Mechanical behaviour of texturised jute and polypropylene blended needle-punched fabrics

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Cross-laid nonwoven fabrics of 80, 120 and 160 punches/cm² have been prepared from chemically-texturized jute (TJ) and blends of TJ and polypropylene (PP), using TJ as a major constituent, and the effects of blend proportion and punch density on flexural rigidity, density, tensile behaviour, stress relaxation and response to cyclic loading studied. Blending of PP with TJ improves the tenacity, initial modulus and extension at break of the nonwoven fabric at all levels of punch density. Stress decay suffered by the fabric subjected to stress relaxation is higher for the blended fabric in comparison to the TJ fabric at both low and high extension levels. Extension cycling lowers the tenacity of TJ and 80:20 TJ/PP fabrics. Permanent set suffered by the blended fabrics is generally lower in comparison to TJ fabric.

Keywords: Cyclic deformation, Needle-punched nonwoven, Polypropylene, Punch density, Stress relaxation, Texturized jute fibres

1 Introduction

Needle-punched nonwoven fabrics find wide applications as floor covering, underfelt, air-filtration medium, geotextile, thermal insulation medium, etc. In all of these applications, manmade fibres are the material of choice. Use of jute fibre in the manufacture of nonwoven fabrics is very limited and is restricted mainly to the heavy needle-felts used by the automobile industry as filling and insulating media. However, in order to diversify the use of jute fibre, attempts are being made to develop jute or chemically-texturized jute nonwoven fabrics alone or in blends with manmade fibres for various applications. In most of the applications, the fabric properties such as tensile properties, relaxation behaviour after deformation at low or expectedly high extension, response to cyclic deformation and flexural behaviour with respect to fibre and process variables are of importance. Sengupta et al. reported the effect of needling parameters on the tensile behaviour of jute nonwoven fabrics prepared from randomly laid web and reinforced with a jute hessian fabric. They observed that the tensile properties of such fabrics depend largely on the tensile properties of reinforcing material and that the use of chemically-texturized jute results in nonwovens with superior tensile properties. In the present investigation, the effects of punch density and blend composition on the tensile properties, relaxation behaviour, response to cyclic loading and flexural properties of chemically-texturized jute and polypropylene blended cross-laid nonwoven fabrics having texturized jute as a major constituent have been studied.

2 Materials and Methods

2.1 Materials

Tossa jute of grade TD-5 was used for chemical texturization. Polypropylene fibre (Denekalon) of 120 mm staple length and 1.7 tex linear density was used for blending with chemically-texturized jute. Physical properties of jute, chemically-texturized jute (TJ) and polypropylene fibres were measured following the method of Samajpati et al. and are given in Table 1.

2.2 Chemical Texturization of Jute

The bundles of jute reeds were cut to 30 cm length and chemically-texturized with 18% NaOH
Table 1 - Physical properties of fibres

<table>
<thead>
<tr>
<th>Fibre type</th>
<th>Density g/cc</th>
<th>Linear density tex</th>
<th>Tenacity cN/tex</th>
<th>Extension at break %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jute</td>
<td>1.45</td>
<td>2.14</td>
<td>30.1</td>
<td>1.55</td>
</tr>
<tr>
<td>Chemically-texturized jute (TJ)</td>
<td>1.50</td>
<td>1.98</td>
<td>28.2</td>
<td>7.40</td>
</tr>
<tr>
<td>Polypropylene (PP)</td>
<td>0.92</td>
<td>1.70</td>
<td>38.7</td>
<td>51.00</td>
</tr>
</tbody>
</table>

solution at 30°C for 30 min, keeping the jute-to-liquor ratio at 1:20. The texturized jute was then washed thoroughly in running water, soured with 1% acetic acid solution for 20 min, washed with water till free from acid and dried in air.

2.3 Preparation of Nonwoven Fabric

Chemically-texturized jute (TJ) reeds were stapled to 70 mm length. Both TJ and polypropylene (PP) fibres were opened manually before blending them in various proportions (80:20, 70:30 and 60:40 TJ/PP) following stack-mixing technique. Nonwoven fabrics (area density, around 300 g/m²) were prepared from both TJ and TJ/PP blended fabrics using a DILO nonwoven plant comprising a card, a camel-back cross-lapper and a needle loom (DILO ODII/6). Needled fabrics with needling densities of 80, 120 and 160 punches/cm² and a needle penetration of 13 mm were prepared using a 36 gauge RB needle. The delivery speed of the needle loom was kept about 20% higher than that of the feed.

2.4 Determination of Tensile Properties

The tensile properties of the nonwoven fabrics, in machine direction, were determined at 65% RH and 22-25°C on an Instron tensile testing machine. The test conditions were: test length, 10 cm; cross-head speed, 5 cm/min; and strip width, 2.5 cm (ref 6). The fabric stress at break was determined as follows:

\[
\text{Stress at break (cN / tex)} = \frac{\text{Breaking load (cN)}}{\text{Specimen width (mm)} \times \text{Fabric area density (g / m²)}}
\]

The initial modulus was evaluated as the ratio of stress and strain at 1% extension. Stress relaxation of the fabric samples was determined by stretching the fabric strips to 20% or 60% of their average breaking extensions and allowing them to relax for 5 min at the extended condition. The stress decay, characterizing the stress relaxation, was calculated as follows:

\[
\text{Stress decay (%)} = \left(\frac{r_1 - r_2}{r_1}\right) \times 100
\]

where \(r_1\) and \(r_2\) are the loads on the fabric at the onset of the stress decay and after stress decay for 5 min respectively.

The fabric samples were further extended to break after stress relaxation and the respective breaking load and extension values were evaluated.

The fabric strips from each specimen were also subjected to extension cycling at 20% or 50% of average breaking extensions for 10 cycles before straining them to break. Permanent set (%) on extension cycling was taken to be equivalent to the % strain at zero load condition after extension cycling. In each case, the average of 10 test results has been reported after testing the statistical significance of the difference between the mean values at 5% level.

2.5 Flexural Rigidity

Flexural rigidity of the fabric samples was determined by measuring the bending length as per the standard cantilever method.

3 Results and Discussion

Jute is a strong, coarse and brittle fibre with very low extensibility (0.8 - 2.0%). Polypropylene (PP), on the other hand, is a flexible, highly extensible, strong and tough fibre with a very low density (Table 1). Jute is extremely prone to break during its processing into nonwoven fabric and a jute web shows a wide distribution of fibre length. However, jute, when chemically-texturized, has a considerably higher extensibility, mainly due to its crimped nature and fineness. Thus, TJ has got a better form retention characteristics than the jute and is expected to be more compatible with PP. However, TJ loses much of its crimp during opening and carding operations making the fibre vulnerable to the needling operation when fibre breaks might occur.

3.1 Density and Flexural Rigidity

During needling, the barbed needles are continuously pushed into and through the fibrous
web to produce a coherent structure with corresponding changes in mass per unit area and thickness, resulting in increases in density, strength and rigidity of the layered web. However, the effect of this process of consolidation by needling would be largely determined by the response of the fibre in the web to the needling process. If the fibre is brittle, as is the case with TJ, the extent of consolidation might not be of the degree which can be achieved with an extensible and tough fibre like PP, particularly at a higher level of punch density. Blending of PP, which is far more flexible and has a considerable lower bulk density, would generate two opposing responses to the needling process. While its lower density and higher flexibility than TJ would tend to make the fabric more flexible and bulky (low density and fineness), its toughness and higher extensibility would abet the consolidation process during needling. TJ; the lowering of flexural rigidity with increase in punch density is a consequence of higher breakage of TJ, the major fibre component, at higher punch density. At a punch density level of 120 punches/cm², incorporation of PP to the extent of 20% with TJ results in lowering of flexural rigidity and bulk density. However, as the PP component in the blend increases to 30% level, both bending rigidity and bulk density increase. This is followed by a slight decrease in both of these attributes as the PP content is further increased to 40%. Evidently, at this punch density, the 30% PP blended fabric has the highest level of fibre consolidation which more than compensates the lower rigidity and bulk density values due to PP.

It is observed from Table 2 that as the PP content in the blend is increased from 30% to 40%, both the bulk density and the flexural rigidity of the fabric decrease for 80 and 120 punches/cm² while they increase for 160 punches/cm². This is apparently due to the fact that at 40% PP content the punch density levels of 80 and 120 punches/cm² are not sufficient to bring about the necessary consolidation in the web as the number of fibres per unit volume of the web increases as a result of lower bulk density and higher fineness of PP. Thus, at these punch density levels, the fabric property is mainly influenced by the properties of PP fibre, as explained earlier, and hence both flexural rigidity and bulk density decrease. However, the increase in punch density to 160 punches/cm² results in consolidation of the fabric to a degree which more than compensates the lower density and higher flexibility due to PP fibre and as a result the flexural rigidity and bulk density values of the fabric increase.

### Table 2—Effect of punch density and blend composition on bulk density and bending rigidity of TJ:PP blended nonwoven fabrics

<table>
<thead>
<tr>
<th>Punch density punches/cm²</th>
<th>Blend composition TJ:PP</th>
<th>Flexural rigidity mg/tex</th>
<th>Bulk density g/cc</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>80:20</td>
<td>4.03</td>
<td>0.105</td>
</tr>
<tr>
<td></td>
<td>70:30</td>
<td>6.20</td>
<td>0.109</td>
</tr>
<tr>
<td></td>
<td>60:40</td>
<td>4.43</td>
<td>0.088</td>
</tr>
<tr>
<td>120</td>
<td>100:00</td>
<td>4.83</td>
<td>0.117</td>
</tr>
<tr>
<td></td>
<td>80:20</td>
<td>3.52</td>
<td>0.112</td>
</tr>
<tr>
<td></td>
<td>70:30</td>
<td>5.32</td>
<td>0.118</td>
</tr>
<tr>
<td></td>
<td>60:40</td>
<td>4.98</td>
<td>0.103</td>
</tr>
<tr>
<td>160</td>
<td>80:20</td>
<td>1.76</td>
<td>0.102</td>
</tr>
<tr>
<td></td>
<td>70:30</td>
<td>5.22</td>
<td>0.127</td>
</tr>
<tr>
<td></td>
<td>60:40</td>
<td>5.90</td>
<td>0.132</td>
</tr>
</tbody>
</table>

TJ—Texturized jute, and PP—Polypropylene

3.2 Tensile Properties

According to Hearle and Sultan, during tensile deformation of needle-punched nonwoven, the fibre curvatures generate normal inward cumulative pressure which restricts the fibre slippage and increases inter-fibre friction. If that is strong enough and if all the fibres are gripped at some points along their lengths, then a strong coherent and self-locking needled fabric will be formed. The effects of punch density and blend proportion on the tensile properties of needled fabric are given in Table 3 and Figs 1 and 2.
3.2.1 Tenacity and Elongation at break

100% TJ nonwoven with 120 punches/cm² shows very low tenacity and elongation at break which improve on increasing the polypropylene content in the blend. It is observed from Table 3 that in case of high TJ containing fabric (TJ/PP, 80:20), the tenacity increases with increase in punch density from 80 to 120 punches/cm² due to higher entanglement of fibres but decreases on further increase in punch density to 160 punches/cm², largely due to the breakage of jute component, resulting in lower entanglement and less effective fibre contribution towards strength. The fibre breakage can also be supported by low bulk density and the rigidity of needled fabric (Table 2). In case of low TJ containing fabric (TJ/PP, 70:30 and 60:40), high needling density improves tenacity and decreases elongation at break owing to greater entanglement and lower jute fibre breakage due to presence of fairly large proportion of highly extensible fibre by number. Greater entanglement and consolidation in the fabric structure decrease slippage of fibres, resulting in lower elongation at break.

Fig. 1 shows the stress-strain curves demonstrating the effect of needling density and blend composition on tensile deformation process. Purdy\textsuperscript{10} reported that the ideal load-elongation curve of a needle-punched nonwoven fabric is characterized by two deformation regions. The initial region shows negligible resistance to deformation and this is followed by a jammed, stiff region. Moreover, before reaching to maximum breaking load, load-elongation curve shows an acute step break effect. In the present study, it is observed that the initial region is not defined enough, specially as texturized jute component or punch density increases, this region does not exist at all (Fig. 2). This can be explained by highly interlocked, consolidated structure and high inter-fibre friction which do not allow the fibre straightening and slipping at very low strains. The load- elongation curve of texturized jute fabric shows mild stick-slip breaks before rupture but with the incorporation of PP fibres in the web this phenomenon disappears (Fig.2).

<table>
<thead>
<tr>
<th>Punch density punches/cm²</th>
<th>Blend composition TJ/PP</th>
<th>Tenacity cN/tex</th>
<th>Extension at break %</th>
<th>Initial modulus cN/tex</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>80:20</td>
<td>0.38</td>
<td>53.0</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>70:30</td>
<td>0.44</td>
<td>62.7</td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td>60:40</td>
<td>0.68</td>
<td>75.4</td>
<td>0.53</td>
</tr>
<tr>
<td>120</td>
<td>100:00</td>
<td>0.11</td>
<td>25.0</td>
<td>0.77</td>
</tr>
<tr>
<td></td>
<td>80:20</td>
<td>0.43</td>
<td>39.2</td>
<td>0.97</td>
</tr>
<tr>
<td></td>
<td>70:30</td>
<td>0.66</td>
<td>49.8</td>
<td>1.19</td>
</tr>
<tr>
<td></td>
<td>60:40</td>
<td>1.02</td>
<td>67.2</td>
<td>1.24</td>
</tr>
<tr>
<td>160</td>
<td>80:20</td>
<td>0.23</td>
<td>36.1</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>70:30</td>
<td>0.68</td>
<td>50.6</td>
<td>1.33</td>
</tr>
<tr>
<td></td>
<td>60:40</td>
<td>1.18</td>
<td>57.0</td>
<td>2.44</td>
</tr>
</tbody>
</table>

Fig.1—Stress-strain curves of needle-punched fabrics [ A—160 punches/cm²; TJ/PP, 60:40; B—120 punches/cm²; TJ/PP, 60:40; C—80 punches/cm²; TJ/PP, 60:40; D—120 punches/cm²; TJ/PP, 70:30; E—120 punches/cm²; TJ/PP, 80:20; and F—120 punches/cm²; TJ/PP, 100:0]

Fig.2—Load-elongation curves of needle-punched fabrics [A—120 punches/cm²; TJ/PP, 70:30; and B—120 punches/cm²; TJ/PP, 100:0]
3.2.2 Initial Modulus

It is evident from Table 3 that 100% TJ fabric with 120 punches/cm² shows comparatively low initial modulus and that with increase in PP component in the web, the initial modulus increases. A similar trend is also observed in fabrics with 160 punches/cm² and can be explained by higher interlocked and consolidated structure due to the presence of highly extensible PP fibres. The deviation from this trend as observed in fabrics with 80 punches/cm² is apparently due to less interlocking and low density (Table 2) which allow fibre straightening and slippage, resulting in low initial modulus for 60:40 TJ/PP blended fabric. The stress-strain curves of TJ and some TJ/PP blended nonwoven fabrics (Fig. 1) show the response of such fabrics to tensile stress as discussed above.

3.3 Stress Relaxation and Rupture after Stress Relaxation

Table 4 shows that stress decay (%) is lowest for the 100% TJ fabric and it increases on blending PP with TJ in all the proportions both at low (0.2BE) and high (0.6BE) extension levels. Apparently, this is due to the high extensibility and viscoelastic nature of the PP fibre. However, at the highest punch density level (160 punches/cm²), the stress decay registers a fall for the 40% PP blended fabric at 0.2BE level, possibly due to the combined effect of highly entangled PP structure in the web and lower incidence of fibre rupture owing to the presence of a large proportion of PP fibres which minimize fibre slippage.

It is apparent from Table 5 that stress relaxation improves the tenacity of the fabrics having highest punch density and higher PP content for relaxation at low level of extension. At the higher level of extension, however, the improvement is observed at all levels of punch density for fabrics containing 30% and 40% PP. TJ and 20% PP blended fabrics fail to show any improvement in tenacity upon stress relaxation. On the contrary, TJ fabric sample exhibits lowering of tenacity after stress relaxation at the higher extension level. The improvement in tenacity might be attributed to the removal of localized stress concentrations in the fabrics during the stress decay process, resulting in a more uniform fabric. The lowering of tenacity in case of TJ after relaxation at higher extension level appears to be a consequence of disposition of the fabric structure due to flow of TJ fibres of wide length distribution.

3.4 Permanent Set and Rupture after Cyclic Deformation

The effects of extension cycling (10 cycles) at two different levels of extension on the elasticity of the fabric, as indicated by the permanent set (%) achieved after extension cycling, and on fabric tenacity are shown in Tables 4 and 5 respectively. It is apparent from Table 4 that blending of PP with TJ improves the elasticity of the nonwoven fabric as is evident by the lower permanent set.

<table>
<thead>
<tr>
<th>Punch density punches/cm²</th>
<th>Blend composition TJ:PP</th>
<th>Stress decay (%) after stress relaxation</th>
<th>Permanent set (%) after 10 extension cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.2 BE</td>
<td>0.6 BE</td>
</tr>
<tr>
<td>80</td>
<td>80:20</td>
<td>30.4</td>
<td>35.8</td>
</tr>
<tr>
<td></td>
<td>70:30</td>
<td>30.8</td>
<td>36.7</td>
</tr>
<tr>
<td></td>
<td>60:40</td>
<td>32.2</td>
<td>38.5</td>
</tr>
<tr>
<td>120</td>
<td>100:00</td>
<td>10.2</td>
<td>27.2</td>
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<td>80:20</td>
<td>30.7</td>
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<td></td>
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<td>33.3</td>
<td>39.7</td>
</tr>
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<td>160</td>
<td>80:20</td>
<td>30.0</td>
<td>34.6</td>
</tr>
<tr>
<td></td>
<td>70:30</td>
<td>32.2</td>
<td>38.2</td>
</tr>
<tr>
<td></td>
<td>60:40</td>
<td>24.4</td>
<td>35.9</td>
</tr>
</tbody>
</table>

BE—Breaking extension
Table 5—Fabric tensile characteristics at rupture after stress relaxation and cyclic deformation

<table>
<thead>
<tr>
<th>Punch density punches/cm²</th>
<th>Blend composition TJ:PP</th>
<th>Tenacity, cN/tex</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rupture after stress relaxation</td>
<td>Rupture after 10 extension cycles</td>
</tr>
<tr>
<td></td>
<td>0.2 BE 0.6 BE</td>
<td>0.2 BE 0.5 BE</td>
</tr>
<tr>
<td>80</td>
<td>80:20</td>
<td>0.400 0.420</td>
</tr>
<tr>
<td></td>
<td>70:30</td>
<td>0.480 0.510</td>
</tr>
<tr>
<td></td>
<td>60:40</td>
<td>0.700 0.870</td>
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<tr>
<td>120</td>
<td>100:00</td>
<td>0.130 0.086</td>
</tr>
<tr>
<td></td>
<td>80:20</td>
<td>0.440 0.460</td>
</tr>
<tr>
<td></td>
<td>70:30</td>
<td>0.670 0.940</td>
</tr>
<tr>
<td></td>
<td>60:40</td>
<td>1.040 1.170</td>
</tr>
<tr>
<td>160</td>
<td>80:20</td>
<td>0.210 0.240</td>
</tr>
<tr>
<td></td>
<td>70:30</td>
<td>0.840 0.910</td>
</tr>
<tr>
<td></td>
<td>60:40</td>
<td>1.350 1.540</td>
</tr>
</tbody>
</table>

BE—Breaking extension

values for 20% and 30% PP blended fabrics. For 60:40 TJ/PP blended fabric, the improvement in elasticity is perceptible only at the highest punch density level, owing to larger number of fibres present in the web due to lower density of PP. Among the blended fabrics, the degree of permanent set increases with increase in PP content at a particular punch density level while it decreases with increase in punch density. Apparently, blending of 20-30% PP with TJ lowers the extent of fibre breakage, improves the length distribution patterns and quality of the fibrous web in such a manner that the web responds favourably to the needling process, resulting in higher entanglement and consolidation of the fibres, leading to a strong and more elastic web. It is evident from Table 5 that extension cycling lowers the tenacity values of TJ and 20% PP blended TJ fabrics. The tenacity values of 30% and 40% PP blended fabrics show some improvement on extension cycling. Apparently, the TJ and 20% PP blended fabrics are fatigued on account of extension cycling, causing lowering of breaking stress. On the other hand, 30% and 40% PP blended fabrics get rid themselves of some localised stress concentrations during extension cycling due to preponderance of highly extensible PP fibres of uniform length in the web, which reorient to result in a more compact and stronger fabric.

4 Conclusions

Physical, mechanical, tensile relaxation and elasticity characteristics of the texturized jute and polypropylene (20%, 30% and 40%) blended needle-punched nonwoven fabrics largely depend on the punch density employed in preparing the fabrics. For 20% and 30% PP blended fabrics, the best results are obtained at 120 punches/cm², while for 40% PP blended fabric, at the 160 punches/cm². This is apparently due to the increase in the number of fibres per unit volume of fibrous webs with increase in PP component in the web, which, in turn, necessitates increasing level of punch density to achieve the desired consolidation of the fibrous web.

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References