Studies on polypropylene - cotton spun yarns and their fabrics

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Polypropylene staple fibres were mixed with cotton in different proportions for producing ring-spun yarns and the yarns so produced were converted into both woven and knitted fabrics. Various fabric properties including low-stress mechanical properties and hand values were determined on Kawabata fabric evaluation system. Mixing of polypropylene resulted in lowering of total hand value and improvement in total appearance value. Polypropylene-cotton knitted fabrics offer better durability performance.

Keywords: Cotton, Low-stress mechanical properties, Polypropylene, Spun yarn, Total appearance value, Total hand value

1 Introduction

Polypropylene is one of the important polyolefin plastics. It is the first stereo regular polymer which has achieved industrial importance. The major advantages of polypropylene are its light weight, resistance from stains and dirt, colour fastness, high abrasion resistance, chemical resistance, resistance to the growth of mildew/fungi and low thermal conductivity. Due to these merits, polypropylene has got wide acceptance in the industrial fabrics, but its utility in apparel sector is yet to meet commercial success.

Apart from the above-mentioned advantages and wide industrial applications, polypropylene has got certain limitations such as low melting point, non-dyeability after being spun, low ultraviolet and thermal stability, poor resilience, low Tg (15-20°C), creep behaviour, poor adhesion to glues and flammability. Due to these limitations, this fibre is used in a limited manner such as for swim suits and socks which are produced from textured multifilament. But, spun polypropylene has not got its share in the market.

To overcome the demerits of polypropylene and to exploit its superior qualities in order to make it widely acceptable in the apparel industry, polypropylene can be mixed/blended with other compatible fibres having rich hand value to produce various apparel items.

In the present work, polypropylene-cotton blended yarns were produced using different blend ratios. The blends were deliberately selected as cotton rich to produce cotton dominant apparel fabrics of better hand values. The properties of polypropylene blended yarns were tested and the yarns were then converted to both knitted and woven fabrics of different constructions. These fabrics were tested for various conventional fabric properties as well as for hand value on Kawabata fabric evaluation system to examine the changes in hand value by addition of polypropylene to cotton.

2 Materials and Methods

2.1 Materials

Polypropylene (PP) and cotton fibres having the following specifications were used for the study.

<table>
<thead>
<tr>
<th>Property</th>
<th>Cotton</th>
<th>Polypropylene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length, mm</td>
<td>30.23</td>
<td>38.00</td>
</tr>
<tr>
<td>Fineness, dtex</td>
<td>1.35</td>
<td>2.34</td>
</tr>
<tr>
<td>Tenacity, mN/tex</td>
<td>251.7</td>
<td>582.8</td>
</tr>
<tr>
<td>Elongation, %</td>
<td>6.32</td>
<td>31.68</td>
</tr>
</tbody>
</table>

2.2 Methods

2.2.1 Yarn Preparation

Four polypropylene-cotton (10:90, 20:80, 30:70 and 40:60) blended yarns and one 100% cotton yarn were prepared.
2.2.2 Yarn Quality Evaluation

2.2.2.1 Breaking Strength and Extension
The breaking strength and extension of the yarn samples were measured on Instron tensile tester using the standard procedures in accordance with ASTM D 2256.

2.2.2.2 Unevenness and Imperfections
The measurement of yarn unevenness and imperfections was done on Uster-2. The yarn irregularity in terms of CV% and the imperfections in terms of thick places, thin places and neps were evaluated.

2.2.2.3 Yarn Count and Count Strength Product
Yarn count was measured with the help of wrap reel and count strength product by using Goodbrand’s lea strength tester. Twenty (20) readings per sample were taken to get the average value.

2.2.2.4 Twist
Single yarn twist was measured on Eureka single yarn twist tester.

2.2.2.5 Flexural Rigidity
Flexural rigidity of the yarns was tested on Shirley weighted ring yarn stiffness tester. Yarn was mounted on a 7.75cm circular ring and weight was applied for 5 s to cause a deflection of 0.5 cm. The flexural rigidity (FR) of the yarn was calculated by using the following formula:

$$FR = \frac{98.1 ML^2}{Z} \text{dyne cm}^2$$

where $M$ = Weight applied
$L = 7.75 \text{cm}$
$Z = $ The value taken from standard diameter/length ratio tables

2.2.3 Fabric Preparation

2.2.3.1 Weaving
Woven fabrics were made on a dobby loom. One up and three down twill weaves were used to give the prominence to the sample yarns which were used as weft. The following parameters were set on the loom:

- Ends/cm : 22.8
- Picks/cm : 25.2
- Warp count : 24.6/2 tex (cotton yarn)
- Weft count : 21.5 tex (polypropylene yarn)
- Loom speed : 160 ppm
- Fabric width : 122 cm

2.2.3.2 Knitting
Single jersey plain knitted fabrics were made on the circular weft knitting machine. The cylinder diameter was 8.9 cm and the number of needles/cm was 7.1.

2.2.4 Fabric Properties

2.2.4.1 Areal Density
Areal density of the fabrics was measured by weighing a strip of 10 cm × 10 cm on a digital balance.

2.2.4.2 Tensile Strength and Extension-at-break
Tensile strength and extension-at-break were measured on Instron tensile tester by strip test method.

2.2.4.3 Bursting Strength
Bursting strength was measured on the Eureka bursting strength tester.

2.2.4.4 Abrasion Resistance
Flat abrasion was tested using the 2/0 polishing emery paper and circular fabric samples of the 1.27cm diameter. Five samples per fabric were tested. A weight of 0.227 kg was put on the pressure head.

2.2.4.5 Pilling of Fabrics
Pilling of fabrics was tested on Sasmira pilling tester. Four samples of the size 12.7 cm × 12.7 cm, made in tubular form, were used. About 18000 revolutions were given to check the pilling of the fabrics, maintaining the speed of the machine at 60 rpm. After 18000 cycles, the fabrics were compared with the standard pilling chart and the gradings I, II and III were assigned.

2.2.4.6 Low-stress Mechanical Properties
The fabrics were tested for low-stress tensile, bending, shear, surface and compressional properties on Kawabata fabric evaluation system. The primary hand value, total hand value (THV) and total appearance value (TAV) were estimated from these results using Kawabata system of equations. For the evaluation of hand values, 16 low-stress mechanical fabric attributes were determined (Table1).

3 Results and Discussion

3.1 Yarn Properties

3.1.1 Tensile Properties
Table 2 shows that the increase in percentage of polypropylene up to 20% initially decreases the yarn strength and subsequently the strength increases with the further addition of PP. However, the extension-at-break continuously increases with the increase in polypropylene proportion. This is due to the more extensibility of the polypropylene fibre. The initial fall in single yarn strength is due to the differential
Table 1 — Fabric mechanical attributes

<table>
<thead>
<tr>
<th>Test</th>
<th>Low-stress mechanical properties</th>
<th>Notation</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile test</td>
<td>Extensibility</td>
<td>EM</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Linearity</td>
<td>LT</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Tensile energy</td>
<td>WT</td>
<td>gf cm/cm²</td>
</tr>
<tr>
<td></td>
<td>Tensile resilience</td>
<td>RT</td>
<td>%</td>
</tr>
<tr>
<td>Shear test</td>
<td>Shear stiffness</td>
<td>G</td>
<td>gf cm/degree</td>
</tr>
<tr>
<td></td>
<td>Hysteresis at 0.5° shear angle</td>
<td>2HG</td>
<td>gf/cm</td>
</tr>
<tr>
<td></td>
<td>Hysteresis at 5° shear angle</td>
<td>2HG5</td>
<td>gf/cm</td>
</tr>
<tr>
<td>Bending test</td>
<td>Bending rigidity</td>
<td>B</td>
<td>gf cm²/cm</td>
</tr>
<tr>
<td></td>
<td>Hysteresis of bending moment</td>
<td>2HB</td>
<td>gf/cm</td>
</tr>
<tr>
<td>Compression test</td>
<td>Linearity of compression thickness curve</td>
<td>LC</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Compressional energy</td>
<td>WC</td>
<td>gf cm²/cm²</td>
</tr>
<tr>
<td></td>
<td>Compressional resilience</td>
<td>RC</td>
<td>%</td>
</tr>
<tr>
<td>Surface characteristics</td>
<td>Coefficient of friction</td>
<td>MIU</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Mean deviation of MIU</td>
<td>MMD</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Geometrical roughness</td>
<td>SMD</td>
<td>µm</td>
</tr>
<tr>
<td>Fabric construction</td>
<td>Weight/unit area</td>
<td>W</td>
<td>mg/cm²</td>
</tr>
<tr>
<td></td>
<td>Fabric thickness</td>
<td>T</td>
<td>mm</td>
</tr>
</tbody>
</table>

Primary hand expressions and their meanings

- KOSHI: Stiffness/firmness
- SHARI: Crispness
- HARI: Anti-drape stiffness/hardness
- FUKURAMI: Fullness/softness
- NUMERI: Smoothness

Table 2 — Tensile properties of yarns

<table>
<thead>
<tr>
<th>Blend ratio (Cotton:PP)</th>
<th>Breaking strength eN/tex</th>
<th>Breaking elongation %</th>
<th>Lea strength kg (lb)</th>
<th>Count Tex(Ne)</th>
<th>CSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>100:0</td>
<td>14.51</td>
<td>6.20</td>
<td>38.6(85)</td>
<td>21.63(27.3)</td>
<td>2320</td>
</tr>
<tr>
<td>90:10</td>
<td>13.70</td>
<td>7.18</td>
<td>36.3(80)</td>
<td>21.47(27.5)</td>
<td>2200</td>
</tr>
<tr>
<td>80:20</td>
<td>12.51</td>
<td>7.70</td>
<td>36.3(80)</td>
<td>21.55(27.4)</td>
<td>2192</td>
</tr>
<tr>
<td>70:30</td>
<td>12.87</td>
<td>7.90</td>
<td>37.2(82)</td>
<td>21.82(27.1)</td>
<td>2263</td>
</tr>
<tr>
<td>60:40</td>
<td>14.63</td>
<td>10.10</td>
<td>39.0(86)</td>
<td>21.63(27.3)</td>
<td>2347</td>
</tr>
</tbody>
</table>

PP — Polypropylene

loading of the fibres in cross-section. Beyond 30% PP, the increase in the yarn strength is in accordance with the Hamburger’s model for blended yarn. Similarly, the count strength product (CSP) value first decreases from 2320 to 2192 and then increases to 2347. The reason for this trend is also attributed to the Hamburger’s model. Therefore, to achieve any improvement in the yarn strength, at least 20% of polypropylene should be added.

3.1.2 Unevenness and Imperfections

The values for unevenness and imperfections are given in Table 3. The absolute unevenness appears to be at higher side. However, there is slight improvement in the Uster CV% of yarn with the addition of polypropylene, but the improvement is not statistically significant. The reduction in the value is due to the evenness of polypropylene staple fibre. The results do not show any definite trend in the thick places, thin places and neps in the yarn with the change in PP proportion in the blends.

3.1.3 Flexural Rigidity

Table 3 shows that the flexural rigidity increases with the increase in polypropylene proportion which is quite obvious. As the polypropylene is a coarse and
stiffer fibre, its presence increases the yarn flexural rigidity.

3.2 Woven Fabric Properties

3.2.1 Tensile and Bursting Strength

The results for various fabric properties are shown in Table 4. It may be observed from the table that both tensile and bursting strengths of the fabrics improve with the increase in polypropylene proportion. This increase is not significant by increasing the PP proportion from 10% to 20%, however after increasing PP proportion to 40% level, the increase in both tensile and bursting strengths has been found to be significant. The trend of tensile strength is in accordance with the single yarn strength and count strength product (CSP). A consistent increase in the bursting strength can be attributed to the more extensibility of the polypropylene.

3.2.2 Abrasion and Pilling

Table 4 shows that with the increase in polypropylene proportion the pilling tendency of the fabrics decreases. This can be attributed to the more hairiness caused by the shorter cotton fibre. It is well known that in a blended yarn the shorter fibres tend to move outwards and longer fibres move towards the core of the yarn. Therefore, with the increase in PP proportion the pilling tendency reduces. In case of blended yarn, bending rigidity is also higher than the cotton yarns and hence the lower pilling tendency. The decrease in the number of cycles to abrade the fabric is clearly observed from the results. This decrease is due to the increase in PP fibre. Table 5 shows that the coefficient of friction of fabrics increases from 0.2094 to 0.2206 with the increase in PP proportion. This increase in coefficient of friction indicates an increase in the contact area and hence the abrasion of the fabric becomes easier, resulting in low abrasion resistance.

3.2.3 Low-stress Mechanical Properties

The results of low-stress mechanical properties are given in Tables 5 and 6. Table 6 shows various fabric attributes with respect to tensile and shears properties. EM is the tensile strain under biaxial extension. The larger the value of EM, the greater will be the wearing comfort. The value of EM indicates that the cotton fabric is less easily extensible than the polypropylene blended fabrics. Therefore, a 40:60 polypropylene-cotton fabric will hinder the least to the movement of body parts due to its high extensibility and hence it might provide higher tactile comfort.

LT represents the linearity of the stress-strain curve. It has some correlation with the handle of the fabric. A higher value of LT is supposed to be better. From this point of view, the fabric sample with 20% PP results in the highest LT values.

WT represents the tensile energy (i.e. the area under the load-elongation curve). It is strongly related with the movement of the body parts in a particular garment and fabric handle. Lower value of WT is better. In this respect, it may be observed from the table that 100% cotton fabric is the best as with the
increase in the percentage of polypropylene the value of WT first increases and then decreases. This is due to the same reason as discussed in the tensile properties of the yarn (section 3.1.1)

Tensile resilience (RT) represents recovery from tensile deformation. A higher value of RT makes the fabric more elastic. In this respect, 100% cotton fabric is found to be the best. With the increase in polypropylene proportion the recovery value reduces.

Shear rigidity (G) is lowest for 100% cotton fabrics. Shear rigidity of a fabric depends mainly on the mobility of warp/weft thread within the fabric while the mobility depends on the type of weave, yarn diameter and surface properties of yarn. The lower value of G is preferred for better handle of the fabric. A high value of G indicates a paper-like property and causes difficulty in tailoring and also discomfort in wearing. Therefore, 100% cotton fabric is the best in this respect.

2HG and 2HG5 are the hysteresises of shear force at 0.5° and 5° respectively. The results show that the hysteresis is the lowest (recovery is better from shear deformation) for the 100% cotton fabrics. With the increase in polypropylene proportion the hysteresis increases and hence recovery from the shear deformation reduces. A high value of hysteresis gives trouble in tailoring and also shows wrinkling during wear.

Bending rigidity (B) is a measure of how easily a fabric can bend. Bending rigidity of the fabric depends upon the bending rigidity of the yarns and the mobility of the warp/weft thread within the fabric. As the weave in all the fabrics is same, the bending rigidity of the fabric mainly depends on the bending rigidity of the yarn. The trend observed is exactly the same as shown by the flexural rigidity of yarns, i.e. with the increase in polypropylene proportion the bending rigidity increases.

Hysteresis of bending moment (2HB) indicates a measure of recovery from bending deformation. A lower value of 2HB is better. In this respect, 100% cotton fabric is found to be better than PP blended fabrics.

It may be mentioned here that all the properties (tensile, shear and bending) are important from dimensional stability point of view during the usage of the fabric. Garments made of polypropylene blended fabrics would tend to bag during usage because of the less recovery.

Linearity of compression (LC) is the highest for the fabrics having 40% PP in the weft direction. WC and RC are similar to WT and RT in tensile testing. LC, WC, RC and T are related to primary hand FUKURAMI (fullness) values.

Coefficient of friction (MIU) is the lowest for 100% cotton fabric. Coefficient of friction depends upon the contact area and the type of weave. Weave being the same in all the cases, MIU only depends on
Table 8 — Primary and total hand values of fabrics (summer)

<table>
<thead>
<tr>
<th>Blend ratio (Cotton:PP)</th>
<th>KOSHI</th>
<th>SHARI</th>
<th>FUKURAMI</th>
<th>HARI</th>
<th>THV</th>
<th>TAV</th>
</tr>
</thead>
<tbody>
<tr>
<td>100:0</td>
<td>2.83</td>
<td>2.01</td>
<td>4.69</td>
<td>3.77</td>
<td>2.07</td>
<td>1.09</td>
</tr>
<tr>
<td>80:20</td>
<td>3.08</td>
<td>1.99</td>
<td>3.96</td>
<td>3.81</td>
<td>1.91</td>
<td>1.08</td>
</tr>
<tr>
<td>70:30</td>
<td>3.09</td>
<td>1.54</td>
<td>4.15</td>
<td>3.86</td>
<td>1.65</td>
<td>1.12</td>
</tr>
<tr>
<td>60:40</td>
<td>3.12</td>
<td>1.24</td>
<td>4.32</td>
<td>3.88</td>
<td>1.51</td>
<td>1.16</td>
</tr>
</tbody>
</table>

Table 9 — Knitted fabric properties

<table>
<thead>
<tr>
<th>Blend ratio (Cotton:PP)</th>
<th>Areal density g/m²</th>
<th>Tensile strength kg/m</th>
<th>Breaking extension %</th>
<th>Bursting strength kg/cm²</th>
<th>Pilling grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>100:0</td>
<td>133.5</td>
<td>67.6</td>
<td>196</td>
<td>4415</td>
<td>II</td>
</tr>
<tr>
<td>90:10</td>
<td>134.9</td>
<td>66.9</td>
<td>201</td>
<td>4905</td>
<td>II</td>
</tr>
<tr>
<td>80:20</td>
<td>143.5</td>
<td>67.3</td>
<td>213</td>
<td>5101</td>
<td>II</td>
</tr>
<tr>
<td>70:30</td>
<td>143.7</td>
<td>68.9</td>
<td>220</td>
<td>5396</td>
<td>I</td>
</tr>
<tr>
<td>60:40</td>
<td>154.5</td>
<td>69.4</td>
<td>229</td>
<td>5886</td>
<td>I</td>
</tr>
</tbody>
</table>

the contact area. As the abrasion resistance of 100% cotton fabric is the highest among all the samples, it can also be attributed to its lower frictional coefficient. MMD gives mean deviation of MIU or, in other words, it is a measure of deviation. SMD represents the geometrical roughness. The 100% cotton fabric has maximum geometrical roughness. This may be due to the maximum number of thick and thin places and unevenness of 100% cotton yarn.

3.2.4 Fabric Hand Value and Appearance Value

From the above low-stress mechanical properties, the primary hand values, total hand values (THV) and total appearance value (TAV) of the fabric samples were estimated using Kawabata system of equation. Considering the fabrics for summer wear, THV was estimated using four primary hand values, such as KOSHI, SHARI, HARI & FUKURAMI. For THV of winter garment, three primary hand values (KOSHI, NUMERI & FUKURAMI) were used. The calculated primary and total hand values for winter and summer wears are given in the Tables 7 and 8 respectively. THV is the measure of tactile comfort provided by the clothing. Whereas, TAV is related to the psychological comfort and is determined by the surface as well as mechanical properties of fabrics. THV is found to be the highest for 100% cotton fabrics while TAV is maximum for fabrics having 40% polypropylene. Though these values are on the lower side but the fabrics tested were grey and no washing treatment was given.

Fabric surface smoothness (NUMERI) and fullness (FUKURAMI) are the most important fabric quality attributes while assessing the fabric handle for winter wears. These values are higher for 100% cotton fabrics. Firmness (KOSHI) is higher for polypropylene blended fabrics.

It may be observed from the results that the primary hand values, such as fabric firmness (KOSHI) and fabric hardness (HARI), are higher for 40:60 polypropylene-cotton fabric while fabric crispness (SHARI) and fullness (FUKURAMI) are better for 100% cotton fabrics in case of summer wear.

3.2.5 Knitted Fabric Properties

Table 9 shows that with the increase in polypropylene percentage the areal density increases. In fact, it should have decreased as the specific gravity of the polypropylene is lower than that of the cotton. Since, a high denier polypropylene fibre (2.34 dtex) is used, areal density increases.

Tensile strength shows similar trend as shown for the woven fabrics. The extension-at-break of the knitted fabrics is higher than that of the woven fabrics. With the increase in polypropylene percentage the extension-at-break increases continuously. Bursting strength of the knitted fabrics also shows continuous increase with the increase in PP proportion. This is due to the more extensibility at the break of the PP. Pilling resistance of the fabrics improves with the addition of polypropylene. It may be observed from the results that the 40:60 PP-cotton fabrics give the least pills on the fabric surface due to the facts explained earlier in the case of woven fabrics. Therefore, it may be concluded that polypropylene-cotton knitted fabrics offer better durability performance provided the product fulfils other serviceability conditions.

4 Conclusions

Blending of polypropylene with cotton fibre helps in improving tensile strength, extension and
unevenness. The improvement in yarn properties is clearly reflected in some of the fabric properties. However, blending of polypropylene with cotton reduces fabric total hand values in both summer and winter uses. Total appearance value shows marginal increases on adding PP to cotton when compared with that of 100% cotton fabric. Among the various low-stress mechanical properties of cotton-polypropylene fabrics, all the recoveries from their corresponding deformations are found to be lower than 100% cotton fabric which indicates that the garments of these blended fabrics would tend to bag during usage. Polypropylene-cotton knitted fabrics offer better durability performance.

References