Effect of thermal treatment on wrap-spun jute yarns

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Wrap-spun jute yarns prepared at hollow spindle spinning machine using polyester (PET), nylon, polypropylene (PP) flat and textured multifilament and PP monofilament yarns as wrapping elements with wrap density of 350 wraps/m were subjected to thermal treatments in dry heat and boiling water. The thermal treatment in dry heat was done for 5, 10, 15 and 30 min at 185°C for PET and nylon wrapped yarns and at 135°C for PP wrapped yarns. Boiling water treatment was carried out for 30 min. On thermal treatment, a downward trend in tenacity was observed in case of polyester, nylon and polypropylene flat multifilament wrapped yarns but no definite trend was observed in case of polypropylene textured multifilament and polypropylene monofilament wrapped yarns, while the breaking extension of all the wrap-spun yarns increased. The work of rupture of wrap-spun yarns also decreased with the increase in treatment time on dry heating except in case of nylon wrapped yarn where the work of rupture improved remarkably up to 10 min of exposure and then again dropped. On boiling water treatment, the work of rupture of PET, nylon and PP flat multifilament wrapped yarns increased and that of PP textured multifilament and PP monofilament wrapped yarns decreased. Initial modulus and secant modulus of all the wrap-spun yarns, except polyester wrapped yarn, generally decreased on dry heating. Residual shrinkage of all the wrap-spun yarns decreased with the increase in treatment time in dry heat. No relationship could be established between the changes in tensile properties of wrap-spun yarns and those of synthetic wrapping yarns.

Keywords: Jute, Residual shrinkage, Tensile properties, Twist liveliness, Wrap-spun yarn

1 Introduction
The wrap-spun yarn manufacturing technology involves wrapping a continuous filament yarn around a staple fibre bundle adopting hollow-spindle technology. The delivery speed of the machine can reach as high as 200 m/min and the rotational speed of the wrapping element (referred as wrapping speed) can be attained up to 35,000 rpm. This results in creation of a high centrifugal force on the wrapping element. At the same time, the wrapping element is subjected to the stresses due to frictional resistance from various machine parts like thread guides, etc. and bending to a wide angle to the yarn axis during wrapping. Besides rewinding of wrapping element prior to spinning also causes development of considerable amount of internal stresses in the filaments. All these stresses cause high curling tendency of wrap-spun yarn which has a deleterious effect on further processing and may cause dimensional instability to the yarn.

The 'setting' is a treatment given to the fibre usually after any mechanical stress to improve its dimensional stability, to reduce curling tendency and to reduce the tendency to shrink by re-heating. The feasibility of such a treatment is related to the stress relaxation which can be achieved by thermal treatments or by swelling agents. Therefore, it was thought that the heat setting of wrap-spun yarn may effect its some mechanical properties. Sengupta et al.1 reported that the work of rupture of wrap-spun jute yarn increases considerably after heat setting. In their work, thermal treatment was done for 5 min and the wrapping elements used were polyester and nylon multifilament yarn and HDPE monofilament yarn. Later on, Choudhuri et al.2 studied the properties of jute and jute-viscose blended wrap-spun yarns using HDPE monofilament and PP multifilament yarns as wrapper elements. The properties of wrap-spun yarns were evaluated after giving a thermal treatment for 5 min. But they did not compare the changes in properties with those of parent wrap-spun yarns. No other reports are available in the literature on the effect of thermal treatment on the wrap-spun jute yarn.

In the present work, the changes in tensile behaviour of wrap-spun jute yarn subjected to thermal treatments for 5 - 30 min have been studied. The

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residual shrinkage and curling tendency of the yarns have also been studied. Polyester, nylon and polypropylene flat multifilament, polypropylene textured multifilament and polypropylene monofilament yarns were used as wrapping elements. In our earlier study on the tensile responses of wrap-spun jute yarns with different types of continuous filament yarn of varying linear density as wrapping element, it was observed that in case of polyester and nylon wrapped yarns the specific work of rupture increased with the increase in wrap density while increasing the wrap density from 250 wpm to 450 wpm at a step of 50. In case of polypropylene, a similar trend for work of rupture was also observed. Among all the PP wrapped yarns, the specific work of rupture was found to be highest in case of 10 tex flat and textured multifilament wrapped yarn of 350 wpm. It was also observed that the initial modulus of wrap-spun yarn with any type of wrapping element decreases with the increase in wrap density. The 9 tex polyester wrapped yarn showed the lowest value of initial modulus while in case of 8.3 tex nylon wrapped yarn the modulus decreased with wrap density up to 350 wpm. The higher specific work of rupture and low initial modulus are among the most desired characteristics of jute yarn for improvement in weaving performance at high speed jute loom as well as for better acceptance of jute fabric for various end uses. Considering the above, the wrap-spun jute yarns having 9 tex polyester, 8.3 tex nylon and 10 tex PP multifilament yarns as wrapping elements and wrap density of 350 wpm were selected in the present work to study the effect of thermal treatment of the wrap-spun yarns.

2 Materials and Methods

2.1 Materials

Jute fibre of commercial hessian warp batch was used as the core component of the yarn. The details of filament yarns used as wrapping elements are given in Table 1.

2.2 Methods

2.2.1 Spinning of Yarns

The wrap-spun jute yarn samples of nominal linear density of 276 tex with 350 wraps/m (wpm) were spun in Suessen Parafil 2000 Wrap-spinning Machine after making the necessary adjustments in some of the machine parameters. The draft and the delivery speed were maintained at 32 and 80 m/min respectively at spinning frame.

2.2.2 Thermal Treatments of Wrap-spun Yarns

The wrap-spun yarn samples in hank form were subjected to thermal treatment in a induced heating machine with dry hot air at constant length condition. The temperature was maintained at 135°C for polypropylene and 185°C for nylon as recommended by Fajgert e t al. and Shroll respectively. In case of polyester, the degree of setting imparted to the material depends on the time and temperature of setting, the previous treatment given to the material, and the tension on the material during setting. So, in case of polyester the temperature was maintained at 185°C, the lower side of the recommended heat-setting temperature range (180 - 210°C). The reason is that the polyester suffers an injurious effect on treatment in air for 30 min at higher temperature, as reported by Ludewig, though the temperature up to 200°C lies within the tolerable limit. Sengupta et al. also maintained the heat-setting temperature at 180°C for polyester. The durations of treatment were maintained as 5 min, 10 min, 15 min and 30 min. The yarn hanks were then allowed to cool at room temperature at the constant length condition. The wrap-spun yarns were also treated in boiling water for 30 min at constant length condition.

<table>
<thead>
<tr>
<th>Wrapping element</th>
<th>Tenacity, g/ tex</th>
<th>Breaking extension, %</th>
<th>Specific work of rupture, mJ/tex-m</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 tex /34 filaments polyester multifilament yarn</td>
<td>7.23</td>
<td>6.90</td>
<td>6.40</td>
</tr>
<tr>
<td>8.3 tex /24 filaments nylon 6 multifilament yarn</td>
<td>6.35</td>
<td>5.44</td>
<td>7.06</td>
</tr>
<tr>
<td>10 tex /24 filaments polypropylene flat multifilament yarn</td>
<td>8.70</td>
<td>7.84</td>
<td>7.64</td>
</tr>
<tr>
<td>10 tex /24 filaments polypropylene textured multifilament yarn</td>
<td>9.29</td>
<td>8.23</td>
<td>5.93</td>
</tr>
<tr>
<td>13.3 tex polypropylene monofilament yarn</td>
<td>9.27</td>
<td>9.75</td>
<td>6.42</td>
</tr>
</tbody>
</table>
2.2.3 Evaluation of Tensile Properties

The load-elongation properties of all the yarns were tested in an Instron universal tensile tester at 65% R.H and 27°C. The gauge length and cross-head speed selected were 500 mm and 500 mm/min respectively. The secant modulus was calculated as the ratio of change in stress to change in strain between the points of zero stress and breaking stress.

2.2.4 Estimation of Residual Shrinkage and Twist Liveliness

The wrap-spun yarn samples in hank form were treated in boiling water for 30 min in relaxed condition to estimate the residual shrinkage. The change in length of the hanks was measured under the pretension of 0.236 g/tex/turn.

The twist liveliness of the wrap-spun yarn was measured by ring-loop method. The yarn of 1 m length was taken out from the package in such a way that no untwisting occurs before making the loop. Two free ends were taken together to make the loop. The twist liveliness was evaluated by counting the number of turns made by the yarn loop without applying any tension. This method has been adopted widely as a commercial practice by the spinners for quick estimation of twist liveliness of a yarn. The number of turns of yarn loop were also estimated after putting a weight of 0.11 g/tex at the lower end of the loop.

3 Results and Discussion

3.1 Effect of Dry Heating on Tensile Properties

Fig. 1 shows that in case of polyester wrapped yarn, the tenacity decreased with the increase in treatment time in dry heat though after 15 min it was regained to some extent. At the same time, the extensibility was found to be remarkably high at 15 min and then dropped. The specific work of rupture, which is the combined effect of tenacity, breaking extension and modulus, also showed a downward trend. Fig. 2 shows that the initial modulus first decreased with the increase in treatment time up to 15 min and then again increased. The yield stress first increased at 5 min, then decreased up to 15 min and again increased though the lowest value did not come down than that of the parent yarn. The yield strain increased remarkably at 15 min and then decreased rapidly at 30 min. The value of secant modulus was found to be lowest at 15 min treatment.

Fig. 3 shows that in case of nylon the tenacity of wrap-spun yarn remained same up to 10 min treatment and then dropped marginally up to 30 min treatment, while the breaking extension increased considerably at 5 min and then decreased with
increase in treatment time though it did not come below the breaking extension of the parent yarn. Fig. 4 shows that the initial modulus increased up to 10 min treatment, decreased at 15 min and then leveled off. The considerable increase in initial modulus and breaking extension resulted in an appreciable increase (about 30%) in work of rupture up to 10 min of exposure but then the work of rupture decreased. Both the yield stress and yield strain followed the similar trend showing their highest value at 10 min treatment. The secant modulus first decreased at 5 min treatment and then showed an upward trend with marginal rate of change. The above findings on the change in tenacity and work of rupture of the wrap-spun yarns are not in agreement with earlier findings. The reason may be the difference in the inherent characteristics of the filament wrapper yarns.

In case of PP flat multifilament wrapped yarn, a drastic reduction in tenacity (Fig. 5) was observed at 5 min treatment and then the tenacity regained up to 30 min treatment, while a considerable improvement in breaking extension was achieved, giving the highest value at 10 min treatment. The drastic reduction in tenacity and initial modulus (Fig. 6) ultimately resulted in considerable loss in work of rupture. Both the initial modulus and the secant modulus were decreased drastically at 5 min treatment and then increased marginally up to 15 min treatment following a similar trend. A similar trend was observed in the case of yield stress also. However, the yield strain value showed an upward trend up to 10 min treatment and then decreased at a lower rate of change up to 30 min treatment.

In case of PP textured multifilament wrapped yarn, similar but erratic trends in tenacity and breaking extension with the time of treatment in dry heat were noted (Fig. 7). In these cases, the highest value was observed at 10 min treatment. As shown in the Fig. 8, the initial modulus decreased drastically after 5 min of treatment and then it was almost leveled off. The drastic reduction in initial modulus ultimately resulted in a drastic reduction in work of rupture (Fig. 7) after 5 min of treatment. No definite trend in secant modulus value was observed. Both yield stress and yield strain increased with the time of treatment, showing the highest value at 10 min treatment.

Fig. 9 shows that the tenacity of PP monofilament wrapped yarn first decreased at 5 min treatment and then it increased up to 30 min treatment though the rate of change was marginal. The breaking extension showed a continuous upward trend with drastic change at 5 min treatment. However, the work of rupture decreased at a very high rate of change at
BASU & ROY: EFFECT OF THERMAL TREATMENT ON WRAP-SPUN JUTE YARNS

![Graph](image1)

**Fig. 7**—Effect of treatment time in dry heat on tenacity, breaking extension and specific work of rupture of wrap-spun jute yarn having polypropylene textured multifilament yarn as wrapping element.

![Graph](image2)

**Fig. 8**—Effect of treatment time in dry heat on initial modulus, secant modulus, yield stress and yield strain of wrap-spun jute yarn having polypropylene textured multifilament yarn as wrapping element.

![Graph](image3)

**Fig. 9**—Effect of treatment time in dry heat on tenacity, breaking extension and specific work of rupture of wrap-spun jute yarn having polypropylene monofilament yarn as wrapping element.

![Graph](image4)

**Fig. 10**—Effect of treatment time in dry heat on initial modulus, secant modulus, yield stress and yield strain of wrap-spun jute yarn having polypropylene monofilament yarn as wrapping element.

5 min treatment, then almost leveled off. Both initial modulus and secant modulus showed a downward trend though the rate of change was marginal after 5 min treatment. The yield stress decreased after 5 min of treatment and then it increased with the time of treatment marginally, while the yield strain showed an upward trend (Fig. 10).

The reason for initial increase in tenacity of polyester and PP textured wrapped yarns is that due to the shrinkage of filaments on thermal treatment, the radial compressive force exerted by the continuous filaments increases, which makes the fibrous cor more compact and results in higher wrapped yarn strength initially. But after further exposure to heat, where the maximum compactness of the core fibre is achieved, the increase in shrinkage only increases the helix angle of the filament, resulting in decrease of yarn strength. In case of nylon, PP flat and PP monofilament, the maximum compactness had already reached before thermal treatment. So, the thermal treatment has only increased the obliquity effect of the wrapper element. The increase in helix angle of the filaments caused an increase in the waviness of the resultant yarn. When these yarns are subjected to tensile loading, first the waviness of the yarns gets straightened without any relative displacement between fibre to filament or fibre to fibre, giving lower moduli and higher extension value of the wrap-spun yarn. It may be noted that PP textured multifilament wrapped yarn showed different trends in tensile properties than those of PP flat multifilament wrapped yarn. This may be due to different surface properties of the filaments.
It may also be noted from Figs 11 and 12 that on dry heating, polyester, PP flat and PP textured multifilament yarns did not show any appreciable change in tenacity. The nylon multifilament yarn showed an upward trend in tenacity up to 15 min of treatment and then the tenacity leveled off. The breaking extension of polyester yarn showed a downward trend up to 15 min of treatment and then increased to some extent. The breaking extension of nylon and PP flat multifilament yarns increased up to 15 min of exposure and then decreased, while PP monofilament yarn showed a downward trend up to 30 min of exposure. No appreciable change in breaking extension of PP textured multifilament yarns was noted. Also, no clear relationship could be established between the tensile behaviour of filament yarns used as wrapping elements and wrap-spun jute yarns.

3.2 Effect of Boiling Water Treatment on Tensile Properties

The drop in tenacity of wrap-spun yarn on thermal treatment was observed in case of boiling water treatment also, except in case of PP monofilament wrapped yarn (Table I). However, the extensibility of all the wrap-spun yarns increased though in case of PP textured multifilament wrapped yarn the increase was marginal. Table I also shows that the work of rupture of polyester, nylon and PP flat multifilament wrapped yarns increased though in case of nylon the increase was marginal. In case of PP textured multifilament and PP monofilament wrapped yarns, the work of rupture deteriorated to some extent.

The decrease in tenacity and increase in breaking extension of wrap-spun yarns may be explained by the increase in obliquity effect of filaments as mentioned earlier.

3.3 Effect of Dry Heating on Residual Shrinkage

It is apparent from Fig. 13 that the wrap-spun yarn with polyester as wrapping element treated for 10 min gave the lowest residual shrinkage, while in case of nylon the lowest residual shrinkage was obtained for wrap-spun yarn treated for 5 min. In case of PP flat and PP textured filament wrapped yarns the residual shrinkage decreased with the increase in treatment time, while in case of PP monofilament wrapped yarn the lowest residual shrinkage was obtained at 10 min of treatment. Comparing the lowest value of all the yarns it is revealed that the polyester gave the most stable yarn followed by nylon and PP filaments. The higher value of residual shrinkage of PP filament wrapped yarn may be due to stereo isomeric structure of polypropylene.

3.4 Effect of Thermal Treatments on Twist Liveliness of Wrap-spun Yarns

Table 2 shows that the twist liveliness of polyester and nylon wrapped yarns increased remarkably after
treated the wrap-spun yarns in dry heat. In case of PP flat and PP textured wrapped yarns the twist liveliness first decreased and then again increased, while in case of PP monofilament the twist liveliness of wrap-spun yarn remained more or less same before and after dry heating. On the other hand, in case of boiling water treatment, the twist liveliness of wrap-spun yarn under tension remarkably reduced. But the result of twist liveliness of wrap-spun yarn without any tension was not much encouraging. In case of polyester, nylon and PP flat multifilament wrapped yarns, the twist liveliness value reduced to around 29%, 28% and 34% respectively, while in case of PP textured and PP monofilament wrapped yarns, no such change was observed. A detailed and systematic investigation is required to explain the different behaviour in the twist liveliness of the wrap-spun jute yarns on thermal treatments under constant length condition.

4 Conclusions

4.1 On thermal treatment, a downward trend in tenacity was observed in case of polyester, nylon and polypropylene flat multifilament wrapped yarns but no definite trend was observed in case of polypropylene textured multifilament and polypropylene monofilament wrapped yarns, while the breaking extension of all the wrap-spun yarns increased.

4.2 In case of nylon wrapped yarn, the specific work of rupture improved up to 15 min treatment, showing a maximum value at 10 min, but in case of other wrap-spun yarns the work of rupture decreased in dry heating. On boiling water treatment, the work of rupture of polyester, nylon and PP flat multifilament wrapped jute yarns increased and that of PP textured and PP monofilament wrapped yarns decreased.

4.3 The initial modulus and secant modulus of all the wrap-spun yarns, except polyester wrapped yarn, generally decreased on dry heating.

4.4 No clear relationship could be established between the change in the tensile properties of wrapping element and those of wrap-spun yarns after dry heating.

4.5 The twist liveliness of wrap-spun yarns can only be reduced on thermal treatment in aqueous medium.

4.6 The residual shrinkage of all the wrap-spun jute yarns decreased with the increase in treatment time in dry heat.

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References