Effect of linear density, twist and blend proportion on some physical properties of jute and hollow polyester blended yarn

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The effect of yarn linear density, twist density and blend proportion on bulk density, tenacity, breaking extension, work of rupture, flexural rigidity, hairiness and friction of jute-hollow polyester blended yarns made on conventional jute spinning system has been studied. Box and Behnken experimental statistical design has been used to study the individual and interactive effects of independent variables. It is observed that the bulk density and coefficient of static friction increase initially with the increase in yarn linear density as well as twist. After reaching the maximum value, further increase in these parameters decreases the properties. In case of all jute yarn, the maximum tenacity reaches at 195 twists/m and 145 tex. However, for 60% jute blended yarn, these values are 210 twists/m and 155 tex. The minimum breaking extension attains at 135 tex with 220 twists/m for all jute yarn and 185 tex with 220 twists/m for 60% jute blended yarn. The specific work of rupture decreases with the increase in jute content in the blend. The maximum specific work of rupture is obtained at 185 tex with 230 twists/m in 60% jute blended yarn. However, in case of all jute yarn the maximum values are obtained at 200 twists/m and 135 tex. The specific flexural rigidity of yarn is higher for all jute yarn compared to that for jute blended yarn. The lowest yarn hairiness is observed at 160tex with 215 twists/m for all jute yarn.

Keywords: Bulk density, Flexural rigidity, Hairiness, Jute, Hollow polyester fibre, Static friction, Tensile properties, Yarn friction

1 Introduction

Jute, the annually renewable and one of the cheapest commercially available high modulus natural fibres, is well known to all as packaging material and carpet backing. Apart from this, today jute finds a diversified path as blended products, such as furnishing material, interior decoration, fashion garments, jute ornaments and blankets. Blending of man-made fibre with jute introduces some improved properties, like bulk, elongation, regularity, luster, etc. Thus, the properties of blended yarn depend on type of fibre, quantity and method of blending. Ali et al. has studied the properties of sulphonated jute fibre and its blends (65% jute) with cotton, rayon, acrylic, polyester and silk waste, and compared their fabric properties with pure cotton and pure sulphonated jute fabrics. Cumming and Atkinson reported that blending of 10% of terylene with jute is suitable for sewing thread in jute coal bag. Rotor-spun short staple jute-polyester yarns have been texturised and compared with apron draft jute frame spun texurised yarn. It is found that the jute and polyester (70:30) blended rotor-spun yarn shows the optimum result.

Recently, Debnath et al. studied various properties of bulked yarn developed from blends of jute and hollow polyester and compared that yarn with commercial woollen and acrylic bulk yarns. The study shows that jute-hollow polyester blended bulk yarn has higher bulk over similar commercial yarns due to low yarn packing. It is evident that various physical properties and their coefficient of variations of jute-hollow polyester and jute-viscose blended yarns are superior compared to all jute yarn.

The main objective of this study is to understand the property-parameter interactions of jute-hollow polyester blended yarns prepared on the conventional jute spinning system. Hollow polyester is different than any other synthetic fibres and still its blending with jute is not explored. It is expected that the blending of hollow polyester with jute may improve some properties like bulk, resilience, softness, luster and fineness of the yarn. Jute has high modulus, good luster and high rigidity. Hence, in the present work, attempts have been made to study the effect of yarn linear density, twist density and blend ratio on the bulk density, tenacity, breaking extension, work of rupture, flexural rigidity, hairiness and friction of jute-hollow polyester blended yarns.

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2 Materials and Methods

2.1 Materials

Tossa jute fibre of TD-3 grade and hollow polyester (0.66 tex fineness and 110 mm length) fibres were selected for the development of jute based yarns. The properties of fibres are shown in Table 1.

2.2 Methods

2.2.1 Spinning of Blended Yarn

The blending of jute-hollow polyester was carried out on conventional jute spinning system. The blending was done at first drawing frame of 3-drawing jute spinning system. The blended sliver obtained from the finisher-drawing machine was spun into yarn on a Mackie apron draft jute spinning machine. The twist for all these yarns was at ‘Z’ direction. The linear density of yarn, twist density (twists/m) and blend ratio of jute and polyester hollow fibres were selected based on the Box and Behnken factorial design. The bulk density of yarn (g/cm³) was calculated using the following relationship:

\[
\text{Bulk density of yarn (g/cm}^3\text{)} = \frac{(\text{Yarn linear density in tex}) \times 1.2727 \times 10^{-5}}{(\text{Yarn diameter in cm})^2}
\]

The diameter of yarn samples was measured with a projection microscope (magnification ×30) under constant tension. An average of 100 readings was considered.

2.2.3 Evaluation of Tensile Properties

The tensile properties were tested on the Instron tensile tester at 610 mm gauge length and 300 mm/min crosshead speed. The tenacity and corresponding breaking extension (%) were observed from the load-elongation curve. The average of fifty readings was taken (Table 3). The specific work of rupture was calculated from the area under stress-strain curves considering the corresponding tex value of the yarn.

2.2.4 Evaluation of Specific Flexural Rigidity

Flexural rigidity of the yarn was evaluated using a mandrel to prepare the yarn ring of 2.95 cm diameter. The yarn ring was gripped and hung on a hook and undistorted length was measured. Now, a dead load of 0.434 g was suspended on the yarn ring to achieve a distortion of about 20%. After 60s from the time of loading the actual distorted loop length was measured. The flexural rigidity was calculated from the method explained by Beevers and the specific flexural rigidity was calculated by the method given by Morton and Hearle.

2.2.5 Evaluation of Yarn Hairiness

Hairiness of the yarns was measured using the JTRL jute hairiness meter at a yarn speed of 27 m/min, keeping the time interval of 5s. The number of hairs at 3 mm hair length setting was recorded. The number of hair at this hair length setting was computed as number of hairs equal to or greater than 3 mm length from average yarn diameter. An average of fifty readings was taken.

2.2.6 Evaluation of Yarn Static Friction

A friction tester with inclined plane principle was used to measure the coefficient of yarn-to-metal (steel) static friction. A metal (steel) rider of a fixed weight (4.3 mN) was allowed to slide over the yarn gripped between two jaws. Distance between two jaws was 0.27 m. The yarn sample was gripped between a fixed jaw and a movable jaw with a tension of 0.166 cN/tex. The inclination of yarn was increased.
from 0° with the speed of 2%/s. The friction angle was noted from the scale immediately when the rider was started slipping. Finally, the coefficient of static friction was calculated as \( \tan \theta \), where \( \theta \) is the degree noted from the scale when the rider starts falling.

### 3 Results and Discussion

Table 3 shows the experimental values of bulk density, tenacity, breaking extension, work of rupture, flexural rigidity, hairiness and friction of jute and hollow polyester blended yarn using Box and Behnken factorial design. Table 4 shows the coefficients and constants of the response surface equations. The \( R^2 \) and \( F \) values show good and significant relationship between the predicted and the experimental values. The contour diagrams (Figs 1-7) were drawn to understand the interactions of tex, twist and blend proportion with different properties of yarn using a standard statistical software.

#### Table 3 — Experimental values of physical properties

<table>
<thead>
<tr>
<th>Sample code</th>
<th>Diameter mm</th>
<th>Bulk density g/cm³</th>
<th>Tenacity cN/tex</th>
<th>Breaking extension %</th>
<th>Specific work of rupture mJ/tex-m</th>
<th>Specific flexural rigidity (mN.mm² × 10⁻⁴)/tex²</th>
<th>Hairiness hairs/m</th>
<th>Coefficient of static friction, ( \mu )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.47</td>
<td>0.743</td>
<td>8.96</td>
<td>1.67</td>
<td>0.68</td>
<td>64.56</td>
<td>43.45</td>
<td>0.482</td>
</tr>
<tr>
<td>2</td>
<td>0.52</td>
<td>0.607</td>
<td>8.29</td>
<td>1.81</td>
<td>0.71</td>
<td>77.77</td>
<td>36.78</td>
<td>0.459</td>
</tr>
<tr>
<td>3</td>
<td>0.66</td>
<td>0.579</td>
<td>10.47</td>
<td>2.25</td>
<td>0.94</td>
<td>86.17</td>
<td>36.52</td>
<td>0.518</td>
</tr>
<tr>
<td>4</td>
<td>0.63</td>
<td>0.635</td>
<td>8.94</td>
<td>2.05</td>
<td>0.77</td>
<td>88.10</td>
<td>37.96</td>
<td>0.530</td>
</tr>
<tr>
<td>5</td>
<td>0.56</td>
<td>0.524</td>
<td>8.09</td>
<td>4.19</td>
<td>1.92</td>
<td>60.79</td>
<td>53.04</td>
<td>0.486</td>
</tr>
<tr>
<td>6</td>
<td>0.47</td>
<td>0.743</td>
<td>10.74</td>
<td>1.18</td>
<td>0.62</td>
<td>134.87</td>
<td>30.45</td>
<td>0.563</td>
</tr>
<tr>
<td>7</td>
<td>0.70</td>
<td>0.514</td>
<td>9.10</td>
<td>2.73</td>
<td>1.08</td>
<td>77.36</td>
<td>33.01</td>
<td>0.491</td>
</tr>
<tr>
<td>8</td>
<td>0.59</td>
<td>0.724</td>
<td>12.69</td>
<td>2.13</td>
<td>1.07</td>
<td>91.91</td>
<td>44.24</td>
<td>0.576</td>
</tr>
<tr>
<td>9</td>
<td>0.59</td>
<td>0.596</td>
<td>7.98</td>
<td>2.57</td>
<td>0.93</td>
<td>60.57</td>
<td>51.36</td>
<td>0.468</td>
</tr>
<tr>
<td>10</td>
<td>0.58</td>
<td>0.617</td>
<td>10.77</td>
<td>1.36</td>
<td>0.65</td>
<td>146.85</td>
<td>51.04</td>
<td>0.533</td>
</tr>
<tr>
<td>11</td>
<td>0.46</td>
<td>0.980</td>
<td>7.49</td>
<td>2.90</td>
<td>1.34</td>
<td>106.91</td>
<td>68.58</td>
<td>0.479</td>
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<tr>
<td>12</td>
<td>0.49</td>
<td>0.864</td>
<td>9.05</td>
<td>1.25</td>
<td>0.54</td>
<td>126.95</td>
<td>76.64</td>
<td>0.686</td>
</tr>
<tr>
<td>13</td>
<td>0.45</td>
<td>1.024</td>
<td>8.19</td>
<td>1.65</td>
<td>0.61</td>
<td>98.99</td>
<td>40.84</td>
<td>0.679</td>
</tr>
<tr>
<td>14</td>
<td>0.44</td>
<td>1.072</td>
<td>8.25</td>
<td>1.63</td>
<td>0.55</td>
<td>97.73</td>
<td>37.50</td>
<td>0.695</td>
</tr>
<tr>
<td>15</td>
<td>0.43</td>
<td>1.122</td>
<td>8.67</td>
<td>1.72</td>
<td>0.67</td>
<td>98.68</td>
<td>33.71</td>
<td>0.683</td>
</tr>
</tbody>
</table>

#### Table 4 — Response surface equation and coefficient of multiple correlation of physical properties

<table>
<thead>
<tr>
<th>Response</th>
<th>Response surface equation</th>
<th>Coefficient of multiple correlation ( R^2 )</th>
<th>Coefficient of multiple correlation ( F_{0.5} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk density</td>
<td>(-25.6325159 + 0.625856X_1 + 0.1640979X_2 + 0.0851262X_3 - 0.0002391X_1^2 - 0.0003818X_2^2 - 0.0000404X_3 + 0.00000699X_1X_2 - 0.0000019X_1X_3 - 0.0000835X_2X_3)</td>
<td>0.8240</td>
<td>2.60</td>
</tr>
<tr>
<td>Tenacity</td>
<td>(-13.53365312 - 0.23044705X_1 + 0.40714533X_2 - 0.1112343X_2 + 0.0008611X_1^2 - 0.00074443X_2^2 + 0.00180322X_3^2 - 0.00031561X_1X_2 + 0.00034559X_1X_3 - 0.00077279X_2X_3)</td>
<td>0.9754</td>
<td>22.00</td>
</tr>
<tr>
<td>Breaking extension</td>
<td>(7.110001063 - 0.15159648X_1 + 0.19294484X_2 - 0.31331527X_3 + 0.000342315X_1^2 - 0.000339659X_2^2 + 0.00120733X_3^2 - 0.00001338X_1X_2 + 0.000288407X_1X_3 - 0.0000288407X_2X_3)</td>
<td>0.9642</td>
<td>15.00</td>
</tr>
<tr>
<td>Specific work of</td>
<td>(1.98632586 - 0.08728958X_1 + 0.11137267X_2 - 0.15163983X_3 + 0.000020424X_1^2 - 0.00016861X_2^2 + 0.00083232X_3^2 - 0.00070886X_1X_2 + 0.00046677X_1X_3 + 0.000033527X_2X_3)</td>
<td>0.9502</td>
<td>10.60</td>
</tr>
<tr>
<td>Yarn flexural</td>
<td>(-1477.7128107 + 8.0003625X_1 + 4.3864306X_2 + 9.1891166X_3 - 0.0161447X_1^2 + 0.00000492X_2^2 + 0.0299212X_3^2 - 0.00049481X_1X_2 - 0.0216085X_1X_3 - 0.0425858X_2X_3)</td>
<td>0.9510</td>
<td>10.77</td>
</tr>
<tr>
<td>Yarn hairiness</td>
<td>(1761.787 + 1.152X_1 - 13.914X_2 - 8.356X_3 - 0.009X_1^2 + 0.031X_2^2 + 0.033X_3^2 + 0.003X_1X_2 + 0.012X_1X_3 + 0.005X_2X_3)</td>
<td>0.8511</td>
<td>3.17</td>
</tr>
<tr>
<td>Coefficient of</td>
<td>(-1.174356E+01 + 2.528813E-02X_1 + 9.146463E-02X_2 + 5.244728E-03X_3 - 8.460906E-05X_1^2 - 2.301788E-04X_2^2 + 1.405246E-04X_3^2 + 1.21058E-05X_1X_2 - 2.6E-06X_1X_3 + 9.009116E-05X_2X_3)</td>
<td>0.9389</td>
<td>0.854</td>
</tr>
</tbody>
</table>

\( X_1 \) = linear density (tex); \( X_2 \) = twist density (twists/m); and \( X_3 \) = blend proportion (jute and hollow polyester).
3.1 Bulk Density

Figure 1 depicts the effect of yarn linear density and twist density on yarn bulk density for 60:40 and 100:0 jute-hollow polyester blended yarns. It is found that the bulk density of jute:polyester blended yarn initially increases with the increase in yarn linear density and reaches to a maximum value. Further increase in linear density of yarn shows the decreasing trend in bulk density. This phenomenon has also been observed with the increase in twist density of yarn. Yarn becomes more compact with the increase in twist at initial level due to lateral forces generated by the fibres, resulting in higher value of yarn bulk density. Further increase in twist may lead to a drop in bulk density due to contraction in yarn structure. Increase in yarn linear density for a particular twist level initially gives more compact structure resulting in reduction in bulk density. But at very high linear density for the same twist, contraction in yarn structure occurs which leads to lower yarn bulk density.

It is apparent that the yarn bulk density decreases with the reduction in jute content in blend. This is because of the introduction of finer, bulkier and lower density hollow polyester fibre.

3.2 Tenacity

Figure 2 shows the effect of yarn linear density and twist on tenacity for 60:40 and 100:0 jute-hollow polyester blends. It is observed that the tenacity of...
jute-polyester blended yarn increases with the increase in jute content in the blend. With the increase in twist, tenacity initially increases, reaches to a maximum point and thereafter it decreases. This phenomenon is more prominent at low linear density and low jute content levels (Fig. 2a). In case of all jute yarn (Fig. 2b), the tenacity decreases with the increase in twist. This may be due to the fact that the obliquity effect attains at much lower twist density in case of all jute yarn as compared to blended yarn.

With the increase in linear density, initially tenacity shows little decrease, but thereafter it increases (Fig. 2). To justify the initial decrease in tenacity, the number of fibres in the yarn cross-section plays an important role. At very low linear density, the number of fibres in the yarn cross-section is also low and the given twist density disturbs the uniformity of the yarn due to fibre slippage. This results in higher imperfections, which leads to the decrease in tenacity. However, with the increase in linear density at a given twist level, the cohesive force developed among the fibres results in the increase in tenacity. These trends hold good at the level of 80% jute content in the blend.

In case of all jute yarn, the maximum tenacity level reaches at approximately 195 twists/m and 145 tex. However, for 60% jute blended yarn these values are approximately 210 twists/m and 155 tex.

3.3 Breaking Extension

The effects of yarn linear density and twist density on breaking extension of the jute-polyester blended yarn at two different blend levels are shown in Fig. 3. Breaking extension decreases significantly in case of all jute yarn as compared to that in case of blended yarn.

It is found that the increase in linear density of yarn decreases the breaking extension for 60% jute blended yarn, whereas it increases for all jute yarn. The amount of fibres per unit cross-section of yarn increases with the increase in linear density at a given twist. As the number of fibre increases, the fibre cohesiveness also increases, ultimately reducing the fibre-to-fibre slippage during tensile loading, resulting in lower breaking extension. However, in case of all jute yarn, the increase in linear density results in higher obliquity and damage of fibres in the yarn, causing higher extension.

With the increase in twist, the effect on breaking extension is very prominent at the high level of linear density for 60% jute blended yarn and at low level for 100% jute. In such cases, breaking extension initially decreases and then increases with the increase in twist. The initial decrease in breaking extension is due to increase in cohesiveness of fibres, whereas the subsequent increase is mainly due to obliquity of fibres in the yarn.

The minimum breaking extension was observed at 135 tex and 220 twists/m for jute yarn and at 185 tex and 220 twists/m for 60% jute blended yarn.

3.4 Specific Work of Rupture

The specific work of rupture decreases with the increase in jute content in the blend (Fig. 4) because of decrease in breaking extension. It decreases with
the increase in linear density for 60% jute blended yarn due to decrease in breaking extension (Fig. 3b). But, for all jute yarn, the work of rupture increases with the increase in yarn linear density, due to increase in breaking extension.

With the increase in twist, the specific work of rupture increases prominently for 60% jute yarn at high linear density, whereas it decreases in case of all jute yarn. This phenomenon can also be explained by breaking extension values.

The maximum specific work of rupture is obtained at 230 twists/m and 185 tex for 60% jute blended yarn. However, in case of all jute yarn, the maximum values are obtained at 200 twists/m and 135 tex approximately.

3.5 Specific Flexural Rigidity

The contour graphs (Fig. 5) show the effect of yarn linear density and twist on specific flexural rigidity of 60:40 and 100:0 jute-polyester blended yarns. With the increase in the jute content in blend the rigidity of yarn increases, which is quite obvious due to the higher rigidity of jute fibre as compared to polyester fibre.

With the increase in linear density, the specific flexural rigidity increases initially but after reaching to maximum value it decreases. Increase in flexural
rigidity is due to the increase in coarseness of the yarn, whereas the decrease in rigidity is due to the obliquity attained in yarn structure and contraction due to twist. In case of 60% jute blended yarn the linear density at which these changes occur is around 180 tex. This value for 100% jute yarn is 155 tex.

The specific flexural rigidity increases with the increase in twist of 60:40 jute-polyester blended yarn. As the twist increases, the yarn becomes more compact resulting in higher rigidity. But, the trend is opposite in case of all jute yarn (Fig. 5b). This may be due to the contraction in the yarn and obliquity in the fibre. Subramanium et al.\textsuperscript{12} also obtained the similar trend in case of polyester and viscose blended spun yarns.

### 3.6 Hairiness

Figure 6 depicts the effect of yarn linear density and twist density on hairiness of 60:40 and 100:0 jute-polyester blended yarns.

Hairiness decreases with the increase in yarn linear density at any level of yarn twist in case of 60% jute blended yarn. Ghosh et al.\textsuperscript{13} have reported the similar phenomenon in case of all jute yarn. But in present study, for all jute yarn, it is observed that the hairiness increases up to 160 tex and then decreases. With the increase in yarn linear density, number of fibres in yarn cross-section increases. Hence, in lower linear density the majority of fibre ends comes out as hairs, but after a certain level of linear density, amount of fibres in yarn cross-section is sufficient to cover up majority of fibre ends which reduces the yarn hairiness. This tendency of hairiness increases with the increase in linear density.

It is observed from Fig. 6a that at lower twist level, the number of hairs is higher. The yarn hairiness reduces with the increase in twist density up to a certain level (215 twists/m) and further increase in yarn twist beyond 215 twists/m increases the hairiness again. However, previous research\textsuperscript{13,14} shows that the hairiness of all jute yarn decreases with the increase in twist multiplier. This may be due to the fact that the increase in twist initially consolidates the fibre mass, resulting in reduction of yarn hairiness. After a certain level of twist, the further increase results in higher fibre rotational speed and higher difference in tension between the outer and the innermost fibres in the spinning delta zone. This is responsible for outward movement of fibre ends from the yarn structure and is the probable reason for increase in hairiness.

### 3.7 Coefficient of Static Friction

The coefficient of static friction increases with the increase in twist, reaches to maximum and then shows declining trend with further increase in twist (Fig. 7a). Effect of linear density on coefficient of static friction also follows similar trend. Initially, with the increase in twist, the ridges formed on yarn surface produce an uneven surface, which increases the static friction. After a certain twist level, the ridges come very close to each other and behave as a smooth surface. The surface smoothness increases with the further increase in twist level.

Area of contact between the rider and the yarn surface during friction tests increases with the...

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**Fig. 6 — Effect of linear density and twist density on hairiness at (a) 60% and (b) 100% levels of jute content**
increase in yarn linear density. This results in the increase in coefficient of static friction. The contact area becomes constant beyond a certain linear density. Further increase in linear density decreases the unevenness of yarn surface for the same twist level, resulting in decrease in coefficient of static friction. Yarn hairiness may also be responsible for such behaviour of coefficient of static friction with the increase in twist and linear density, the similar trend is also observed in case of yarn hairiness.

It is also clear from Fig. 7 that with the increase in percentage of jute the coefficient of friction increases. This may be due to the surface roughness, stiffness and coarseness of jute component.

4 Conclusions

The study shows that the yarn linear density, twist and blend ratio have significant effect on physical and mechanical properties of the jute as well as jute-polyester blended yarn, as stated below:

4.1 Bulk density and coefficient of static friction increase initially with the increase in yarn linear density as well as twist. After reaching the maximum value, further increase of these parameters decreases the properties.

4.2 In case of all jute yarn, the maximum tenacity level reaches at approximately 195 twists/m and 145 tex. However, for 60% jute blended yarn these values are approximately 210 twists/m and 155 tex. Beyond these levels of twist and linear density, tenacity decreases.

4.3 The minimum breaking extension is observed at 135 tex and 220 twists/m for all jute yarn and at 185 tex and 220 twists/m for 60% jute blended yarn.

4.4 The specific work of rupture decreases with the increase in jute content in the blend. The maximum specific work of rupture is obtained at 185 tex with 230 twists/m for 60% jute blended yarn. However, in case of all jute yarn the maximum values are obtained at 200 twists/m and 135 tex approximately.

4.5 The specific flexural rigidity of yarn is higher for all jute yarn as compared to blended yarn. For all jute yarn, with the increase in linear density, it decreases initially and then increases. It also decreases with the increase in twist; but, the trend is opposite in case of blended yarn.

4.6 The lowest yarn hairiness is observed at 160tex with 215 twists/m for all jute yarn. But for yarn having 60% jute content, the lowest hairiness value is obtained at lower yarn linear density.

Industrial Importance: This study will be useful to the industry for designing jute-hollow polyester blended yarn with desired quality.

Acknowledgement

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References

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