Dimensional Stability of Plain Weft Knitted Fabrics

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The dimensional stability of plain weft knitted fabrics made from 2/30' and 2/40' grasi crimp and acrylic yarns has been investigated under three different conditions of relaxation, viz. dry relaxation, wet relaxation and tumble drying. It is found that in dry- and wet-relaxed states, the structure depends on the stitch length and yarn diameter. The plain weft knitted structure has been found to be a rationally determinate structure in the fully relaxed state, as in any other state the nature of the knitted loop is dependent on the physical properties of yarn, mechanical processing and knitting variables. The values of $K_c$, $K_w$, $K_s$ and $K_I$ (constants of proportionality for courses/in, wales/in, stitch density and stitch length respectively) have been found to be constant, predictable and independent of yarn or machine variables in fully relaxed state. In any other fabric state, these values may vary considerably and have little commercial value. Fabric thickness has been found to be independent of loop length, but dependent on yarn diameter in fully relaxed state.

Munden$^1$ and Doyle$^2$ established that the length of the yarn in the knitted loop plays a major role in determining the dimensions of a knitted fabric. Although the knitting variables, such as yarn tension and fabric take-down tension, may appear to be significant at the stage at which the fabric is removed from the machine, a subsequent relaxation process can lead to a state in which the dimensions are completely independent of these variables. But we find that when the fabric is removed from the machine, there are no forces acting on it any longer, as the loops attempt to counteract the stresses imposed during knitting. However, since each loop interacts with the adjoining loops, complete recovery is not physically possible. With the increasing degree of relaxation, the fabric will tend towards the minimum energy state. For this reason, four different relaxation techniques were chosen in the present study to see as to which technique is suitable for reaching a stable configuration.

From a theoretical study, Munden and Postle$^3$ concluded that for dry-relaxed fabrics, the values of $K_w$, $K_s$ and $K_I$ (constants of proportionality for wales/in, courses/in and stitch density respectively) depend upon the yarn diameter. Shanahan and Postle$^4$ predicted that for full relaxed fabrics, both $K_c$ and $K_w$ are functions of $I/d$, where $d$ is the yarn diameter.

Hepworth and Leaf$^5$ have recently proposed a theoretical model for full relaxed fabrics in jammed condition. This model takes account of geometrical jamming between adjacent loops and predicts that dimensions vary with $d/I$. In addition to these theoretical analyses, some interesting experimental studies on the subject have also been reported.

Wolfaardt and Knapton$^6$ showed that the value of $K_I$ is dependent on the yarn linear density for woollen fabrics, although no similar conclusions were drawn for $K_c$ and $K_w$. Knapton et al.$^7$ showed that after ten laundering cycles, the value of $K_c$ for cotton fabrics shows some dependence on fabric tightness (measured by $\sqrt{T/l}$, where $T$ is the linear density in tex, and $l$, the stitch length in inches, although $K_I$ was relatively constant.

It is observed that apparently conflicting conclusions can be drawn from the reports published so far. So, due to insufficient experimental evidence, two different counts, viz. 2/30' and 2/40', were chosen in the present study to see the variation in the dimensions of plain fabrics in various relaxed states with change in stitch length and yarn diameter. Thus, the effect of yarn diameter on relaxed dimensions is considered.

Materials and Methods

Fabrics were knitted from acrylic fibres of 2 denier and 51 mm staple length and grasi crimp fibres of 1.75 denier and 51 mm staple length. Yarns of low twist liveliness (twist multiplier, 2.5) were selected to minimize the spirality effect, which is a problem, particularly with plain fabrics, and no single yarns were used for this reason. In addition, two counts, viz. 2/30' and 2/40', were taken for both acrylic and grasi crimp fibres.

Fabrics were knitted on a circular knitting machine of 15 gauge and 7.5 in diameter. 336 needles of needle number 44 were used on the knitting machine. Four different stitch lengths were chosen to produce a wide range of fabric cover factors from a given yarn.
Stitch lengths were measured on a Shirley crimp tester with an end load of 10 g. Fabric thickness was measured on Essdrel thickness gauge tester with a total load of 20 g f/cm², which is equivalent to a pressure of 1.96 x 10⁻³ N/mm². Different relaxation techniques were used to bring the fabric to minimal energy level.

Dry relaxation—After being knitted, the tubular fabrics were laid flat for several days to facilitate recovery from the stresses imposed during knitting. Prior to testing, all the samples were conditioned in standard atmosphere (RH, 65% and temperature, 27 ± 2°C). Sample lengths of approx. 15 in were cut and a square of 10 x 10 in was marked on each sample with a fine waterproof ink. The samples were then laid flat for 48 hr, after which they were in dry-relaxed state. The dry-relaxed dimensions were measured at this stage.

Wet relaxation (a)—The samples were placed in trays containing water and 0.5% Lissapol at room temperature. Only minimal agitation of samples took place. They were allowed to soak for 24 hr and then dried under standard conditions. At this stage, the dimensions of the samples were measured.

Wet relaxation (b)—The samples were wetted with 1% Lissapol in boiling water for 10 min by placing the fabric on a perforated sheet to prevent distortion. They were then dried in a circulating air oven at 115°C for 30 min. At this stage, the dimensions of the fabrics were measured.

Tumble drying—The samples were dipped in water for 24 hr. After soaking, they were hydroextracted and then tumble dried in a tumble drier for 60 min. At this stage, the dimensions of the samples were measured.

Results and Discussion

The dimensional stability of the weft knitted plain fabrics has been investigated under three different conditions of relaxation, viz. dry relaxation, wet relaxation and tumble drying. The process of relaxation for a knitted fabric involves change in the internal force situation for the structure so as to bring about an equilibrium state of minimum internal energy. Consequently, redistribution of yarn within the loop takes place.

Effect of courses/in—The values of courses/in are plotted against the reciprocal of stitch length for 2/30" acrylic fabrics (Fig. 1) obtained by measuring courses/in after every relaxation treatment. It is

Table 1—Average Values of $K_c$, $K_w$ and $K_r$ for Fabrics Knitted from Acrylic and Gras Crimp Yarns

<table>
<thead>
<tr>
<th>Yarn</th>
<th>Count</th>
<th>Dry relaxed</th>
<th>Wet relaxed A</th>
<th>Wet relaxed B</th>
<th>Tumble dried</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrylic</td>
<td>2/30&quot;</td>
<td>4.56 (-4.5)*</td>
<td>4.77 (-2.75)</td>
<td>5.56 (-1.6)</td>
<td>6.07 (-0.7)</td>
</tr>
<tr>
<td>Acrylic</td>
<td>2/40&quot;</td>
<td>4.18 (-5.0)</td>
<td>4.47 (-4.5)</td>
<td>5.46 (-3.8)</td>
<td>6.16 (-1.0)</td>
</tr>
<tr>
<td>Gras crimp</td>
<td>2/30&quot;</td>
<td>4.00 (-5.5)</td>
<td>4.54 (-4.5)</td>
<td>5.43 (-3.0)</td>
<td>6.14 (-0.6)</td>
</tr>
<tr>
<td>Gras crimp</td>
<td>2/40&quot;</td>
<td>3.71 (-6.0)</td>
<td>4.75 (-4.8)</td>
<td>5.41 (-2.75)</td>
<td>6.15 (-1.2)</td>
</tr>
</tbody>
</table>

*Values in parentheses show the magnitude of intercept.
observed that for the different ranges of construction, courses/in and the reciprocal of stitch length are linearly related and a constant value of $K_e$ is obtained. A similar trend has been observed for 2/30° and 2/40° grasi crimp fabrics, except a slight difference in the magnitude of intercepts. The results obtained are in agreement with those obtained on the basis of Munden's relation, according to which courses/in is inversely proportional to the stitch length.

It is also observed that the values of $K_e$ are approximately the same for fabrics knitted from acrylic and grasi crimp yarns. The average values of $K_e$ and the intercepts obtained from the experimental results are given in Table 1. The values of $K_e$ show more spread in dry-relaxed state as compared to that in tumble dried state, confirming that tumble drying is a more reliable method for obtaining a fabric in undistorted state and brings a stable configuration.

Effect of wales/in—The values of wales/in are plotted against the reciprocal of stitch length for acrylic fabrics (Fig. 2) determined by measuring wales/in after every relaxation treatment. It is observed that for the different ranges of construction, wales/in and the reciprocal of stitch length are linearly related and a constant value of $K_w$ is obtained. A similar trend has been observed for grasi crimp fabrics, except a slight variation in the magnitude of intercepts. The average values of $K_w$ and the intercepts obtained from the experimental results are given in Table 1. The results obtained are again in agreement with those obtained on the basis of Munden's relation, according to which wales/in is inversely proportional to the stitch length.

It is also observed that the values of $K_w$ are approximately the same for fabrics knitted from both acrylic and grasi crimp yarns. Also, the values of $K_w$ show more spread in dry-relaxed state than in tumble dried state, confirming that tumble drying is a more reliable method for obtaining a fabric in undistorted state and brings a stable configuration.

Effect of stitch density(S)—The method involving measurement of stitch density is more accurate than the other methods for studying fabric variables. The use of stitch density or number of loops per unit area of fabric is preferred to linear measurements, since it is less affected by distortion. This is because increase in length, produced by longitudinal stresses, is compensated to a certain extent by decrease in width. The values of stitch density for 2/30° acrylic fabric are plotted against the reciprocal of square of stitch length in Fig. 3. A similar trend has been observed for 2/40° acrylic and 2/30° and 2/40° grasi crimp fabrics, except a slight variation in the magnitude of intercepts. It is observed that for the different ranges of construction, the stitch density varies linearly with the reciprocal of square of stitch length and a constant $K_s$ is obtained. The average values of $K_s$ are given in Table 1.

The results obtained are in agreement with those based on Munden's relation, according to which for a knitted fabric, the stitch density or the number of loops per unit area is inversely proportional to the square of stitch length. It is also observed from these results that the values of $K_s$ are approximately the same for fabrics knitted from both acrylic and grasi crimp yarns. The values of $K_s$ show more spread in dry relaxed state than in tumble dried state, confirming that tumble drying is more reliable for obtaining a fabric in undistorted state and brings in a stable configuration.

Effect of yarn diameter—According to Doyle², the values of courses/in, wales/in and stitch density are independent of the yarn material, structure and system of knitting, but dependent on loop length. The relationships are: courses/in = $K_e/l$, wales/in = $K_w/l$, and stitch density = $K_s/l^2$, where $l$ is the stitch length and $K_e$, $K_w$ and $K_s$ are constants. These relationships are indeed linear, but the lines plotted do not pass through the origin, as predicted. Instead of this, they make an intercept. In fully relaxed state (tumble
The values of $K_s$ are plotted against cover factor values for dry relaxed and fully relaxed acrylic yarns ($2/30s$ and $2/40s$) in Fig.5. It is observed that the difference in the values of $K_s$ for the two counts is noticeable but small. However, in dry relaxed state, this difference is not apparent and there is a definite dependence of $K_s$ on cover factor; the value of $K_s$ increases proportionately with increase in the value of cover factor. In tumble dried state, this difference is negligibly small, giving a horizontal line parallel to the axis, i.e. the relationship is constant.

Effect of relaxation treatments on fabric length and width dimensions — The length and width dimensions of the plain knitted fabrics are dependent on the cover factor as seen in Figs 6-8, where the values of $K_c$, $K_w$ and $K_l$ are plotted against cover factor for acrylic yarns. It is observed that $K_w$ is proportional to $-p$ (cover factor) and $K_c$ is proportional to $+q$ (cover factor), where $p$ and $q$ are constants that acquire different values for the different fabric relaxation treatments.

Effect of loop shape factor (courses per in/wales per in) — Loop shape factor is a measure of the ratio of the loop width to the loop length. This ratio, by geometry of loop, should be constant for fabrics in the completely stable configuration. The ratio is, however, critically affected by any fabric distortion, since such distortion causes increase in one parameter with decrease in the other.

The ratio of courses/in to wales/in is plotted against the reciprocal of stitch length for dry relaxed and tumble dried acrylic and grasi crimp fabrics in Fig.4. In the case of dry relaxation, individual points show a greater spread from the average value. However, the spread is minimized in the case of tumble drying and shows a constant relationship, indicating that the full relaxation treatment (tumble drying) is more reliable for obtaining a fabric in undistorted state and leads to a stable configuration.

Effect of cover factor — Cover factor (ratio of the projected area of the threads to the total area) is given by $\frac{1}{l \sqrt{c}}$ (where $l$ is the stitch length; and $c$, the count).
states compared. These values decrease progressively as the fully relaxed state is approached, but even in this state, values of p and q are finite, though small.

This relationship is more obviously pronounced in Fig. 8, where the values of loop shape factor \( K_1 \) are plotted against those of cover factor for 2/30" and 2/40" acrylic yarns. For dry relaxed fabrics, the value of \( K_1 \) varies from 1.02 to 1.15 for 25.4% change in stitch length, whereas in the fully relaxed state, these differences are considerably reduced. The value of \( K_1 \) varies linearly with cover factor in the dry relaxed state (although the spread is higher) with a marked dependence on yarn count, i.e. \( K_1 \) is not a constant, as suggested by Munden, but is directly proportional to the cover factor. However, in the fully relaxed state, \( K_1 \) is independent of yarn count at any value of cover factor. Again, \( K_1 \) is not a constant, though the change in its value is very small compared with that in the dry relaxed state.

**Effect of loop length on fabric thickness (t)**—The fabric thickness data are plotted against loop lengths for the dry, wet and fully relaxed grasi crimp and acrylic fabrics in Figs 9 and 10 respectively. It is observed that there is a definite decrease in fabric thickness with increase in loop length in both dry and wet relaxed conditions. The measured values of thickness in these states for any loop length are considerably different, indicating dependence of fabric thickness on the relaxed condition of the fabric. The value of the slope of the curve for the wet relaxed fabric is lower than that for the dry relaxed fabric. In the fully relaxed state, however, the thickness is constant at \( t = 0.0374 \) in for 2/30" grasi crimp fabrics and at \( t = 0.0386 \) in for 2/30" acrylic fabrics and is independent of the loop length. This is in agreement with the mathematical model of Peirce. It may be concluded that in fully relaxed state, thickness is constant and is dependent on yarn diameter.

**Effect of fabric weight per unit area**—Fabric weight (g/m²) is plotted against the reciprocal of stitch length for the dry relaxed and fully relaxed acrylic fabrics in Figs 11 and 12 respectively. It is evident that weight per unit area is linearly related to the reciprocal of stitch length, as predicted by Doyle and Munden. Hence, for gross weight differences, such as between summer and
3 The ratio of courses/in to wales/in (loop shape factor) shows a greater spread from the average value in the case of dry relaxation. The ratio, however, stabilizes with full relaxation, indicating that the full relaxation treatment brings about a stable configuration in the fabric.

4 In dry relaxed state, the values of $K_0, K_w, K_s$ and $K_t$ show dependence on cover factor; the values increase proportionally with increase in the value of cover factor. However, in fully relaxed state, they show very little dependence on cover factor.

5 In dry and wet relaxed states, there is a definite decrease in fabric thickness with increase in loop length. In fully relaxed state, thickness is, however, constant and shows dependence on yarn diameter.

6 Weight per unit area of fabric varies inversely with the length of yarn knitted into the stitch.

**References**