Effect of Stitch Length on Some Properties of Cotton 1 X 1 Rib Knitted Fabrics

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Abstract

For dry relaxed cotton 1 X 1 rib knitted fabrics is investigated experimentally the effect of stitch length on the porosity P(%), the air permeability V(cc/cm²/sec), the thermal retaining property H(%), the bending length L(mm), the breaking strength S(kgf), the elongation E(%), and on the dimensional properties (Uc=CuX lu, Uw=WuX lu, Uo=UcX Uw, Uc/Uw=Cu/Wu and the ratio t/l, where Cu and Wu are the course units/unit fabric length and wale units/unit width, t is the stitch length in cm, r the fabric thickness in cm and l the loop length in cm). Uc is approximately constant and independent of the stitch length. When the stitch length increases, Uw, P(%), V(cc/cm²/sec) and E(%)'s in course, 22.5° and 45° directions increase, and Uc, Uc/Uw, the ratio t/l, H(%), L(mm) and S(kgf) in each direction, and E(%)'s in wale and 67.5° directions decrease.

1. Introduction

Many researchers showed that the dimensional and other properties of plain-jersey fabrics are dependent on the loop length. However, little works had been reported on these properties of 1X1 rib knitted fabrics. Several authors studied on the dimensional properties of 1X1 rib fabrics, that is, of false-twist yarns by Cotton and Bladon[11], of worsted yarns by Kapton et al[2-4] and by Wolfaardt and Knapton[5], and of cotton yarns by Poole and Brown[6] and by the author[7]. Smirfit[8] investigated some physical properties of worsted 1X1 rib fabrics. Nutting and Leaf[9] proposed a generalized geometry of weft knitted fabrics by introducing a term having the yarn diameter. Wolfaardt[10] proposed the fabric tightness of 1X1 rib structure. Postle[11] showed that the thickness of knitted structures is related to the effective diameter of the yarn and to the curvature of the loop. Shanahan and Postle[12] investigated the possibility of jamming in various types of weft knitted structures. Kawabata, Niwa and Kawai[13] proposed the structure models of 1X1 rib fabrics for calculating theoretically the tensile properties of these fabric. Carnaby and Postle[14] studied on the shear properties of wool weft knitted structures.

This paper attempts to investigate the effect of stitch length on the dimensional properties, the porosity, the air permeability, the thermal retaining property, the bending length, and the breaking strength and the elongation of cotton 1X1 rib knitted fabrics.

2. Experimental

2.1 Fabric details

Fabrics were knitted on a 6-feeder, 1128-needle (dial and cylinder combined), 10-in-diameter circular rib knitting machine. The machine speed was set at 32 rev/min, the input tension at 5.0 gf. A combed cotton yarn 30s/1 cotton count (19.7 tex) was knitted into 1X1 rib fabrics with five different stitch lengths. After knitting, the fabrics were laid flat on a smooth surface in the atmosphere for three days.

2.2 Method of measurement

Each fabric was revealed, and the course length was measured 30 times using a course length tester under 5.0 gf. The stitch length (lu) was calculated from the number of cylinder needles and the average course length. The fabric tightness (K) was calculated from the following equation proposed by Wolfaardt[10]:

\[ K = n\sqrt{T/lu} \] .......................... (1)

where n is the number of loops in SKC which is the smallest repeating unit of 1X1 rib structure. Since the same yarn was used in this study, the fabric tightness (K) is in proportion to 1/lu.

Each length of 100 courses and 100 ribs was measured for each fabrics ten times using a vernier caliper with the accuracy of 0.01 mm, and the course units/unit fabric length (Cu) and wale units/unit width (Wu) were calculated from those average lengths. The dimensional parameters of 1X1 rib knitted fabrics were calculated from the following equations proposed by Knapton et al[2-5]:

\[ U_c = C_u \times W_u \times l_u^2 = S_u \times l_u^2 \] ........................ (2)

\[ U_c = C_u \times l_u \] ................................. (3)

\[ U_w = W_u \times l_u \] ................................. (4)
\[ U_C / U_W = C_U / W_U \] ................................. (5)

where \( S_U \) is the fabric density.

The fabric thickness (\( t \)) in cm was measured 15 times under 7 gf/cm\(^2\) pressure, and the ratio \( t/l \) was calculated from the average thickness and the loop length (\( l=lu/2 \)).

The weight per unit fabric area \( W_r(g/cm^2) \) was measured six times using an automatic balance with the accuracy of 1 mg.

The porosity \( P(\%) \) was calculated from the following equation:

\[ P(\%) = (1 - (W_r/l^{1.54}t)) \times 100 \] ................................. (6)

where the fiber density of cotton is 1.54 g/cm\(^3\).

The air permeability \( V(cc/cm^2/sec) \) was measured 15 times using an air permeability tester of Frazier's type.

The thermal retaining property \( H(\%) \) was measured five times using the rate of cooling method and calculated from the following equation:

\[ H(\%) = (1 - (T_b / T_C)) \times 100 \] ................................. (7)

where \( T_b \) and \( T_C \) are the cooling time every 1°C from 80°C to 70°C when the heating body was not covered and was covered by fabrics, respectively.

The bending length \( L(mm) \) for each direction (course, 45° and wale directions) was measured five times using the cantilever method.

The breaking strength \( S(kgf) \) and the elongation \( E(\%) \) for each direction (course, 22.5°, 45°, 67.5° and wale directions) were measured five times using a tensile tester.

3. Results and Discussion

3.1 Dimensional properties

Although the results were not shown here, \( U_C \), \( U_W \), \( S_U \) and \( C_U/W_U \) decrease with the increase of stitch length (\( l_u \)). \( C_U \), \( U_W \) and \( S_U \) are linearly related to \( 1/l_u \) and \( 1/l^2_u \), respectively. The fabric thickness (\( t \)) is approximately constant and independent of the stitch length (\( t=0.70 \) mm, \( CV=1.39\% \)). The weight per unit fabric area \( W_r(g/cm^2) \) for 1X1 rib knitted fabrics increases linearly with the decrease of stitch length. Munden\(^{[15]} \) showed that the weight per unit fabric area \( W_F(g/cm^2) \) for plain-jersey fabrics is given by the following equation:

\[ W_F(g/cm^2) = N \times l \times w = K_s \times w/l \] ................................. (8)

where \( N \) is the stitch density/cm\(^2\), \( l \) the loop length in cm, \( w \) the weight in g of 1 cm of yarn and \( K_s \) the product of \( N \) and the square of \( l \). Applying this equation for plain-jersey fabrics to 1X1 rib knitted fabrics, the following equation is obtained:

\[ W_r(g/cm^2) = S_U \times l_u \times w = U_S \times w/l_u \] ................................. (9)

If \( U_S \) and \( w \) are approximately constants, it is clear from eq.(9) that \( W_r \) is in proportion to \( 1/l_u \).

The stitch length (\( l_u \)), the dimensional parameters \( (U_S, U_C, U_W \text{ and } U_C/U_W) \) and the ratio \( t/l \) are shown in Table 1.

The stitch length \( (l_u) \), the dimensional parameters \( (U_S, U_C, U_W \text{ and } U_C/U_W) \) and the ratio \( t/l \) are shown in Table 1.

\[ U_S \text{ is approximately constant and independent of the stitch length (} U_S=53.4, CV=0.68\%. \text{ When the stitch length increases, } U_C \text{ and } U_C/U_W \text{ decrease and } U_W \text{ increases.} \]

Table 1 Relation between \( U \)-values and \( t/l \), and the stitch length (\( l_u \))

<table>
<thead>
<tr>
<th>( l_u(cm) )</th>
<th>( U_C )</th>
<th>( U_W )</th>
<th>( U_S )</th>
<th>( U_C/U_W )</th>
<th>( t/l )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.423</td>
<td>8.31</td>
<td>6.42</td>
<td>53.4</td>
<td>1.30</td>
<td>0.334</td>
</tr>
<tr>
<td>0.463</td>
<td>8.19</td>
<td>6.48</td>
<td>53.1</td>
<td>1.26</td>
<td>0.309</td>
</tr>
<tr>
<td>0.504</td>
<td>7.81</td>
<td>6.79</td>
<td>53.0</td>
<td>1.15</td>
<td>0.281</td>
</tr>
<tr>
<td>0.532</td>
<td>7.67</td>
<td>7.03</td>
<td>53.9</td>
<td>1.09</td>
<td>0.264</td>
</tr>
<tr>
<td>0.564</td>
<td>7.41</td>
<td>7.26</td>
<td>53.8</td>
<td>1.02</td>
<td>0.248</td>
</tr>
</tbody>
</table>

Mean 7.88 6.80 53.4 1.16 0.287
CV % 4.21 4.71 0.68 8.94 10.8

Table 2 A comparison among \( U \)-values for dry relaxed cotton 1X1 rib fabrics

<table>
<thead>
<tr>
<th></th>
<th>( U_C )</th>
<th>( U_W )</th>
<th>( U_S )</th>
<th>( U_C/U_W )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fletcher et al</td>
<td>Mean</td>
<td>8.12</td>
<td>6.13</td>
<td>49.0</td>
</tr>
<tr>
<td>(K=12.2−16.3)</td>
<td>CV %</td>
<td>10.5</td>
<td>14.3</td>
<td>5.58</td>
</tr>
<tr>
<td>Poole et al</td>
<td>Mean</td>
<td>8.20</td>
<td>5.69</td>
<td>46.8</td>
</tr>
<tr>
<td>(K=12.5−18.7)</td>
<td>CV %</td>
<td>7.35</td>
<td>4.25</td>
<td>4.43</td>
</tr>
<tr>
<td>This paper</td>
<td>Mean</td>
<td>7.88</td>
<td>6.80</td>
<td>53.4</td>
</tr>
<tr>
<td>(K=15.7−20.4)</td>
<td>CV %</td>
<td>4.21</td>
<td>4.71</td>
<td>0.68</td>
</tr>
</tbody>
</table>

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A comparison among U-values for dry relaxed cotton 1X1 rib knitted fabrics is shown in Table 2.

The mean values and CV(%) of U-values for dry relaxed 1X1 rib fabrics by Fletcher and Roberts [16], and by Poole and Brown [6] were recalculated in order to facilitate comparison with the values found here. The mean values of $U_c$ and $U_c/U_w$ found here are smaller than those by them, and those of $U_w$ and $U_b$ found here are larger than those by them. This is probably due to the difference in the fabric tightness and the machine gauge.

The ratio $t/l$ increases linearly with the increase of fabric tightness, as in the case of cotton plain-jersey fabrics [17,18] and of cotton 1X1 rib fabrics [17]. Postle [11] showed that the theoretical value of the ratio $t/l$ for 1X1 rib knitted fabrics becomes a constant (=0.288). Although the mean value of the ratio $t/l$ found here is similar to the theoretical value by Postle, the change is very large ($t/l=0.287$, CV=10.8 %).

3.2 Porosity, air permeability and thermal retaining property

The stitch length ($l_u$), the porosity ($P$), the air permeability ($V$) and the thermal retaining property ($H$) are shown in Table 3.

<table>
<thead>
<tr>
<th>$l_u$ (cm)</th>
<th>$P$ (%)</th>
<th>$V$ (cc/cm²/sec)</th>
<th>$H$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.435</td>
<td>78.4</td>
<td>133.8</td>
<td>20.9</td>
</tr>
<tr>
<td>0.463</td>
<td>79.6</td>
<td>162.4</td>
<td>17.2</td>
</tr>
<tr>
<td>0.504</td>
<td>81.0</td>
<td>195.3</td>
<td>15.0</td>
</tr>
<tr>
<td>0.532</td>
<td>81.6</td>
<td>212.0</td>
<td>12.0</td>
</tr>
<tr>
<td>0.564</td>
<td>82.6</td>
<td>228.0</td>
<td>8.7</td>
</tr>
</tbody>
</table>

When the stitch length increases, the porosity and the air permeability increase and the thermal retaining property decreases. It is well known that the total porosity consists of the following two constituents:

1. the void space between fibers of the yarn,
2. the void space between yarns of the fabric.

Since the same yarn was knitted into 1X1 rib fabrics with different stitch lengths in this study, the increase of porosity with stitch length is probably due to the increase of void space between yarns of the fabric. Therefore, the air permeability increases linearly with the increase of porosity.

It is well known that the thermal retaining property is closely related to the fabric thickness. The change of $H(\%)$ calculated from the regression equation obtained for plain-woven fabrics by the author [19] is very small from 12.5% ($l_u=0.435$ cm) to 12.1% ($l_u=0.564$ cm). It is clear from Table 3 that the change of $H(\%)$ in this study is very large from 20.9% ($l_u=0.435$ cm) to 8.7% ($l_u=0.564$ cm). It is well known that the values of $H(\%)$ increase with the increase of void space between fibers and decrease with the increase of void space between yarns. Therefore, the values of $H(\%)$ in this study decrease linearly with the increase of porosity.

3.3 Bending length

The stitch length ($l_u$) and the bending length ($L$) in each direction are shown in Table 4.

The bending length in each direction decreases with the increase of stitch length. The decreasing rate of bending length with stitch length for the surface of fabrics is smaller than that for the back of fabrics. The bending length for each stitch length increases with the increase of the oblique angle to the course direction. The difference of bending length between the surface and the back of fabrics in each direction increases with the increase of stitch length. The bending length for the same stitch length is the longest in the wale direction and the shortest in the course direction. The difference of bending length between directions is probably due

<table>
<thead>
<tr>
<th>$l_u$ (cm)</th>
<th>course</th>
<th>back</th>
<th>45°</th>
<th>course</th>
<th>back</th>
<th>45°</th>
<th>wale</th>
<th>back</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.435</td>
<td>22.2</td>
<td>23.5</td>
<td>25.3</td>
<td>26.9</td>
<td>35.9</td>
<td>33.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.463</td>
<td>21.2</td>
<td>20.8</td>
<td>24.7</td>
<td>24.6</td>
<td>35.7</td>
<td>27.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.504</td>
<td>19.5</td>
<td>17.3</td>
<td>23.6</td>
<td>22.6</td>
<td>34.9</td>
<td>26.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.532</td>
<td>18.8</td>
<td>14.8</td>
<td>22.8</td>
<td>21.7</td>
<td>34.1</td>
<td>25.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.564</td>
<td>18.0</td>
<td>11.9</td>
<td>22.4</td>
<td>21.0</td>
<td>33.7</td>
<td>24.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean | 19.9 | 17.7 | 23.8 | 23.4 | 34.9 | 27.4|

CV % | 7.75 | 23.4 | 4.63 | 9.19 | 2.47 | 11.5|
to the shape of loop, and that between the surface and the back of fabrics is probably due to the size and the shape of loop. Since the stitch length was controlled by cam setting of the cylinder in this study, the difference of loop size between the surface and the back of 1X1 rib knitted fabrics increases with the increase of stitch length.

3.4 Breaking strength and elongation
The stitch length ($l_u$) and the breaking strength ($S$) in each direction are shown in Table 5.

Table 5 Relation between the tensile strength ($S$ kgf) for each direction and the stitch length ($l_u$)

<table>
<thead>
<tr>
<th>$l_u$(cm)</th>
<th>course</th>
<th>22.5°</th>
<th>45°</th>
<th>67.5°</th>
<th>wale</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.435</td>
<td>22.0</td>
<td>16.7</td>
<td>24.6</td>
<td>45.3</td>
<td>65.8</td>
</tr>
<tr>
<td>0.463</td>
<td>20.3</td>
<td>15.4</td>
<td>17.3</td>
<td>43.2</td>
<td>63.0</td>
</tr>
<tr>
<td>0.504</td>
<td>17.1</td>
<td>12.3</td>
<td>14.0</td>
<td>37.9</td>
<td>61.7</td>
</tr>
<tr>
<td>0.532</td>
<td>15.0</td>
<td>10.3</td>
<td>11.9</td>
<td>34.9</td>
<td>60.9</td>
</tr>
<tr>
<td>0.564</td>
<td>12.8</td>
<td>9.0</td>
<td>10.3</td>
<td>31.7</td>
<td>60.1</td>
</tr>
</tbody>
</table>

Mean 17.4 12.7 15.6 38.6 62.3
CV % 19.3 23.0 32.4 13.1 3.20

The breaking strength in each direction decreases with the increase of stitch length. The decreasing rate of breaking strength with stitch length is the largest in the 45° direction and the smallest in the wale direction.

Tabata\[20\] showed that the breaking strength per unit fabric width for plain jersey fabrics is given by the following equations, and indicated that $a$ and $b$ for the plain jersey fabrics knitted of acrylic yarns become both about 0.40:

$$P_c = a \times C \times f \quad \text{(10)}$$

$$P_w = 2b \times W \times f \quad \text{(11)}$$

where $P_c$ and $P_w$ are the breaking strength per unit fabric width in the course and the wale directions for plain-jersey fabrics, $a$ and $b$ the strength efficiency in the course and the wale directions, $C$ and $W$ the courses/cm and the wales/cm, and $f$ the yarn breaking strength.

Applying those equations for plain-jersey fabrics to 1X1 rib knitted fabrics, the following equations are obtained:

$$R_c = a \times C_u \times f \quad \text{(12)}$$

$$R_w = 4b \times W_u \times f \quad \text{(13)}$$

where $R_c$ and $R_w$ are the breaking strength per unit fabric width in the course and the wale directions for 1X1 rib knitted fabrics.

The breaking strength per unit fabric width calculated from eqs. (12) and (13), and the experimental values found here are shown in Table 6.

It is clear from Table 6 that $a$ decreases and $b$ increases with the increase of stitch length. The mean value of $a$ becomes 0.39 and that of $b$ becomes 0.41, and both mean values are similar to those for acrylic plain-jersey fabrics.

The stitch length ($l_u$) and the breaking elongation ($E$) in each direction are shown in Table 7.

When the stitch length increases, the breaking elongation increases in course, 22.5° and 45° directions, and decreases in 67.5° and wale directions. The breaking elongation for each stitch length decreases with the increase of the oblique angle to the course direction.

Tabata\[20\] showed that the breaking elongation for plain-jersey fabrics knitted of spun yarns becomes about 340% in the course direction and about 60% in the wale direction. The mean value of breaking elongation found here becomes 330% in the course direction and 55% in the wale direction. Although those mean values are similar to those by Tabata, the value of CV(%) is very large in the course direction (19.1%) in the course

Table 6 A comparison of experimental values ($E_X$) with calculated values ($C_d$)

<table>
<thead>
<tr>
<th>$l_u$(cm)</th>
<th>course direction</th>
<th>wale direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_x$(kgf)</td>
<td>$C_d$(kgf)</td>
<td>$a$</td>
</tr>
<tr>
<td>0.435</td>
<td>22.0</td>
<td>53.0</td>
</tr>
<tr>
<td>0.463</td>
<td>20.3</td>
<td>49.1</td>
</tr>
<tr>
<td>0.504</td>
<td>17.1</td>
<td>43.0</td>
</tr>
<tr>
<td>0.532</td>
<td>15.0</td>
<td>40.0</td>
</tr>
<tr>
<td>0.564</td>
<td>12.8</td>
<td>36.5</td>
</tr>
</tbody>
</table>

Mean 17.4 44.3 0.390 62.3 151.8 0.411
CV % 19.3 13.5 6.24 3.20 4.78 1.60
4. Conclusion

The effect of stitch length on some properties for cotton 1X1 rib knitted fabrics is investigated experimentally.

The results obtained are as follows:

(1) Although $U_k$ is close enough to a constant and independent of the stitch length, $U_c$, $U_w$ and $U_c/U_w$ are dependent on the stitch length.

(2) The ratio $t/l$ and the weight per unit fabric area decrease with the increase of stitch length.

(3) When the stitch length increases, the porosity and the air permeability increase and the thermal retaining property decreases.

(4) The bending length in each direction decreases with the increase of stitch length. The bending length for each stitch length increases with the increase of the oblique angle to the course direction.

(5) The breaking strength in each direction decreases with the increase of stitch length. The strength efficiency of 1X1 rib knitted fabrics is about 40% both in the course and in the wale directions.

(6) When the stitch length increases, the breaking elongation increases in course, 22.5° and 45° directions and decreases in 67.5° and wale directions. The breaking elongation for each stitch length decreases with the increase of the oblique angle to the course direction.

References