Dimensional and physical properties of 3-D fabrics produced on the flat knitting machines

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The dimensional and physical properties of 3-D fabrics produced using different loop lengths and yarn combinations of cotton and polyester on electronic flat knitting machines have been studied. It is observed that the yarn combination, tightness and washing treatment affect the fabric properties. In addition, while the tightness of fabric increases or when the samples are washed, the course spacing, wale spacing, weight and thickness of the fabric increase and the air permeability decreases.

Keywords: 3-D fabrics, Cotton, Dimensional properties, Knitting, Physical properties, Polyester, Sandwich fabric

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1 Introduction

The applications of 3-D fabrics started at the end of 1960's, although their development dates back to the 19th century. 3-D technical textiles are used in different applications, such as protective clothing, transportation, geotextiles, building construction, packing materials, military, medicine and sports.

Kovar classified 3-D fabrics into four groups, namely (i) products with one major dimension, (ii) products with two major dimensions (double or multi-layer fabrics), (iii) spatial products based on deformed flat fabrics, and (iv) fully spatial products. The fabrics with two dimensions, also known as sandwich textiles, are used in this study. They have at least two layers. Different structures are obtained by weaving, warp and especially weft knitting technology.

It is possible to produce the complex 3-D fabrics, like box, cone and sphere, on electronic flat knitting machines. Various fibres, like polyamide, polyester, kevlar and glass, which have high resistance can be used for these structures. 3-D fabrics produced on these machines can be divided into two types, namely fully-fashioned fabrics (whole garment), and three-dimensional (3-D) fabrics.

Shaped pieces can be knitted in a modern flat knitting machine by utilizing different structural combinations and different stitch lengths, altering the number of operating needles from course to course, and using the link-off method. These shaped pieces are used as bandages in medical applications, filters, seat covers and linings of helmets.

Three-dimensional sandwich fabrics (two-faced fabrics) are mainly produced using two different techniques. Two independent fabric structures are connected by cross threads or by fabric layers in these techniques (Fig. 1). The space between the two fabric layers depends on the distance between two needle beds in the first technique and generally this distance is very limited. For the second type sandwich structure, front and back fabric layers are connected using different fabric layers with or without transfer of stitches.

In the present work, the effect of structural parameters of yarn and fabric on the dimensional and

![Fig. 1—Cross-sections of some 3-D sandwich fabrics](a) triple face structure 1 (connecting layers are not alternated), and b — triple face structure 2 (connecting layers are alternated)
physical properties of 3-D fabrics produced on the flat knitting machines has been studied.

2 Materials and Methods

2.1 Preparation of Samples

Ring-spun cotton (Co) yarn (Ne 20/4, \(a = 2.768\)) and polyester (PES) continuous filament yarn (150/7 den) were used. Knitting process was performed on 8 gauge Stoll CMS 422 electronic knitting machine using four cam systems. Samples were knitted using three different structures (Fabric types 1, 2 and 3) and three different loop lengths, representing a range of tight, medium and loose fabrics. Schematic appearance and photos for each structure are shown in Figs 2-4 respectively. The construction details of three types of fabric are given below.

Fabric type 1—Two independent fabric layers, knitted using two separate yarns, were connected by cross threads and tucks. Samples were knitted using four different yarn combinations, namely Co-Co-Co, Co-PES-Co, PES-Co-PES and PES-PES-PES, representing yarn’s material for 1st layer – cross thread – 2nd layer respectively.

Fabric type 2—In this structure, two independent fabric layers were knitted using two separate yarns. The fabric layers were connected by tucks which were made with the same yarns. Yarn combinations for two

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Fig. 2—Knitting movement, surface and cross-section view of Fabric type 1
[A – 1st layer thread, B – 2nd layer thread, and C – cross thread]

Fig. 3—Knitting movement, surface and cross-section view of Fabric type 2
[A – 1st layer thread, B – 2nd layer thread]
Fabric layers were Co-Co, Co-PES and PES-PES respectively.

**Fabric type 3**—For this structure, two independent fabric layers were knitted on front and back needle beds using two separate yarns. The fabric layers were connected by loop transfers. Yarn combinations for two fabric layers were Co-Co, Co-PES and PES-PES respectively.

### 2.2 Relaxation and Washing Treatments

The dry relaxation and washing treatments were applied to the samples. For dry relaxation, samples were kept on a smooth flat surface in a standard atmosphere for a week. After taking the measurements, samples were washed in a domestic washing machine at 30 °C by adding 0.05 g/l wetting agent. After a brief hydro-extraction, samples were laid on a flat surface in a standard atmosphere for a week and measurements were taken.

### 2.3 Test Methods

After every relaxation state of the samples, loop length ($\ell$), courses/cm (cpc), wales/cm (wpc), mass per unit area ($G$) according to TS251 (ref. 7), thickness ($t$) according to TS7128 (ref. 8) and air permeability (AP) according to TS391 (ref. 9) were measured.

A statistical program (SPSS 10.0 for Windows) was used and the Student’s t-test (for $\alpha = 0.05$) was applied to determine the statistical importance of a variation in a parameter.

During the evaluation, loop length was taken as an independent variable and the other parameters were considered as its functions. To determine the relationship between dependent and independent variables, the enter method, one of the multiple regression methods, was applied to dry and wet relaxed samples separately, and the regression equations were obtained from these analyses. $p$ values of each independent parameter were examined to observe the importance of parameters in the equations. Ergun emphasized that if $p$ value of a parameter is greater than 0.05, the parameter wouldn’t be important in the equation and should be ignored. Results for each fabric type were evaluated separately.

### 3 Results and Discussion

#### 3.1 Fabric Type 1

Loop length of the samples with cotton surface is 20% greater than the others for the same tightness scale values. It is possible to explain this situation by the texturing process applied to PES yarn, because the yarn which is under tension between the cone and the yarn carrier becomes longer. When the yarn gets free, it becomes bulkier, curlier, thicker and shorter during measurements. Loop lengths of cross threads mainly depend on the distance between needle beds, and the variance of these values with tightness is less. There are no important changes at different loop lengths on washing, as reported earlier.

The cpc and wpc of the samples with PES surface are greater than those of the others consequently because of the shorter loop length of PES stitches. The material of cross thread does not affect these values. While average 13% increase in cpc values is
significant, the increase in wpc values for all fabrics is not statistically significant after washing treatment.

There is a direct relationship between mass per unit area and tightness. The weights of samples with PES surface yarn are greater because of the shorter loop lengths when the PES yarn is used as cross thread, the fabric weight decreases. The weight of all the samples shows average 9% increase because of the shrinkage occurred after washing treatment.

Statistical evaluation clearly shows that the loop length is not important for fabric thickness. This value is affected from the distance between needle beds. If the same yarn materials are used as the surface yarn and cross thread, the fabric thickness values would be less. While the thickness of samples with cotton surface shows a 12% increase after washing, the variations in thickness for PES fabric are not important. This shows that the cotton is affected excessively from the wet processing.

The air permeability of fabrics also increases with the increase in loop length as a result of larger holes in loops. As the longer cross thread causes an increase in the amount of yarn between two fabric surfaces, the air permeability decreases. The value of air permeability is independent from yarn type used in the surfaces but it depends on the type of yarn used as cross thread. When cotton yarn is used as cross thread, the fabric thickness values would be less. While the thickness of samples with cotton surface shows a 12% increase after washing, the variations in thickness for PES fabric are not important. This shows that the cotton is affected excessively from the wet processing.

During the statistical evaluation, the regression equations and correlation coefficients were evaluated between the loop parameters and the loop lengths which belong to face ($l_{front}$) and back ($l_{back}$) surface yarns and cross thread ($l_{cross}$). The co-equations for all the yarn combinations are given in Table 1. Low correlation coefficient values for thickness show that the different parameters have more effect on the fabric thickness besides loop lengths.

### Table 1—Equations for Fabric type 1

<table>
<thead>
<tr>
<th>Relaxation</th>
<th>Regression equation</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>$wpc = 5.46 + 0.02 l_{cross} - 0.18 l_{back}$</td>
<td>0.884</td>
</tr>
<tr>
<td></td>
<td>$cpc = 18.15 - 0.70 l_{cross} - 0.69 l_{back}$</td>
<td>0.925</td>
</tr>
<tr>
<td></td>
<td>$G = 14.57 - 1.16 l_{front} + 0.35 l_{cross}$</td>
<td>0.937</td>
</tr>
<tr>
<td></td>
<td>$t = 3.96 - 0.55 l_{front} + 0.11 l_{cross} + 0.388 l_{back}$</td>
<td>0.555</td>
</tr>
<tr>
<td></td>
<td>$AP = 77.87 - 21.51 l_{front} - 21.22 l_{cross}$</td>
<td>0.817</td>
</tr>
<tr>
<td></td>
<td>$+ 41.56 l_{back}$</td>
<td></td>
</tr>
<tr>
<td>Wet</td>
<td>$wpc = 5.46 + 0.02 l_{cross} - 0.18 l_{back}$</td>
<td>0.798</td>
</tr>
<tr>
<td></td>
<td>$cpc = 17.93 - 0.14 l_{cross} - 1.15 l_{back}$</td>
<td>0.858</td>
</tr>
<tr>
<td></td>
<td>$G = 14.80 + 0.93 l_{front} + 0.31 l_{cross} - 2.05 l_{back}$</td>
<td>0.833</td>
</tr>
<tr>
<td></td>
<td>$t = 3.21 + 0.28 l_{front} + 0.05 l_{cross} - 0.29 l_{back}$</td>
<td>0.374</td>
</tr>
<tr>
<td></td>
<td>$AP = 44.98 - 27.13 l_{front} - 13.19 l_{cross}$</td>
<td>0.685</td>
</tr>
<tr>
<td></td>
<td>$+ 39.68 l_{back}$</td>
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</tr>
</tbody>
</table>

* $wpc$—Wale per cm, $cpc$—Course per cm, $G$—Mass per unit area, $t$—Thickness, and $AP$—Air permeability.

Table 1—Equations for Fabric type 1

During the statistical evaluation, regression equations and correlation coefficients were evaluated between the loop parameters and the loop lengths which belong to face ($l_{front}$) and back ($l_{back}$) surface yarns and cross thread ($l_{cross}$). The co-equations for all the yarn combinations are given in Table 1. Low correlation coefficient values for thickness show that the different parameters have more effect on the fabric thickness besides loop lengths.

#### 3.2 Fabric Type 2

Loop length changes according to yarn materials and is found to be shorter for PES yarn. This variation, which is statistically significant, arises from the curls that occur after the texturing process. Loop lengths belonging to the connecting course yarns are longer than the surface course yarns as proposed in previous paper. The effect of washing on the loop length is not statistically significant.

There is an inverse relationship between cpc & loop length, and wpc & loop length. Therefore, while tightness increases, the loop width and height consequently the fabric width and length decrease. Loop width and height of fabrics with PES yarn are less. The variation in loop width after washing is not significant. But the loop height and consequently the fabric length decrease on washing.

An increase in loop length causes a decrease in fabric weight. The weights of cotton-PES samples are higher than those of the other samples. After washing, the weights of all the fabrics increase average 8% and this variation is significant according to t-test.

Loop length does not affect the thickness of 2nd type of fabrics. It is observed that the PES-PES samples are the thinnest, and cotton-cotton and cotton-PES samples have higher thickness values respectively. Thicknesses of all the samples increase after washing.

Evaluation of air permeability could be made in only washed samples because of the insufficient data available for dry relaxed samples. The air permeability of fabrics with more cotton decreases because the cotton fibres are staple and PES fibres are continuous filament. Hairy surface of staple fibres covers the gaps between loops and hence the air permeability decreases. The air permeability of all the fabrics decreases average 30% after washing.

Regression equations and correlation coefficients are investigated between the loop parameters, and the loop lengths which belong to loop(L) and loop-tuck(T) courses are knitted on the front and back needle beds ($l_{front-L}$, $l_{front-T}$, $l_{back-L}$, and $l_{back-T}$ respectively). The co-equations obtained for all the yarn combinations are given in Table 2.
The effect of washing on loop length is not significant. The difference between loop lengths of the front and the back surface yarns for all the dry relaxed samples is significant (significance level 95%) and front bed loops are longer. It is thought that this difference occurs because the loop transfer connects the fabric layers and increases the yarn tension and yarn length. This tension could be eliminated after washing treatment.

A significant decrease is observed in cpc and wpc values of all the samples with the increase in loop length. While the increase in wpc values is not significant, an average 21% increase is observed in cpc values after washing treatment.

There is a reverse relationship between loop length and fabric weight for all the samples. The weight difference between cotton-cotton and cotton-PES samples is not significant. However, the weight of samples with PES yarn on both the surface is significantly lower. When all the samples are considered, an average 21% increase is observed in weight after washing treatment.

The t-test shows that the tightness doesn’t create an important variation in fabric thickness. As the PES yarn is thicker because of the texturing process, it shows a significant increase in thickness. On the other hand, fabric thickness is determined by the yarn thickness. The fabric thickness increases after washing.

Because of the holes which occur when a new loop is formed instead of the transferred loop, the air permeability of many samples couldn’t be measured. Measurements indicate a reverse relation between the tightness of fabric and the air permeability. The type of material used does not affect the air permeability. The results show an average 50% decrease in air permeability on washing. The regression analysis was not applied because of missing measurements.

The regression equations and correlation coefficients between the loop parameters and the loop lengths which belong to face (front) and back (back) surface loop yarns were investigated and are given in Table 3.

4 Conclusions

It is apparent that the loop lengths which belong to PES yarn are considerably shorter because of texturing process. The type of yarn used affects the cpc, wpc and fabric weight of all the fabrics. When the tightness of the fabric increases, the cpc, wpc and mass per unit area also increase and air permeability decreases for all the fabric structures. In addition, the loop lengths belonging to the connection courses which have tucks are longer than the loop lengths that have only loops. Thickness of the samples is affected by the type of yarn. For example, when the surface yarn and cross thread are different, the thickness of Fabric type 1 increases. Washing is the most important factor in loop dimensions. An increase in cpc, wpc, fabric weight and thickness, and a decrease in air permeability have been observed on washing.

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