Influence of sheath-core fibre characteristics on the properties of dref-3 friction yarns

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The effect of sheath fibre fineness and length on the tensile and bending properties of dref-3 friction yarn has been studied using polyester and acrylic fibres. Sheath fibre fineness influences the tenacity of polyester yarns significantly but not of acrylic yarns. With the decrease in fibre fineness the polyester yarn tenacity decreases as the number of sheath fibres declines and the corresponding wrappings become loose. For acrylic yarn, the effect is less pronounced as the fibre fineness was limited to only 2.22 dtex. The sheath fibre length mainly affects tenacity and extension of polyester yarns by changing the sheath fibre extent. However, the acrylic yarns remain unaffected as the sheath fibre extent does not change much with change in sheath fibre length.

Keywords: Core-sheath fibres, Dref-3 yarn, Fibre fineness, Fibre length, Friction spinning, Friction yarn

1 Introduction

Dref-3 friction yarns have a distinct core-sheath structure where the fibres in the core are straight, parallel and partially false twisted and those in sheath are helically wrapped around it. The core-sheath ratio generally varies from 40:60 to 70:30 depending on the yarn linear density and process parameters, as reported by Linda and Sawhney. During the manufacturing process, the core fibres are introduced by an apron drafting system in the nip of two rotating friction drums and the sheath fibres, in an opened state, are made to land on them either perpendicularly or at an angle. Consequently, the sheath fibres get wrapped around core by the torque generated by the rotating drums. Such a structure would derive its strength primarily from the resistance to slippage induced in the core fibres by the inward radial pressure generated by sheath fibres as a result of imposed strain. Once the slippage is completely restricted, the strength will depend on the strength of core fibres. The strength of such structure will therefore depend not only on the number of load bearing fibres in core but also on the number of sheath fibres active in generating radial pressure due to their strained helical configuration. The level of strain that the sheath fibres will undergo, at a given level of yarn strain, will depend upon the effectiveness of the wrapping, which, in turn, would be governed by:

- physical and mechanical characteristics of sheath fibres,
- configuration of sheath fibres,
- sheath fibre length and its variability, and
- the wrapping characteristics: (a) degree of firmness of wraps, (b) wrap angle and its uniformity, and (c) distribution characteristics of sheath fibres.

Therefore, the role of core and sheath fibres are quite different in deciding the final strength of the yarn. In the present work, the influence of fineness and length of sheath fibres on tensile properties of dref-3 friction yarn has been studied using polyester and acrylic fibres.

2 Materials and Methods

2.1 Fibres

Polyesters and acrylic fibres having different staple length and fineness were used in present study. The fibres were tested on Instron tensile tester following the standard procedure for tensile properties. The characteristics of these fibres are given in Table 1.

2.2 Preparation of Yarns

The polyester and acrylic fibres were processed on card and draw frame to produce slivers of 2.5 ktex and 3.5 ktex to be used in core and sheath respectively. Polyester yarns of 42 and 59 tex and acrylic yarn of 74 tex were spun. To study the influence of
Table 1 — Properties of polyester and acrylic fibres

<table>
<thead>
<tr>
<th>Fibre type</th>
<th>Fineness dtex</th>
<th>Length mm</th>
<th>Tenacity cN/tex</th>
<th>Breaking extension %</th>
<th>Modulus cN/tex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyester</td>
<td>1.56</td>
<td>38</td>
<td>42.0 (13)</td>
<td>17.6 (22)</td>
<td>577</td>
</tr>
<tr>
<td></td>
<td>2.33</td>
<td>38</td>
<td>39.6 (14)</td>
<td>21.3 (41)</td>
<td>542</td>
</tr>
<tr>
<td></td>
<td>3.33</td>
<td>32,38,44</td>
<td>32.1 (22.2)</td>
<td>38.0 (18.2)</td>
<td>425</td>
</tr>
<tr>
<td>Acrylic</td>
<td>1.33</td>
<td>38</td>
<td>33.1 (37)</td>
<td>35.8 (31)</td>
<td>430</td>
</tr>
<tr>
<td></td>
<td>1.67</td>
<td>38</td>
<td>26.3 (36)</td>
<td>37.0 (30)</td>
<td>448</td>
</tr>
<tr>
<td></td>
<td>2.22</td>
<td>32,38,44</td>
<td>22.0 (20)</td>
<td>36.5 (21)</td>
<td>375</td>
</tr>
</tbody>
</table>

The values in parentheses indicate CV%.

fibre fineness, 42 tex polyester yarns were spun using 1.56, 2.33 and 3.33 dtex, 38 mm fibres in the core. For each core type, the sheath fibre fineness was varied from 1.56 dtex to 3.33 dtex. Acrylic yarns of 74 tex were produced using 1.33, 1.67 and 2.22 dtex, 38 mm fibres in the core. For each core type, the sheath fibre fineness was varied from 1.33 dtex to 2.22 dtex. The core sheath ratio was 60:40 for all the yarns except when the coarsest polyester fibre (3.33 dtex) was used in the core. The core-sheath ratio for this yarn was 70:30.

To study the influence of sheath fibre length, 60 tex polyester and 74 tex acrylic yarns were spun. The fineness was 3.33 dtex and 2.22 dtex for polyester and acrylic fibres respectively and the lengths were 32, 38 and 44 mm. Keeping the core-sheath ratio at 70:30, nine polyester yarns were produced from nine possible combinations of core and sheath. Acrylic yarn with 44 mm fibres in sheath could not be spun as the repeated end breakages were encountered, probably due to too much buckling of long sheath fibres. Therefore, six acrylic yarns could only be produced. All the yarns were produced on a three-head laboratory model dref-3 friction spinning machine with a pair of opening roller running at a constant speed of 12,000 rpm. The drum speed and delivery speed chosen were 4500 rpm and 125 m/min respectively.

2.3 Determination of Yarn Tenacity

The tensile properties of the yarns were evaluated on Instron tensile tester (model 4301) interfaced with the PC. The yarns were tested at a gauge length of 500 mm. The crosshead speed was adjusted according to the extensibility of the specimen so that it breaks within 20±2 s. The parameters recorded were tenacity (cN/tex) and breaking extension (%). All the tests were performed in a standard atmosphere of 65±2% RH and 27±2°C. At least fifty readings were taken for each sample to estimate the average values.

2.4 Determination of Proportional Fibre Extent

Tracer fibre techniques as described by Morton and Yen and Hearle and Gupta were used to find the end-to-end distance of fibres inside the yarn body. A mixture of mono-bromonaphthalene and liquid paraffin (2:1 by volume) was used to optically dissolve the undyed polyester fibres. Tricresol phosphate was used to do the same for acrylic fibres. The fibre extent was measured on a projection microscope. Sixty readings were taken for each sample and the average fibre extent was taken. The mean fibre extent was then expressed as a percentage of original fibre length to determine the proportional fibre extent (%).

2.5 Measurement of Yarn Unevenness

The yarn unevenness were assessed on a Uster evenness tester. The yarns were tested at a speed of 25 m/min for 5 min. Ten readings were taken for each sample and the average was taken.

2.6 Determination of Structural Integrity

The structural integrity was determined by performing cyclic loading test at constant tension on an Instron tensile tester. The yarns were subjected to a load of 250g. The concurrence of hysteresis curves was found to occur at the end of 8–10th cycle in the case of polyester and 12-18th cycle in the case of acrylic. The area of the first cycle (A1) and the cycle after which concurrency occurred (A2) were measured by a planimeter. Fifteen tests were carried out for each sample. The extend of loss in integrity was calculate by finding % decay as:

\[
\text{Decay (\%) } = \left( \frac{A_1 - A_2}{A_1} \right) \times 100
\]

2.7 Measurement of Inter-fibre Friction

A special attachment was used on Instron tensile tester to determine fibre-to-fibre coefficient of friction. The assembly was fixed on the lower crosshead of Instron. It has a smooth platform. At one side of the platform was a vertical stand on which a pulley on anti-friction bearing was mounted. On the other side, there was a provision for gripping fibre fringe.
Fibre fringes were prepared following the method suggested by Lord. The width of the fringe was kept one inch and the density of the fibres in the fringe was approximately 5 mg/cm². Now one end of a fringe was gripped in a fixed jaw. The other fringe was placed above the first with a weight of 20 g on it. A light plastic strip clamped the other end of the second fringe, which was, in turn, connected by an inextensible cord to the load cell of Instron. As the crosshead moved downward, the top fringe slid over the lower one and a load was registered due to the frictional resistance between the fringes. The crosshead was moved at a slow speed of 1 cm/min. The load was recorded. The average recorded load was calculated based on fifteen readings. The ratio of the average load to the weight placed on the fringe was found out to determine the coefficient of friction. The CV% of coefficient of friction was between 5 and 7.

3 Results and Discussion

3.1 Influence of Sheath Fibre Fineness

The influence of sheath fibre on the tensile properties of polyester and acrylic dref-3 yarns is shown in Figs 1–4. It is observed from Fig. 1 that irrespective of the fineness of fibres used in core, the tenacity of polyester yarns decreases as the sheath fibres become coarser. The fall in tenacity is more pronounced when the sheath fibre fineness changes from 2.33 dtex to 3.33 dtex. This was found to be significant at 5 % level. However, for acrylic yarns (Fig. 3), hardly any decrease in tenacity is observed for the yarns containing 1.33 or 1.67 dtex fibre in the core. The reduction in tenacity is observed only in one situation, i.e. for the yarn containing 2.22 dtex fibres in core and the sheath fibre fineness changing from 1.33 dtex to 1.67 dtex. Thereafter, hardly any decrease in tenacity is observed. The yarn strength is seen to be mainly decided by the intrinsic strength of core fibres for polyester yarns. However, this is not so obvious for acrylic yarns. As an example even though 1.67 dtex fibre is weaker than 1.33 dtex fibre, the strength of the yarns spun is fairly same.

As the sheath fibre is made coarser, no change in breaking extension is observed both for polyester and acrylic fibre yarns. In case of polyester yarns (Fig. 2), the intrinsic breaking extension of core fibres decides the breaking extension of the final yarn. The yarn consisting of 3.33 dtex fibre in core shows the highest breaking extension since the breaking extension of the constituent fibres is also maximum (38%). For acrylic yarns (Fig. 4), similar breaking extension of all the fibres used do not make much difference in the breaking extension of the corresponding yarns.
The decrease in tenacity as the sheath fibres become coarser can be attributed to: (i) ineffective and irregular wrapping of sheath fibres, (ii) tenacity of wrapped sheath fibres, and (iii) modulus of sheath fibres.

As the sheath fibres become coarser, the wrapping of these fibres around core is not likely to be very tight because of the high bending rigidity of the fibres which increases to the square of fibre fineness\(^8\). Besides, the number of sheath fibres in the cross-section also reduces (Table 2). As an example, when 1.56 dtex fibre is used as core, the number of fibres in sheath changes from 108 (for 1.56 dtex fibre) to only 51 (for 3.33 dtex fibre). When the yarn is strained, the corresponding strain development in sheath fibres will be less in the case of loosely wrapped sheath fibres. As a result, the inward pressure generated by the sheath fibres would also be less in magnitude. Besides the actual number of sheath fibres being less, the pressure will not be uniformly distributed on the yarn core. Hence, the yarn tenacity with coarse sheath fibres is expected to decrease.

The hysteresis, i.e. decay %, also increases with the increase in coarseness of sheath fibres for both polyester and acrylic yarns (Table 3). The decay is on an average higher for acrylic yarns. The number of cycles required to reach concurrency can also be seen to increase with the coarseness of sheath fibres. Similarly, for a given sheath fibre fineness as the core fibres become finer, both the decay and the number of cycles required to reach concurrency reduce. As the cyclic loading progresses, the structural rearrangement within the yarn takes place. The slippage of constituent fibres within the structure, which is the main source of energy loss, gradually reduces and the structure as a whole becomes more stabilized. In this process, some permanent deformation occurs in the yarn. The higher decay and greater number of cycles required to reach concurrency with increased sheath fibre coarseness indicate poorer integrity of these yarns. Hence, a reduction in tenacity, as observed for polyester, is expected.

In case of acrylic, the sheath fibre fineness varied from 1.33 dtex to 2.22 dtex. Since the change in fineness of the fibres in sheath was restricted up to 2.22 dtex, probably the bending rigidity of the fibres did not increase enough to cause the wraps becoming loose and ineffective. Besides, the number of sheath fibres in all the cases was large enough to cause effective wrapping around the core. Hence, a reduction in yarn tenacity, though expected, is not observed. In case of polyester also, for similar fineness variation (from 1.56 dtex to 2.33 dtex) of sheath fibres the fall in tenacity is marginal. The polyester yarn containing finest (1.56 dtex) and

<table>
<thead>
<tr>
<th>Yarn type (line density)</th>
<th>Core: Sheath ratio</th>
<th>Fibre fineness dtex</th>
<th>Estimated no. of fibres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyester (42 tex)</td>
<td>60:40</td>
<td>1.56</td>
<td>163</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.33</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.33</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>60:40</td>
<td>1.56</td>
<td>108</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.33</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.33</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>70:30</td>
<td>3.33</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.33</td>
<td>38</td>
</tr>
<tr>
<td>Acrylic (74 tex)</td>
<td>60:40</td>
<td>1.33</td>
<td>332</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.67</td>
<td>177</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.22</td>
<td>133</td>
</tr>
<tr>
<td></td>
<td>60:40</td>
<td>1.67</td>
<td>265</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.67</td>
<td>177</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.22</td>
<td>133</td>
</tr>
<tr>
<td></td>
<td>60:40</td>
<td>2.22</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.67</td>
<td>177</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.22</td>
<td>133</td>
</tr>
</tbody>
</table>

The values in parentheses indicate number of cycles required to reach concurrency.
strongest core fibres is strongest since the fibre cohesion is highest in addition to strength.

In case of acrylic, the replacement of strong core by weaker one did not make much of a difference in strength as stated earlier. To find an answer to this, the broken ends of the yarns were visually observed and compared with polyester yarns. The long tapered

fracture zone for all acrylic yarns revealed slippage to be the predominated mode for failure. In such cases, the fibre-to-fibre friction of core fibres would play a critical role in deciding the ultimate strength. Hence, it was measured. The fibre-to-fibre friction of 1.67 dtex acrylic fibre (0.70) was found to be much more than that of 1.33 dtex fibre (0.60). The higher friction was compensating the inherent weakness of the fibres, giving similar strength for acrylic yarns with 1.33 dtex and 1.67 dtex fibres in core. The yarns with 2.22 dtex fibres in core was weak as the fibres were weak too.

3.2 Influence of Sheath Fibre Length

For polyester yarns having 44 mm fibre in the core, the tenacity and breaking extension remained almost constant (Fig. 5 and 6). But when 32 mm fibre was used in core, both yarn tenacity and breaking extension first increased and then decreased. This was found to be significant at 5% level of significance. A similar trend is discernible for the yarn with 38 mm fibre in core. For acrylic yarns (Fig. 7 and 8), the tenacity and breaking extension did not change much with change in sheath fibre length. They are not different at 5% level of significance. Therefore, tenacity and breaking extension were seen to change in a sympathetic manner for both the yarns. As the sheath fibres are released from the opening rolls, they travel through the transport channel and land on a slow speed friction drum. This causes most of the sheath fibres to buckle or to get deformed as can be observed from the fibre extent data (Table 4).

The buckling tendency is expected to be more for longer and fine fibres. The absolute fibre extent increased a bit as the sheath fibre length was changed from 32 mm to 38 mm. This small change in sheath fibre extent caused the polyester yarns to be stronger.
and more extendable. Further increase in sheath fibre length causes sheath fibre extent to decrease and so the strength of the yarn too. This increase followed by decrease in yarn tenacity is not so obvious for other polyester yarns having 38 mm and 44 mm fibres in core. In both these cases, the core fibre being too long, slight change in absolute fibre extent of sheath fibres do not make much of a difference in tenacity as sufficient cohesion can develop in long overlapping core fibres even if wrapping varies in length to some extent due to the change in sheath fibre length.

Another interesting observation is that the polyester yarn with 38 mm fibre in the core is stronger than the yarns with 44 mm and 32 mm fibres in the core. One would expect the yarn with 44 mm fibre in core to be strongest. To seek an answer to this, all the yarns were tested for uniformity on Uster evenness tester. The results (Table 5) show that the unevenness is lowest for the yarn having 38 mm fibre in core, irrespective of the sheath fibre length used. The most stable spinning operation was observed when the core fibres were of 38 mm and specially when the sheath fibres along with it were of 38 mm. Higher unevenness of 44 mm core fibre yarn made it to be weaker than 38 mm core fibre yarn. The higher values of unevenness for both 32 mm and 44 mm core fibre yarns can be possibly due to the drafting irregularity generated by the drafting system while drafting the corresponding slivers. The settings between the rollers were appropriate for 38 mm fibres. Hence, any decrease or increase in fibre length probably lead to more irregularity. For acrylic yarns, going from 32 mm to 38 mm in sheath, did not make much of a difference in sheath fibre extent (Table 4). Wrapping characteristics, therefore, did not change and hence the yarn tenacity and breaking extension too.

4 Conclusions

4.1 As the sheath fibres become coarser, the tenacity of polyester yarns decreases but it remains more or less constant for acrylic yarns.

4.2 With an increase in sheath fibre length the tenacity and breaking extension of the polyester yarns with 32 mm core fibres first increases and then decreases. However, the tenacity of polyester yarns having long core fibres and of all spun acrylic yarns remains unaffected. Acrylic yarn with 44 mm sheath fibres could not be spun.

References


