Dimensional parameters of single jersey cotton knitted fabrics

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The problem of unpredictable shrinkage of cotton knitted fabrics and garments faced by the industry has been investigated by knitting single jersey cotton fabrics using the similar yarn and knitting parameters as used in the industry and finishing them. Through linear regression analysis, the variable factors, which affect the shrinkage and should be included in the domain of the quality control system, have been identified and predictive equations are established. Although, the variable factors, namely linear density, twist factor, machine gauge and stitch length, influence the shrinkage to a variable degree, stitch length is the dominating factor. If shrinkage can be controlled, fabric weight is predicted with high accuracy.

Keywords: Cotton knitted fabric, Dry relaxation, Full relaxation, Fabric weight, Shrinkage, Stitch length

1 Introduction

The cotton knitted fabric and garment manufacturers encounter an enormous problem of shrinkage. In spite of a fair amount of research, a comprehensive solution is still elusive. The fabric undergoes relaxation as it is washed and dried causing change in dimensions. If the fabric is delivered to the garment manufacturers with a very low residual shrinkage, the perceptible shrinkage by the wearer will be negligible. Hence, the challenge before the knitter and finisher is to select appropriate knitting and dyeing/finishing combination to achieve the low residual shrinkage.

The investigation of the problem was initiated by following the previous works in this field. It is reported¹ that stitch length is the unit parameter of the knitted structure which is proportional to the inverse of the wales or courses per inch. Thus, wales or courses per inch will be separately related to stitch length through a value of constant parameter (kₖ) for courses and (k₉ₕ) for wales², whereas kₖ is the area parameter proportional to stitch density. Experiments³⁶ have been conducted to find the values of kₖ and k₉ₕ and it is found that different materials, yarn parameters and structures, wet processing routes, washing and rinsing conditions, etc. give rise to different values of kₖ and k₉ₕ. However, subsequent research⁷ has shown that all 100% cotton fabrics knitted on the same construction using yarns from the same spinning system and processed through same dyeing and finishing routes would have same values of kₖ and k₉ₕ, implying that if a particular set of machineries is used for manufacturing 100% cotton single jersey fabrics, the values of kₖ and k₉ₕ would be constant. Investigation by Hepworth et al.⁸ has shown that the value of kₖ increases steadily with tightness factor specially when it is more than 6.0.

Analytical methods based on assumed geometry of loop⁹ or force analysis using the theory of elastica¹⁰ could not include all the parameters related to loop size and shape originating from viscoelastic nature of cotton yarns. However, it has been recognized that twist liveliness plays an important role in loop structure¹¹.

Onal et al.¹² included one more variant of single jersey knits, namely double pique in their study and showed that this structure shrinks less widthwise but more lengthwise than the plain single jersey fabric. In a recent publication, Ulson de Souza et al.¹³ re-established the importance of k-factors and reported that the final quality of the cotton knitted product can be determined in advance eliminating the costly wastage of product developments by trial and error.

In order to develop an alternative model to relate the courses and wales per inch with yarn and fabric parameters, it is appropriate to consider those parameters, namely yarn diameter and yarn twist beside the stitch length¹⁴, which have direct influence on the wales and courses per inch. It is necessary to explore how far these parameters influence the wales and courses per inch and therefore the shrinkage.

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Moreover, for measuring the shrinkage values, the fabric is required to achieve a reference state in order to be dimensionally stable and this state would be the base for measurement. An elaborate investigative work, known as ‘Starfish Project’\textsuperscript{15}, established the laundering regimen which has been adopted in the present work to achieve the reference state.

The main objective of this investigation is to specify the best possible dimensions of the 100% cotton single jersey knits those would be taken into consideration by the garment manufacturers. Moreover, a predictive system is required to be established which is simple, reliable and accurate enough to develop products and revising the parameters of existing products.

2 Materials and Methods

The experimental set-up was planned after a short survey in the knitters by selecting the yarn linear densities (tex), yarn twist factor (twist multiplier), machine gauge (needles per inch) and stitch length (cm) as well as fabric weight (g/m\textsuperscript{2} or GSM) in dry relaxed and washed relaxed states. Four levels of tex values, each with 3 levels of twist factors were selected. Each of these 12 samples of yarns was knitted at 4 levels of stitch lengths and employing 3 gauges of cylinder in the knitting machine. Thus, the plan of experiment consisted of a total of 144 fabric samples.

2.1 Materials

Combed cotton yarns with four linear densities, namely 29.53 tex (20\textsuperscript{s} Ne), 24.61 tex (24\textsuperscript{s} Ne), 19.68 tex (30\textsuperscript{s} Ne) and 16.4 tex (36\textsuperscript{s} Ne), each with twist factors 33.5 (3.5 TM), 36.4 (3.8TM) and 39.2 (4.1 TM) were chosen. These 12 samples of yarns were tested for their properties and the results are summarized in Table 1.

2.2 Sample Preparation and Testing

The above yarns were knitted by a single jersey circular knitting machine having 24 inch (61 cm) diameter, equipped with 48 feeders, positive feed devices and adjustable fabric pulley take-down system. During preparation of fabric samples, care was taken to keep the yarn tension constant at 12cN for all 48 feeders. Cylinders of 16, 20 and 24 gauges (needles per inch) were used for all the 12 samples of yarns and, for each cylinder, the nominal stitch lengths selected were 0.28, 0.30, 0.32 and 0.34 cm by changing the cam setting and positive feed device in the machine.

### Table 1—Tenacity, elongation, unevenness and imperfections of yarns used

<table>
<thead>
<tr>
<th>Tex (count)</th>
<th>Tex-twist factor (TM)</th>
<th>Tenacity mN/tex</th>
<th>Elongation, %</th>
<th>Unevenness U%</th>
<th>Imparfections/1000m</th>
</tr>
</thead>
<tbody>
<tr>
<td>29.53 (20\textsuperscript{s})</td>
<td>33.5 (3.5)</td>
<td>29.54 (1.70)</td>
<td>187.9</td>
<td>4.63</td>
<td>8.24</td>
</tr>
<tr>
<td>29.53 (20\textsuperscript{s})</td>
<td>36.4 (3.8)</td>
<td>29.03 (1.36)</td>
<td>151.9</td>
<td>4.85</td>
<td>8.4</td>
</tr>
<tr>
<td>29.53 (20\textsuperscript{s})</td>
<td>39.2 (4.1)</td>
<td>29.51 (1.77)</td>
<td>240.9</td>
<td>5.0</td>
<td>8.28</td>
</tr>
<tr>
<td>24.61 (24\textsuperscript{s})</td>
<td>33.5 (3.5)</td>
<td>24.10 (2.36)</td>
<td>164.2</td>
<td>4.37</td>
<td>9.08</td>
</tr>
<tr>
<td>24.61 (24\textsuperscript{s})</td>
<td>36.4 (3.8)</td>
<td>23.76 (2.0)</td>
<td>198.7</td>
<td>4.79</td>
<td>8.36</td>
</tr>
<tr>
<td>24.61 (24\textsuperscript{s})</td>
<td>39.2 (4.1)</td>
<td>23.74 (1.93)</td>
<td>201.5</td>
<td>4.65</td>
<td>4.65</td>
</tr>
<tr>
<td>19.68 (30\textsuperscript{s})</td>
<td>33.5 (3.5)</td>
<td>29.68 (1.78)</td>
<td>210.9</td>
<td>4.25</td>
<td>9.09</td>
</tr>
<tr>
<td>19.68 (30\textsuperscript{s})</td>
<td>36.4 (3.8)</td>
<td>29.64 (2.33)</td>
<td>177.3</td>
<td>4.14</td>
<td>9.12</td>
</tr>
<tr>
<td>19.68 (30\textsuperscript{s})</td>
<td>39.2 (4.1)</td>
<td>30.22 (1.61)</td>
<td>201.2</td>
<td>4.64</td>
<td>9.43</td>
</tr>
<tr>
<td>16.4 (36\textsuperscript{s})</td>
<td>33.5 (3.5)</td>
<td>16.36 (0.96)</td>
<td>145.7</td>
<td>3.87</td>
<td>9.7</td>
</tr>
<tr>
<td>16.4 (36\textsuperscript{s})</td>
<td>36.4 (3.8)</td>
<td>16.64 (1.35)</td>
<td>169.5</td>
<td>3.95</td>
<td>9.82</td>
</tr>
<tr>
<td>16.4 (36\textsuperscript{s})</td>
<td>39.2 (4.1)</td>
<td>16.53 (0.84)</td>
<td>177.4</td>
<td>4.1</td>
<td>10.25</td>
</tr>
</tbody>
</table>
The bleaching was carried out in industry under normal industrial parameters and all fabric samples were processed in the same bath, for which the fabric samples were stitched together end to end. Subsequently, the fabrics were given compaction treatment and each fabric sample was separately set in the compaction machine to achieve the nominal finishing targets. The route of wet processing is given below:

Scour & bleach (Soft flow) → Centrifuge → Tubular dry → Compressive shrinkage (Compaction)

The procedure detailed by Heap et al.15 was adopted for full relaxation treatment using a fully automatic front loading domestic washing machine and a tumbler dryer. All fabric samples were undertaken for this treatment which consisted of (i) a standard wash at 60°C using Surf Excel Matic detergent, rinse and spin, followed by standard tumble drying for 30 min at 60°C until dry, and (ii) four cycles of rinsing and tumble drying, making five cycles in all.

Relevant parameters, namely loop length, courses/cm, wales/cm and fabric weight were recorded after conditioning these samples for 72 h in a standard atmosphere of 27± 2°C and 65 ± 2% RH.

For measurement of shrinkage, a 50cm² area was drawn on each sample using an indelible marker before the start of the washing procedure at three different places. After the completion of the relaxation procedure and conditioning, the length and width of the square were again measured to determine the length-wise and width-wise shrinkage separately.

3 Results and Discussion
A set of 1440 data points was obtained. In order to develop a realistic and reliable predictive system for shrinkage, data was analysed using a SYSTAT® software. The details of measured parameters in reference states are shown in Fig.1.

It has been found that there is an inverse relationship between wales per centimeter (wpcm) and courses per centimeter (cpcm) with stitch length with considerably high coefficient of determination of 0.952 and 0.978 respectively. It is also found that the dimensional constants are same for all the fabrics as 4.412 for $K_w$ and 5.785 for $K_c$ with the ratio $K_r (K_c/K_w) = 1.31$ and it is believed that using the same material and yarn manufacturing system, knitting under identical conditions and processing with identical machines and process parameters will lead to constant values of $K_c$ and $K_w$.

3.1 Development of Mathematical Model
At this stage, in order to develop a reliable mathematical model for predicting the wpcm and cpcm, which is one of the principal objectives of the study, the statistical analysis is pursued by employing General Linear Model (GLM) technique in which all the four variables, namely tex, twist factor, gauge and stitch length, including their two-level interactions, are considered as independent variables and their dependence on wpcm and cpcm are explored separately. Square root of tex values are considered since yarn diameter is regarded as having influence on wpcm and cpcm and, yarn diameter being a rather difficult to measure quantity, square root of tex values will be more reliable as diameter is directly proportional to it.

This exercise is carried out for two different sets of data, one for the reference state and the other for the dry relaxed state. For the reference state, the required
equations, which are furnished below, are obtained through backward elimination method in which insufficient factors were removed based on p-value of 0.05:

\[
\begin{align*}
\text{wpcm} & = 0.271 + 3.942/\ell + 0.015*G/\ell + 0.010*G*\sqrt{T} \ldots (1) \\
\text{cpcm} & = 1.935 + 6.349/\ell + 0.089*\alpha - 0.266*\sqrt{T}/\ell + 0.022*\alpha*\sqrt{T} \ldots (2)
\end{align*}
\]

where \(\ell\) is the stitch length in mm; \(T\), the linear density of yarn in tex; \(\alpha\), the twist factor of yarn; and \(G\), the gauge of machine in needles per inch.

From the Eqs (1) and (2), the square of multiple coefficients of regression (\(r^2\) values) of 0.955 and 0.982 and the standard errors of estimate of 0.215 and 0.185 for wpcm and cpcm respectively indicate that these equations are well-capable to predict the wpcm and cpcm for cotton bleached single jersey fabrics.

In order to comprehend the technical aspects of the above Eqs (1) and (2), i.e. in the reference state, the response surfaces have been generated to analyse the influence of different variables on wpcm and cpcm (Figs 2 and 3).

Figure 2 (a) shows that the wpcm increases with gauge and decreases with reciprocal of stitch length which is attributed to the fact that higher gauge leads to more needles per inch and thus increase in wpcm values. Figure 2(b) shows the increasing trend of wpcm with respect to gauge and yarn linear density. In fact, significant interactions exist between the independent variables in influencing the wpcm. The counterbalancing influence of the gauge and square root of yarn linear density generates a plateau in the surface response curve.

Figure 3(a) shows that the cpcm values increases with the increase in reciprocal of stitch length which is expected since with the decrease in stitch length, the number of stitches, especially cpcm increases, although there is very minute influence of linear density. Decrease in cpcm with regard to twist factor,
as shown in [Fig. 3(b)], can be ascribed to higher distortions of loops caused by the higher twist in constituent yarns.

3.2 Prediction of Shrinkage and Weight of Fabrics

After the predictive equations are established, the next logical step would be to determine the calculated values of shrinkage and analyse their association with actual values of shrinkage as measured in reference states. For obtaining the calculated values of shrinkage\%, the following equations are generated for values of wpcm and cpcm in dry relaxed state, i.e. after bleaching and finishing to their nominal width and conditioning for 48 h:

\[
\begin{align*}
\text{wpcm} & = 0.271 + 4.203/\ell - 0.006*G \\
\text{cpcm} & = -5.621 + 7.653/\ell - 0.063*G
\end{align*}
\]

Therefore, the calculated values for width shrinkage are obtained as the percentage difference between Eqs (1) and (3), whereas those for length shrinkage are the percentage difference between Eqs (2) and (4). The actual shrinkage values measured are the percentage difference between dry relaxed and fully relaxed states which are termed as ‘measured shrinkage’.

Figures 4(a) and (b) show the scatter plots of the associations between the calculated and the measured values of shrinkages. It may be inferred that for bleached single jersey fabrics, reliable relationship is obtained between calculated values of shrinkage, using the predictive equations, and measured values of shrinkage in reference states with excellent degree of association.

In a similar manner, very good coefficient of regression between calculated and measured values of fabric weight (g/m\(^2\)) in reference state is obtained, as shown in Fig. 5. It is inferred that appropriate control of shrinkage leads to achieve proper fabric weight with cotton yarns.

3.3 Validation of Predictive Model

In order to validate the predictive Eqs (1) and (2), a part of the total experiment is replicated by randomly selecting 6 types of yarns from the parent stock and knitted 12 single jersey samples with various stitch lengths and gauges. The fabrics were bleached and finished to nominal width following the same route of chemical processing as before. The fabric parameters of the replicated samples and the error\% from their
model values are furnished in Table 2. The highest and the lowest error% are observed as 3.05 and (-)2.71 in wpcm and 3.10 and 1.45 in cpcm.

4 Conclusion

4.1 Each of the four parameters, namely stitch length, square root of linear density, gauge of machine and twist factor, influences the dimensional parameters to variable degrees.

4.2 It is found that stitch length is the dominating factor in influencing the dimensional parameters of these fabrics.

4.3 Gauge of machine is positively correlated with wpcm and the relationship between wpcm and yarn linear density is sensitive to variation of gauge of machine.

4.4 Effect of stitch length on cpcm is observed to be considerable, whereas that of linear density and yarn twist factor is marginal.

4.5 The reliability in prediction of dimensional parameters and fabric weight (g/m²) using the parameters in reference state is observed to be very high.

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