Low-stress mechanical properties and fabric
hand of cotton and polylactic acid fibre
blended knitted fabrics

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Low-stress mechanical behavior of cotton-rich/polylactic
acid blended fabrics has been investigated and the results are
compared with cotton and polylactic acid fibre fabrics. The
polylactic acid fibres are mixed with cotton fibres in two different
proportions, namely 20\% and 35\% and spun into 14.76 tex (40
Ne) yarn. The yarns are then knit into single jersey structure
followed by chemical pretreatments and relaxation. The relaxed
fabrics are tested for low-stress mechanical properties using
Kawabata evaluation system for fabrics (KES-F) and the hand
values are calculated. The results show that the addition of PLA
fibres to cotton enhances the smoothness and softness of the
blended fabrics. The total hand value of the fabrics ranges
between 3.2 and 3.5.

Keywords: Cotton, Fabric handle, Knitted fabric, Low-stress
mechanical property, Objective measurement, Polylactic
acid

The phenomenon of fabric hand is one of the most
significant characteristics in determining the fabric
marketing, and for providing the fabric scope of end-
uses, performance and appearance. The sensations of
stiffness or limpness, hardness or softness, and
roughness or smoothness constitute fabric hand.
Subjective assessment of fabric hand by human
judges rely on psychophysical approaches or
psychological techniques. The pioneering work on
objective assessment of fabric was done by Peirce\(^1\)
and the concept of fabric hand was studied by many
workers\(^2-7\). The basic elements that can fundamentally
affect fabric hand are the fibre characteristics, yarn
type, fabric construction and type of dyeing and
finishing processes\(^8-9\). The Kawabata evaluation
system for fabrics (KES-F) measures physical,
mechanical and surface properties of fabrics in low
stress region, and total hand value (THV) of the fabric
is calculated based on these measurements.

Cotton fibre is known for its excellent comfort
properties. As it is well known that a single fibre
cannot impart all the desirable properties, cotton fibres
are blended with other fibres to meet different end-use
requirements. For example, cotton is blended with
polyester to improve crease recovery and durability.
The low-stress mechanical properties of blended
fabrics have been studied by many researchers. Sharma
\textit{et al}.\(^10\) studied low stress mechanical properties of
100\% wool and 55/45 polyester: wool fabrics. Behera
and Mishra\(^11\) studied the fabric handle of wool: cotton,
wool: linen, wool: silk and silk: linen fabrics. Frydrych
and Matusaik\(^12\) investigated the fabric hand of cotton
and cotton/polyester fabrics. However, no published
literature is available on the low-stress mechanical
behavior of cotton/PLA blended fabrics. PLA fibre is a
biodegradable synthetic fibre made from lactic acid,
which is obtained from the purification and
fermentation of sugars from corn, sugar beet, or wheat
starch. PLA fibres are generally circular in cross-
section and have a smooth surface. The density of the
fibre is 1.25 g. cm\(^{-3}\) and the moisture regain is
0.4–0.6\% (ref. 13). The blending of PLA with cotton
can enhance the softness, smoothness and moisture
management properties of the resultant fabric. In a
recent study\(^14\), the usefulness of cotton/PLA blend for
sportswear application was reported. In this study, the
low-stress mechanical behavior of cotton-rich/PLA
blended fabrics has been investigated and compared
with 100\% cotton fabric.

**Experimental**

The cotton (MCU-5 variety) and polylactic acid
(PLA) fibres were sourced from a local industry
manufacturing blended yarns. The properties of cotton
and PLA fibres are given in Table 1.

The staple length and fineness are the two most
important fibre properties that need to be matched for
satisfactory processing of blends. The cotton fibres
were processed up to the stage of combing, and then
combed cotton was taken back to the blowroom for
mixing with PLA fibres\(^15\). The PLA fibres were
mixed with cotton fibres in two different proportions,
namely 20\% and 35\%. The blended fibres were then

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spun into yarns using a compact ring spinning system to a nominal count of 14.76 tex (40s Ne) with a twist factor of 36.4 (3.8 TM); 100% cotton and 100% PLA yarns were also spun to the same count to enable comparison between the yarns.

The yarns were then knitted into fabrics using a KNITMAC 16 inch diameter, 24 gauge single jersey knitting machine equipped with 27 numbers of positive storage feeders to a GSM of 110.

The plain knitted fabrics were scoured and bleached by adopting a single-stage scouring and bleaching process. The 100% PLA fabric was given a mild scouring treatment to remove added impurities during mechanical processing. The fabrics were then subjected to dry and wet relaxation treatments before conditioning and testing. The construction particulars and the bursting strength of knitted fabrics are given in Table 2. The GSM of fabrics was in the range of 130-135.

The samples were tested for low-stress mechanical properties using KES-F tester, which include measurement of tensile, shearing, bending, compression and surface properties. Specimens of size 20 cm × 20 cm were used. Each value is the average of four test results. Testing was carried out at standard laboratory conditions (20 ± 2 °C and 65 ± 2% relative humidity (RH). From the low-stress mechanical properties, primary hand values of Koshi (Stiffness), Fukurami (resilience) and Numeri (Softness) were obtained. From the primary hand values, total hand value (THV) of the fabrics was obtained.

Results and Discussion

The results of low-stress mechanical behaviour of materials measured using Kawabata evaluation system are given in Table 3.

<table>
<thead>
<tr>
<th>Fibre properties</th>
<th>Cotton</th>
<th>PLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length, mm (2.5% span length)</td>
<td>30</td>
<td>38</td>
</tr>
<tr>
<td>Fineness, den</td>
<td>1.2 (3.4 mic)</td>
<td>1.4</td>
</tr>
<tr>
<td>Tenacity, g/tex</td>
<td>25 (Bulk)</td>
<td>32</td>
</tr>
<tr>
<td>Elongation, %</td>
<td>6.7</td>
<td>25</td>
</tr>
</tbody>
</table>

Table 2 — Construction particulars and properties of fabrics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cotton</th>
<th>Cotton/PLA (80/20)</th>
<th>Cotton/PLA (65/35)</th>
<th>PLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yarn count, tex</td>
<td>14.96</td>
<td>14.58</td>
<td>14.67</td>
<td>14.82</td>
</tr>
<tr>
<td>Yarn diameter, mm</td>
<td>0.249</td>
<td>0.236</td>
<td>0.231</td>
<td>0.192</td>
</tr>
<tr>
<td>Fabric count, wales/cm × courses/cm</td>
<td>17×23</td>
<td>18×23</td>
<td>18×23</td>
<td>18×23</td>
</tr>
<tr>
<td>Stitch length, mm</td>
<td>2.46</td>
<td>2.46</td>
<td>2.47</td>
<td>2.46</td>
</tr>
<tr>
<td>Fabric weight, g/m²</td>
<td>135</td>
<td>133</td>
<td>130</td>
<td>132</td>
</tr>
<tr>
<td>Bursting strength, kg/cm²</td>
<td>8.2</td>
<td>7.9</td>
<td>7.3</td>
<td>6.3</td>
</tr>
</tbody>
</table>

Tensile Properties

In the tensile test, tensile linearity (LT), tensile energy (WT), tensile resilience (RT) and extensibility (EMT) have been measured. The LT values of cotton and PLA do not show much difference. Cotton fabric shows a higher WT value compared to PLA fabric. RT value of PLA is better than that of 100% cotton fabric, indicating that the PLA can recover well and can retain its shape well. The values for blends are found close to that of cotton as expected. The higher EMT [%] of PLA fabric is due to better elongation property of PLA material as compared to that of cotton and it blends.

Shear Properties

In the shearing test, properties such as shear stiffness (G), shear stress at 0.5° (2HG) and shear stress at 5° (2HG5) have been measured. Lower value of shear rigidity of PLA indicates lesser resistance to shear and better drape. It has been observed that the shear hysteresis of cotton fabric is higher than that of PLA material, indicating poor recovery from shear stress.

<table>
<thead>
<tr>
<th>Property</th>
<th>Cotton</th>
<th>Cotton/PLA (80/20)</th>
<th>Cotton/PLA (65/35)</th>
<th>PLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile LT [-]</td>
<td>1.03</td>
<td>1.06</td>
<td>1.01</td>
<td>0.97</td>
</tr>
<tr>
<td>WT, gf.cm/cm²</td>
<td>2.53</td>
<td>2.46</td>
<td>2.35</td>
<td>2.02</td>
</tr>
<tr>
<td>RT, %</td>
<td>36.0</td>
<td>36.6</td>
<td>37.5</td>
<td>43.8</td>
</tr>
<tr>
<td>EMT, %</td>
<td>9.7</td>
<td>11.4</td>
<td>13.2</td>
<td>14.2</td>
</tr>
<tr>
<td>Shear G, gf/cm deg</td>
<td>1.21</td>
<td>1.19</td>
<td>1.06</td>
<td>1.04</td>
</tr>
<tr>
<td>2HG, gf/cm</td>
<td>6.68</td>
<td>5.57</td>
<td>5.27</td>
<td>5.76</td>
</tr>
<tr>
<td>2HG5, gf/cm</td>
<td>5.99</td>
<td>5.00</td>
<td>4.91</td>
<td>5.29</td>
</tr>
<tr>
<td>Bending B, gf.cm²/cm</td>
<td>0.0295</td>
<td>0.0281</td>
<td>0.0254</td>
<td>0.0226</td>
</tr>
<tr>
<td>2HB, gf.cm²/cm</td>
<td>0.0380</td>
<td>0.0372</td>
<td>0.0254</td>
<td>0.0226</td>
</tr>
<tr>
<td>Compression LC [-]</td>
<td>0.543</td>
<td>0.531</td>
<td>0.528</td>
<td>0.527</td>
</tr>
<tr>
<td>WC, gf.cm²/cm²</td>
<td>0.068</td>
<td>0.065</td>
<td>0.056</td>
<td>0.043</td>
</tr>
<tr>
<td>RC, %</td>
<td>56.82</td>
<td>58.31</td>
<td>60.98</td>
<td>77.98</td>
</tr>
<tr>
<td>Surface MIU [-]</td>
<td>0.231</td>
<td>0.229</td>
<td>0.219</td>
<td>0.206</td>
</tr>
<tr>
<td>MMD [-]</td>
<td>0.0130</td>
<td>0.0154</td>
<td>0.0144</td>
<td>0.0117</td>
</tr>
<tr>
<td>SMD, µm</td>
<td>4.65</td>
<td>4.65</td>
<td>3.67</td>
<td>3.62</td>
</tr>
<tr>
<td>Weight W, mg/cm²</td>
<td>13.56</td>
<td>13.26</td>
<td>13.01</td>
<td>13.18</td>
</tr>
<tr>
<td>Thickness To, mm</td>
<td>0.835</td>
<td>0.820</td>
<td>0.780</td>
<td>0.704</td>
</tr>
<tr>
<td>Tm, mm</td>
<td>0.583</td>
<td>0.558</td>
<td>0.550</td>
<td>0.542</td>
</tr>
</tbody>
</table>
Bending Properties

The values given in Table 3 show that 100% cotton fabric has the maximum bending rigidity in comparison to blended fabrics and 100% PLA fabric. The addition of the PLA component to cotton reduces the bending rigidity; the reduction is almost proportional to the blend percentage. The higher bending rigidity of cotton is due to higher diameter of cotton yarns in comparison to blended yarns and 100% PLA yarn. The bending rigidity and bending hysteresis are positively correlated to each other. As expected, the 100% cotton fabric shows the maximum hysteresis loss which is followed by cotton/PLA (80/20) and cotton/PLA (65/35) fabrics. The PLA (100%) fabric shows the lowest bending rigidity and hysteresis because of the lowest yarn diameter and smooth surface of fibres which results in lower inter-yarn friction.

Compression Properties

Compression properties of cotton fabrics such as fabric thickness at a pressure of 0.5 g/cm² (T₀) and 50 g/cm² (Tm), compressional linearity (LC), compressional energy (WC) and compressional resilience (RC) have been measured. The LC values of the samples are more or less in the same range. The low work compression values (WC) of PLA fabric shows that it has less compressibility than cotton. The lower yarn diameter of PLA also justify the results as the yarn is more compact. However, the recovery from compression (RC) of PLA material is better than cotton and cotton-rich blends. Even with 65/35 proportion, the compressional recovery is similar to that of cotton.

Surface Properties

The surface characteristics of a fabric influence the handle, comfort and aesthetic properties of the cloth. Cotton fabric shows higher coefficient of friction (MIU) and geometric roughness (SMD) than PLA fabric. Higher coefficient of friction of cotton is due to the surface characteristics of yarn like the hairiness, etc. PLA has a smooth surface structure and hence shows a lower friction value. The blended fabric friction falls in between cotton and PLA. The MIU and SMD values are not much affected with the addition of 20% PLA fibre in the blend. However, with 65/35 blend, the coefficient of friction and geometrical roughness shows a significant reduction, implying an increase in smoothness of fabric.

Hand Values of Fabrics

The results of primary and total hand values are shown in Table 4. These hand values are evaluated from the low-stress mechanical properties of fabrics. The fabric are evaluated for use as knitted innerwear application. It can be seen that the stiffness of cotton fabric are high as compared to PLA material. The smoothness value of PLA is high as compared to cotton and cotton-rich blends. The total hand values (THV) of samples are found to be in the range of 3.2 - 3.5, with PLA showing slightly better values than cotton.

The low-stress behavior of fabric is governed by fibre properties, yarn structure, fabric geometry and finish applied to the fabric. In the present investigation, the effect of fibre material on the low-stress mechanical behavior and fabric hand has been brought out and all other parameters like yarn structure, twist, knit design and fabric weight are kept almost at the same level. The fabrics are also not subjected to any kind of finishing treatment like softening finish. It has been found that with the addition of 20% PLA fibres to cotton, there is a significant positive change in the properties of fabrics. The changes become more pronounced at the higher level of 65/35 blend proportions. The total hand value (THV) of fabrics investigated ranges between 3.2 and 3.5.

References


Table 4 — Hand values of different single jersey fabrics

<table>
<thead>
<tr>
<th>Sample</th>
<th>Koshi (Stiffness)</th>
<th>Fukurami (Fullness &amp; Softness)</th>
<th>Numeri (Smoothness)</th>
<th>THV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>8.99</td>
<td>4.69</td>
<td>3.46</td>
<td>3.22</td>
</tr>
<tr>
<td>Cotton/PLA (80:20)</td>
<td>8.55</td>
<td>4.72</td>
<td>3.75</td>
<td>3.26</td>
</tr>
<tr>
<td>Cotton/PLA (65:35)</td>
<td>8.44</td>
<td>4.85</td>
<td>4.64</td>
<td>3.34</td>
</tr>
<tr>
<td>PLA</td>
<td>8.40</td>
<td>5.74</td>
<td>5.69</td>
<td>3.54</td>
</tr>
</tbody>
</table>