Studies on tensile responses of wrap-spun jute yarn

A N Roy* & G Basu
National Institute of Research on Jute and Allied Fibre Technology, 12 Regent Park, Calcutta 700 040, India

Received 10 April 2000; accepted 24 May 2000

Wrap-spun jute yarns of 276 tex linear density have been spun at different wrap densities (250, 300, 350, 400 and 450 wpm) using polypropylene, polyester and nylon of different linear densities as wrapping elements. It is observed that in the case of 23.3 tex polypropylene multifilament and 17.2 tex polyester multifilament wrappers, the yarn could not be spun beyond 350 wpm due to the excessive breakage of wrapping elements. The breaking strength of the wrap-spun jute yarn increases with the increase in wrap density up to an optimum level and then decreases. The breaking extension of the wrap-spun jute yarns increases but initial modulus decreases with the increase in wrap density.

Keywords: Breaking extension, Initial modulus, Jute, Nylon, Polyester, Polypropylene, Tenacity, Work of rupture, Wrap density, Wrap-spun yarn

1 Introduction

For the new and unconventional applications of jute, research and development work on diversified products was initiated long back. As a result, various fields have been identified and suitable products have been developed where jute is the major component. One of the such developments is the wrap-spun jute yarn produced by adopting hollow spindle technology.

Behery and Nunes, in their studies on wrap-spun yarns having polyester staple fibres as core and polyester continuous filament as wrapping element, showed that the tenacity and breaking extension of wrapped yarns increase with the increase in linear density and tenacity of wrapping filament and wrapping density. Khatua et. al., in their study on wrap-spun jute yarn having jute fibre as core and different synthetic filaments (viscose rayon, nylon, polyester multifilaments and HOPE monofilament) as wrapping elements, showed similar results. It was further reported by them that the tenacity of wrap yarn, beyond the optimum level, either falls or becomes steady at the higher wrap density. Sen Gupta et. al., in their study on wrap-spun jute yarn, reported that for equivalent wrap densities, the polyester filament wrapper gives higher tenacity than nylon filament followed by the HDPE monofilament. They also reported that the tenacity increases with the increase in wraps per meter for all the wrapped jute yarns studied. Most of these workers used synthetic multifilament or monofilament yarns as wrapping elements, restricting the wrap density to the maximum of 300 wpm, and the choice of nature, type of filaments and their denier within a limited option. Therefore, it was thought worthwhile to engineer wrap-spun jute yarns over a wide range of wrapping density with a variety of filaments as wrapping elements and to study some of their physical properties. Detailed study on wrap-spun jute yarn over a range of linear density using jute fibre as core and biodegradable cellulosic yarn (cotton yarn and viscose rayon multifilament yarn) as wrapping element has already been reported by Roy et. al.

In the present study, wrap-spun jute yarns were spun with a nominal linear density of 276 tex (8 lb/syn) by varying the wrap density from 250 wpm to 450 wpm at a step of 50 wpm. Different types of continuous filament yarns, namely polypropylene (PP), polyester (PET) and nylon, were selected as wrapping elements and three different deniers were selected for both PET and flat PP multifilaments. In addition, the nylon, textured PP multifilaments and PP monofilament were also used as wrapping elements. The tensile responses of all these yarns were studied.

2 Materials and Methods

Jute fibre of commercial hessian warp batch was used. The details of wrapper filament yarns used are given in Table 1.

---

*To whom all the correspondence should be addressed.
Phone: 4212115-6-7; Fax: 0091-033-4712583;
E-mail: nirjaft@wb.nic.in
Table 1 — Details of wrapper filament yarns

<table>
<thead>
<tr>
<th>Type of filament</th>
<th>Linear density tex</th>
<th>No. of filaments</th>
<th>Breaking load N</th>
<th>Extension %</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP monofilament</td>
<td>13.3</td>
<td>9.45</td>
<td>22.15</td>
<td></td>
</tr>
<tr>
<td>PP flat multifilament</td>
<td>4.4</td>
<td>1.71</td>
<td>31.05</td>
<td></td>
</tr>
<tr>
<td>PP flat multifilament</td>
<td>10</td>
<td>3.38</td>
<td>25.17</td>
<td></td>
</tr>
<tr>
<td>PP flat multifilament</td>
<td>23.3</td>
<td>7.37</td>
<td>20.95</td>
<td></td>
</tr>
<tr>
<td>PP textured multifilament</td>
<td>10</td>
<td>4.08</td>
<td>30.8</td>
<td></td>
</tr>
<tr>
<td>Polyester multifilament</td>
<td>5.6</td>
<td>1.42</td>
<td>15.0</td>
<td></td>
</tr>
<tr>
<td>Polyester multifilament</td>
<td>9</td>
<td>5.47</td>
<td>21.45</td>
<td></td>
</tr>
<tr>
<td>Polyester multifilament</td>
<td>17.2</td>
<td>10.93</td>
<td>20.73</td>
<td></td>
</tr>
<tr>
<td>Nylon multifilament</td>
<td>8.3</td>
<td>2.33</td>
<td>11.2</td>
<td></td>
</tr>
</tbody>
</table>

PP — Polypropylene

Wrap-spun jute yarn (nominal linear density, 276 tex) was spun successfully on Suessen Parafil 2000 wrap spinning machine available at M/s New Central Jute Mills Ltd, West Bengal, after making necessary adjustments in some of the machine parameters. Forty-one different wrap-spun jute yarn samples were prepared using different wrapper filament yarns as mentioned in Table 1, maintaining the draft and delivery speed at 32 and 80 m/min respectively at the spinning stage. Jute fibre was processed through conventional jute spinning system up to the second drawing stage. The sliver thus obtained was once again processed through the second drawing machine, keeping the doubling and draft the same to get more regular sliver.

The load-elongation properties of all the yarns were tested on an Instron tensile tester at 65% RH and 27°C. The gauge length and cross-head speed selected were 500 mm and 500 mm/min respectively.

3 Results and Discussion

It has been observed earlier while comparing wrap-spun, flyer-spun cover and flyer-spun conventional jute yarns that the wrap-spun jute yarn having wrap density higher than 250 wpm shows an improvement in tensile properties over the conventional flyer-spun yarn. Hence, in the present study, the initial wrap density was chosen as 250 wpm and it was increased up to 450 wpm in steps of 50 wpm for the detailed study on the effect of wrap density on the tensile responses of wrap-spun jute yarn. However, in the cases of 23.3 tex PP multifilaments and 17.2 tex PET multifilaments as wrapping elements, the yarn beyond wrap density of 350 wpm could not be spun due to the excessive breakage of wrapping element. This may be due to the attainment of very high dynamic strain level of coarser filaments during spinning, as explained by Roy et al.

3.1 Structure and Failure Mechanism of Wrap-spun Yarn

The jute fibre core of wrap-spun jute yarn, prepared in hollow-spindle machine, is aligned parallel to yarn axis and instead of twisting the staple fibres, a continuous filament/spun yarn is wrapped around these parallel-laid staple fibres. The wrapping element exerts a radial tension on the parallel fibre core, thereby providing the necessary frictional force between the individual fibres in the core. A waviness on the yarn profile is developed during wrapping of filament/spun yarn around core jute fibre bundle due to the high dynamic radial pressure exerted by the wrapping element during the spinning process. During tensile loading along the yarn axis, the wrap-spun yarn undergoes the following different stages of structural deformations till the ultimate failure:

- In the first stage, the waviness of the yarn profile and crimp of the yarn get straightened which shows the elastically deformation region.
- In the next stage, the wrapping element starts straightening from its coil structure and at the same time slippage between the wrapping element and the fibrous core occurs to a small extent. However, the extent of this slippage mainly depends on the surface property, frictional inter-relationship between wrapper and core elements and binding force of the wrapping element. The radial pressure exerted by the wrapping element is increased, resulting in an increase in inter-fibre cohesive force due to the enhancement of structural integrity of core fibre bundle, and the diameter of the yarn starts reducing.
- In the third stage, two different phenomena occur simultaneously: (i) further slippage between wrapping element and core fibre bundle, and (ii) when the tensile load exceeds the inter fibre frictional resistance, the fibres at the core start to slip past each other until they get separated from each other, resulting in ultimate failure of the yarn. At the same time, the wrapping element coils get
further straightened and then extended up to its rupture point. The breakage of wrap-spun yarn may be of catastrophic or stick-slip type depending on the physical properties of the wrapping element, wrap density, etc.

3.2 Breaking Tenacity

Fig. 1 shows that in the case of PP filament wrapped jute yarns the breaking tenacity of all the wrap-spun yarns, except in the case of 23.3 tex multifilaments, increases with the increase in wrap density up to a certain level and then it decreases. With the increase in wrap density the radial compressive force exerted by the wrapping element increases, making the fibrous core more compact and resulting in higher wrap yarn strength. But after a certain wrap density where the maximum compactness of core fibres is achieved, the increase in wrap density only increases the helix angle of the wrapping element and decreases the yarn strength. In the case of 23.3 tex multifilament wrapper, the decrease in breaking tenacity of wrap-spun yarn with the increase in wrap density might be due to the fact that the maximum compactness of the fibrous core is already attained within 250 wpm.

It is observed that in the case of higher linear density of the wrapping element, the required wrap density to achieve the maximum breaking tenacity is lower than that of finer wrapping element. The wrapping element having higher wrapping density provides higher filament-to-fibre contact area which imparts higher radial pressure to the core, thereby increasing the inter-fibre friction and restraining the core fibres from slippage.

Fig. 2 shows that in case of nylon and polyester filaments of higher denier, the breaking tenacity of wrap-spun yarn increases marginally with the increase in wrap density up to 300 wpm. Whereas in case of polyester filaments of lower denier (5.6 tex and 9 tex), the downward trend in wrap yarn tenacity is observed with the increase in wrap density. This may be due to the fact that higher initial modulus of polyester as compared to that of PP filament (Fig. 3) enables the wrap-spun yarn with polyester filament wrapper to attain optimum tenacity at lower level of wrap density (250 wpm).

It is also observed that the filaments having higher breaking load generally give higher tenacity of the wrap-spun yarn at lower level of wrap density but no definite trend is observed.

3.3 Breaking Extension and Initial Modulus

Figs 4 and 5 show that the extensibility of all the wrap-spun yarns increases with the increase in wrap density and that the increase is rapid after 300 wpm, except in case of 10 tex PP flat multifilament where
the extensibility increases rapidly after 250 wpm. The increase in wrap density results in the increase in the length of the wrapping element around the fibrous core, thereby providing extra length to extend the yarn till its ultimate failure.

It may be mentioned here that no clear relationship is observed between the breaking extension of wrapping filaments and that of the wrap-spun yarns.

Figs 6 and 7 show that the increase in wrap density results in a marginal decrease in initial modulus. This is true for all the wrap-spun yarns. As mentioned earlier, the removal of waviness of the wrap-spun yarn during the tensile loading gives the elastic modulus or the initial modulus of the yarn. Higher wrap density means more number of wraps per unit length of yarn, resulting in more waviness on yarn profile which ultimately decreases the initial modulus of the wrap-spun yarn.

3.4 Work of Rupture

Fig. 8 shows that in case of PP wrapper the work of rupture first increases with the increase in wrap density and then decreases, except in the case of 10 tex PP textured multifilament where the work of rupture increases continuously with the increase in wrap density up to 450 wpm. This indicates the potential increase in work of rupture beyond 450 wpm. However, 10 tex PP flat multifilament gives the highest work of rupture at 350 wpm.

In case of polyester and nylon multifilaments, all the wrap-spun yarns show upward trend in work of
rupture with the increase in wrap density (Fig. 9). In both the cases, the trend in breaking extension of the yarn apparently predominantly influences the toughness of the yarn.

4 Conclusions

4.1 Breaking strength of the wrap-spun jute yarn increases with the increase in wrap density up to a certain level and then it decreases.

4.2 Breaking extension of the wrap-spun jute yarn increases with the increase in wrap density up to a certain level and then it levels off.

4.3 Initial modulus of the wrap-spun yarn shows a declining trend with the increase in wrap density.

4.4 The trend in breaking extension of wrap-spun yarns is apparently predominant on the trend of work of rupture.

4.5 It is not possible to spin wrap-spun jute yarn beyond the wrap density of 350 wpm with the wrapping element of very high linear density due to the excessive breakage of wrapping filament.

Acknowledgement

The authors are thankful to Dr S K Bhattacharyya, Director and Dr B P Sarkar, Head, Mechanical Processing Division, both of NIRJAF, Calcutta, for their valuable suggestions during the study. They gratefully acknowledge the contributions made by Late A. Majumder, Principal Scientist, NIRJAFT, in planning of the work. The authors are also thankful to M/s New Central Jute Mills, Calcutta, for providing necessary facilities to prepare wrap-spun yarn samples.

References