation</th>
<th>Sum-square</th>
<th>Degree-freedom</th>
<th>Mean-squares</th>
<th>Calculate-F</th>
<th>Significance level</th>
<th>Critical-F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twist factor</td>
<td>0.72865</td>
<td>1</td>
<td>0.72865</td>
<td>34.8255</td>
<td>0.02753</td>
<td>18.5127</td>
</tr>
<tr>
<td>Yarn count</td>
<td>2.6002</td>
<td>2</td>
<td>1.30001</td>
<td>62.1336</td>
<td>0.01583</td>
<td>19.0000</td>
</tr>
<tr>
<td>Error</td>
<td>0.04184</td>
<td>2</td>
<td>0.02092</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3.37052</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 4: ANOV Results of the Effects of Yarn Count and Twist Factor of Weft Yarn on Thermal Conductivity of Compact Yarn Fabric

<table>
<thead>
<tr>
<th>Source - Variation</th>
<th>Sum-square</th>
<th>Degree-freedom</th>
<th>Mean-squares</th>
<th>Calculate-F</th>
<th>Significance level</th>
<th>Critical-F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twist factor</td>
<td>2.04166</td>
<td>1</td>
<td>2.04166</td>
<td>39.5161</td>
<td>0.02438</td>
<td>18.5127</td>
</tr>
<tr>
<td>Yarn count</td>
<td>3.61</td>
<td>2</td>
<td>1.805</td>
<td>34.9354</td>
<td>0.02782</td>
<td>19.0000</td>
</tr>
<tr>
<td>Error</td>
<td>0.10333</td>
<td>2</td>
<td>0.05166</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5.755</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
conductivity of both woven fabrics. As the weft yarn count increases, the thermal conductivity of ring and compact yarn fabrics has the same trend. Also, as the weft yarn twist factor increases the thermal conductivity reacts in the same manner. It was evaluated that weft yarn count accounted for 75% and 60% of the effects on thermal conductivity for both ring and compact yarn fabrics respectively. It was also found that twist factor accounted for 21% and 34% of the effects on thermal conductivity for ring and compact yarn fabrics respectively.

The statistical analysis proved that increasing twist factor of filling yarn leads to an increase in the ring and compact yarn fabrics thermal conductivity by 17% and 24% respectively. Whereas in the case of the effect of weft yarn count it was found that increasing from 40 Ne to 60 Ne leads to an increase in the thermal conductivity by approximately.

The regression models which correlate thermal conductivity of ring and compact yarn fabrics with both weft yarn count and its twist factor have the following linear models:

Thermal conductivity (W m⁻¹K⁻¹) --- ring fabric = -8.7806 + 0.0798 * X + 2.3232 * Y
Thermal conductivity W m⁻¹K⁻¹ --- compact fabric = -15.0541 + 0.0939 * X + 3.9779 * Y

The \( R^2 \) values of these models were 0.98 for both types of woven fabrics.

**4.3. Effects on Air Permeability**

Air permeability is often used to evaluate and compare the breathability of woven fabrics for different end uses, for instance uniforms, shirtings, raincoats, --- etc. The values of ring and compact woven fabrics air permeability versus their weft yarn counts and twist factors are plotted in figures 5 and 6 respectively. The

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Source - Variation</th>
<th>Sum-square</th>
<th>Degree-freedom</th>
<th>Mean-squares</th>
<th>Calculate-F</th>
<th>Significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twist factor</td>
<td>11266.67</td>
<td>1</td>
<td>11266.67</td>
<td>21.8045</td>
<td>0.042927</td>
<td>18.51276</td>
</tr>
<tr>
<td>Yarn count</td>
<td>105833.3</td>
<td>2</td>
<td>52916.67</td>
<td>102.4194</td>
<td>0.009669</td>
<td>19.00003</td>
</tr>
<tr>
<td>Error</td>
<td>1033.333</td>
<td>2</td>
<td>516.6667</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>118133.3</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Source - Variation</th>
<th>Sum-square</th>
<th>Degree-freedom</th>
<th>Mean-squares</th>
<th>Calculate-F</th>
<th>Significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twist factor</td>
<td>21600</td>
<td>1</td>
<td>21600</td>
<td>48</td>
<td>0.020204</td>
<td>18.51276</td>
</tr>
<tr>
<td>Yarn count</td>
<td>109433.3</td>
<td>2</td>
<td>54716.67</td>
<td>121.5926</td>
<td>0.008157</td>
<td>19.00003</td>
</tr>
<tr>
<td>Error</td>
<td>900</td>
<td>2</td>
<td>450</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>131933.3</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
results of the statistical analysis listed in tables 4 and 5 indicated the significance influence of both variables on both types of fabrics’ air permeability at 0.01 significance level.

From these figures, for both types of fabrics, increasing trend can be disclosed confirming that as the levels of twist factor and weft yarn count increases, the air permeability of both fabrics increases.

It was calculated that weft yarn count accounted for 88% and 82% of the effects on air permeability of ring and compact fabrics respectively. It was also noticed that twist factor accounted for 9% and 16% of the effects on air permeability of ring and compact fabrics respectively. An increase of yarn count leads to increasing the air permeability of ring yarn fabrics from 325 to 625 cm³/cm².sec; while in the case of compact yarn fabrics, increasing yarn count increased air permeability by 74%. It was also found that air permeability of ring and compact yarn fabrics was increased by 19% and 21% respectively with the increase in the twist factor.

The regression models which correlate thermal conductivity of ring and compact yarn fabrics with both weft yarn count and its twist factor have the following linear forms:

\[
\text{Air permeability (cm}^3/\text{cm}^2.\text{sec)} - \text{ring fabric} = -1305 + 17.5 \times X + 233.3333 \times Y
\]

\[
\text{Air permeability (cm}^3/\text{cm}^2.\text{sec)} - \text{compact fabric} = 1698.3333 + 20.5 \times X + 333.3333 \times Y
\]

The \( R^2 \) values of these models were 0.99 for both types of woven fabrics.

CONCLUSION

Due to the difference between their compact and ring spun yarns structures, they have different characteristics which reflected in their woven fabrics. Therefore, fabrics woven from both spinning systems differ in their physical, mechanical, and comfort properties.

In this study, thermal comfort characteristics of compact and ring yarns were compared and investigated. The influences of weft yarn count, fabric type and weft yarn twist factor on thermal comfort parameters were examined. The findings of this study can be drawn as follows:

- It was noticed that thermal comfort parameters, namely air permeability, thermal conductivity and resistance were significantly affected by spinning method, weft yarn count and twist factor.

- Thermal resistance of compact and ring yarn fabrics are adversely affected by both weft yarn count and twist factor. As the levels of both variables increases the thermal resistance of both types of fabrics decreases.

- Because of their hairiness and bulkiness, ring yarn fabrics exhibited higher thermal resistance than their corresponding compact yarn fabrics.

- By contrast to thermal resistance, weft yarn count and twist factor have a positive influence on thermal conductivity of both fabrics.

- Due to lower thickness, compact yarn fabrics were more permeable to the air than those made ring spun yarns.

REFERENCES


https://doi.org/10.1177/0040517508099396


https://doi.org/10.1016/j.carbpol.2013.07.047


https://doi.org/10.1177/0040517514512377


https://doi.org/10.1080/00405000.2013.835092

https://doi.org/10.1080/02737169.2014.11885419


https://doi.org/10.1007/BF02908169
