Structure and properties of polyester MJS plied yarns

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The influence of ply twist and twist direction on the structure and properties of polyester MJS yarns has been studied. It is observed that the effect of plying on fibre and yarn structural parameters is significant. If the direction of Z-wrapped surface fibres is coincident with the direction of ply twist, the helix angle and helix diameter are high, but the mean fibre extent is very low. The increase in ply twist factor results in larger helix angle, larger helix diameter, smaller yarn diameter and lower fibre extent. Yarn properties also remarkably improve after plying. The improvement in yarn properties depends upon the amount and direction of ply twist. A plied yarn produced by twisting in a direction opposite to that of wrapping of surface fibres is stronger, less extensible, less rigid, more even, and has higher abrasion resistance. Yarns plied in the Z-direction are more rigid than those plied in the S-direction. While the flexural rigidity of yarns plied in the S-direction with higher ply twist factor is considerably lower than that of the corresponding single yarns, the flexural rigidity of those yarns plied in the Z-direction invariably decreases as the ply twist factor is increased.

Keywords: Air-jet spinning, Flexural rigidity, MJS yarn, Plying, Polyester yarn, Yarn properties

1 Introduction

In view of the growing demand for quality textiles throughout the world, the production of man-made fibre yarns on air-jet spinning machines is receiving increasing attention. These yarns have not been accepted as a substitute for ring-spun yarns. Jet-spun yarns are generally 15-40% weaker, more rigid and have lower abrasion resistance than the equivalent ring-spun yarns. Elsewhere it is stated that the jet-spun yarns have a higher resistance towards abrasion and axial friction with a sharp edge. However, if the higher strength and low rigidity are the main requirements, these can be improved to a certain extent by plying of jet-spun yarns. During plying, the yarn strands consisting of bundle of fibres wrap around each other, which, in turn, facilitate better utilization of fibre properties. Chattopadhyay reported that the plying enhances the tenacity of air-jet spun yarns, irrespective of the direction of ply twist, and that the breaking extension of 40 tex polyester-viscose (48:52) yarn increases with folding twist and is higher for Z-direction of ply twist. Karthikeyan et al. have made a comparative evaluation of the improvement in tenacity and breaking extension of polyester-cotton ring and MJS plied yarns. They reported that with the increase in doubling twist in a 2-fold MJS yarn, the tenacity decreases but breaking extension increases. They also reported that the per cent strength realization of 2/62s polyester-cotton jet-spun yarns is more or less equal (30-40%) to that of ring-spun folded yarns. In coarse counts (30s polyester-cotton), the strength realization of air-jet spun folded yarn is twice than that of its ring counterpart. Oxenham and Punj et al. reported an improvement in the tensile properties of jet-spun yarns following plying. However, these reports do not mention about the direction of plying. Trials have been conducted at TITS to bring out the influence of plying on yarn properties. The initial results from these trials have already been published. However, the information with regard to the combined influence of ply twist and its direction on the structure and properties needs further corroboration and systematic investigation. The present work was, therefore, aimed at studying the influence of ply twist and its direction on structure and properties of polyester MJS plied yarns.

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Two sets of yarns of 11.8 and 19.6 tex were spun from 100% polyester staple fibre (51 mm, 1.66 dtex and 29.74 cN/tex) on an air-jet spinning machine operating under normal textile mill conditions. Lap made on a Lakshmi Rieter's blow room line was carried on a semi-high production MMC card. The card sliver was given three passages on a Lakshmi Rieter's DO/2S drawframe to produce a finisher sliver of 3.1 ktx. The finisher sliver was spun into 11.8 and 19.6 tex yarns on a Murata air-jet spinner (802 MJS). First nozzle pressure of 2.0 kg/cm², second nozzle pressure of 3.5 kg/cm², spinning speed of 200 m/min and feed ratio of 0.98 were kept constant. The single yarns were plied and twisted in both Z and S directions on a Texmaco ring doubler using three twist factors.

2.2 Tests
2.2.1 Fibre and Yarn Structural Parameters
Prior to processing, a small fraction of dyed fibres was added to the grey fibres during mixing and the lot was spun into yarns in the normal way. The yarns were then immersed in a fluid with the same refractive index as that of the fibres so that the dyed fibres could be readily observed through a projection microscope. The fibre and yarn structural parameters, namely helix angle, helix diameter, fibre extent, hook extent, number of hooks and yarn diameter, as indicated in Fig. 1, were then measured for dyed sheath fibres using a magnification of x 100. Eighty observations were made on each yarn sample.

2.2.2 Yarn Properties
The yarns were tested for the following properties as per ASTM standards: tenacity and breaking extension (Instron), flexural rigidity by ring loop method (Shirley weighted ring yarn stiffness tester), abrasion resistance (CSI abrasion tester), evenness and imperfections (Uster 3), and hairiness (Zweigle hairiness meter).

3 Results and Discussion
3.1 Fibre and Yarn Structural Parameters
3.1.1 Helix Angle and Helix Diameter
The results for structural parameters are given in Tables 1 and 2. It is evident that both ply twist and twist direction are critical factors associated with differences in helix angle. However, the helix angle is more sensitive to the direction of twist than the level of ply twist. For Z-ply yarns, the helix angle varies from 33.4° to 41.3° for 11.8 tex yarn and from 32.9° to 38.3° for 19.6 tex yarn. Similarly for S-ply yarns, the helix angle varies from 25.5° to 29.2° for 11.8 tex yarn and from 27.7° to 33.5° for 19.6 tex yarn, and are thus considerably lower than those for Z-ply yarns. This trend can be accounted for by the role played by surface fibres. The surface fibres are wrapped in Z-direction. As the ply twist in the S-direction is introduced, the individual strands rotate on their axes, causing Z-wrapped surface fibres to untwist and become loose initially. The increase in ply twist keeps on untwisting the surface fibres until the twist becomes zero, and any further increase in ply twist may reverse the twist of the surface fibres. The helix angle increases considerably with the ply twist factor.

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<tr>
<td>11.8</td>
<td>29.66</td>
<td>21.3</td>
<td>25.5</td>
<td>33.4</td>
<td>114</td>
<td>138</td>
<td>145</td>
<td>26.1</td>
<td>21.5</td>
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<td>19.6</td>
<td>34.45</td>
<td>21.3</td>
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<td>38.7</td>
<td>114</td>
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<td>237</td>
<td>28.3</td>
<td>17.3</td>
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</table>
In general, the values of helix diameter for polyester MJS plied yarns range between 138 µm and 237 µm, depending upon the processing factors. The influence of twist direction on helix diameter (Table 1) is similar to that of helix angle. As the ply twist factor increases, the helix diameter increases, irrespective of the direction of ply twist.

### Table 2 - Effect of ply twist and twist direction on hook extent and number of hooks

<table>
<thead>
<tr>
<th>Yarn tex</th>
<th>Ply twist factor</th>
<th>Hook extent, mm</th>
<th>Hooks</th>
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<tbody>
<tr>
<td></td>
<td>Single yarn</td>
<td>S-ply yarn</td>
<td>Z-ply yarn</td>
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<tr>
<td>L</td>
<td>T</td>
<td>B</td>
<td>Total</td>
</tr>
<tr>
<td>29.66</td>
<td>0.342</td>
<td>0.136</td>
<td>0.063</td>
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<tr>
<td>34.45</td>
<td>0.342</td>
<td>0.204</td>
<td>0.243</td>
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<td>39.23</td>
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<td>0.175</td>
<td>0.217</td>
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<td>29.66</td>
<td>0.261</td>
<td>0.122</td>
<td>0.157</td>
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<tr>
<td>34.45</td>
<td>0.261</td>
<td>0.113</td>
<td>0.197</td>
</tr>
<tr>
<td>39.23</td>
<td>0.261</td>
<td>0.141</td>
<td>0.214</td>
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</table>

L = Leading hook; T = Trailing hook; and B = Both end hook.

3.1.2 Fibre Configuration and Mean Fibre Extent

Table 1 shows the changes in the mean fibre extent of polyester MJS yarns after plying; the values are lower for plied yarns than that for the corresponding single yarns. It can be observed from Table 1 that the 19.6 tex S-ply yarn produced with lowest ply twist has more fibre extent which, however, reduces with the increase in ply twist factor. This is because during ply twisting in S-direction, the Z-twisted sheath fibres in the single yarns are unwrapped in the beginning of twisting but later bind each other as the ply twist factor further increases. Consequently, as the twist per unit length of the plied yarn increases, the mean fibre extent decreases.

Table 2 shows that both hook extent and number of hooks decrease substantially on plying. For both S-ply and Z-ply MJS yarns, there is no evidence of any systematic relationship between hook extent and ply twist factor.

3.2 Yarn Properties

#### 3.2.1 Tenacity and Breaking Extension

Table 3 shows an increasing trend in yarn tenacity due to plying. The increase in tenacity for 11.8 tex yarn ranges from 61.08% to 66.70% for S-direction and from 51.93% to 56.40% for Z-direction plying, depending upon the amount of ply twist factor. Similarly, for 19.6 tex yarn, the increase in tenacity is 78.78-83.31% for S-direction and 70.90-76.09% for Z-direction. It can, therefore, be stated that the increase in tenacity is very high for both S-direction and Z-direction of ply twist. In MJS yarn, the parallel fibres in the core are bound by a small percentage of surface fibres wrapped in Z-direction. During ply twisting in S-direction, the two strands of single yarn rotate on their own axes, causing the core fibres to twist and the surface fibres to unwrap or untwist. The greater improvement in tenacity in S-ply yarns, irrespective of structure loosening up, is due to the better wrapping of the two strands around each other, an important aspect on which the cohesion and strength of plied yarn depend. In case of Z-ply yarn, the maximum increase in tenacity is found to be achieved at the lowest ply twist factor of 29.66 and it decreases marginally as the twist factor is increased to 34.45 and then to 39.23.

#### 3.2.2 Breaking Extension

Plying also causes a marked increase in breaking extension of polyester MJS yarns (Table 3). The increment can be attributed to the helical arrangement of the majority of the core fibres and a reduction in the number of weak places as a result of their mutual support. The increase in breaking extension is about 36.64-54.28% for S-ply yarns, whereas for Z-ply yarns, it is 45.57 - 59.93%. Further, the per cent increment in breaking extension of plied yarns in relation to the breaking extension of single yarns increases with the increase in twist factor.

#### 3.2.3 Flexural Rigidity

Table 3 shows that the Z-ply yarns are considerably more rigid than the S-ply yarns. This is expected because of the greater restriction imposed by further twisting of Z-wrapped surface fibres, which, in turn, gives less freedom to fibres to be displaced during...
bending. It can be seen that the S-ply yarns show an interesting behaviour at higher twist factors; beyond the twist factor of 29.66, the S-ply yarns show less rigidity than the corresponding single yarns.

In the air-jet spun yarns, the clustering effect of core fibres due to their parallel arrangement and tight winding by surface fibres allows little freedom to movement of fibres during bending. The plying in S-direction decreases this effect as the loosening of the surface fibres releases their tight grip on the core fibres. The loosening of surface fibres obviously enhances the freedom of movement of fibres. This implies that the decrease in flexural rigidity on plying in S-direction increases with the increase in ply twist factor. However, an increase in ply twist factor beyond a certain limit again restricts the freedom of movement of fibres due to the twisting of core fibres.

On the other hand, the flexural rigidity of Z-twist plied yarns consistently decreases with the increase in ply twist factor from 29.66 to 39.23. The continuous decrease in the flexural rigidity of such yarns with an increase in ply twist factor may be attributed to the helical yarn geometry as described by Backer. The breakage of surface fibres due to over twisting also partly explains the lower rigidity of Z-ply yarns at higher twist factors.

### 3.2.4 Abrasion Resistance

Plying could also significantly improve the abrasion resistance of polyester MJS yarns; the improvement is however lower for the yarns made with Z-ply twist and higher for the yarns made with S-ply twist (Table 4). The higher abrasion resistance of S-ply yarns can be attributed to some amount of fibre mobility caused by reverse ply twist. The fibres in case of Z-ply are too rigidly bound in the yarn, resulting in lower abrasion resistance. In the case of S-ply yarn, the abrasion resistance increases linearly with the increase in ply twist factor owing to the reinforcing effect of the surface fibres. On the other hand, when the twist is inserted in Z direction, the abrasion resistance does not show significant change with the increase in ply twist factor. If anything, it shows a little drop due to the increase in fibre rigidity.

### 3.2.5 Hairiness

The hairiness results relative to different ply twist factors and directions of twist are given in Table 4.
Expectedly, there is a marked reduction in yarn hairiness on plying. The reduction in hairiness is about 68.32-88.21\% for 11.8 tex yarn, whereas for 19.6 tex yarn, it is 34.27-66.44\%. These results imply a strong inverse relationship between yarn hairiness and ply twist factor. This could be explained by the fact that an increase in ply twist results in firm embedment of protruding fibres in the body of yarn.

### 3.2.6 Mass Irregularity and Imperfections

The yarn evenness values and imperfections are given in Tables 4 and 5. The values show a substantial improvement in yarn unevenness as a consequence of plying. Further, the S-ply yarns are slightly more regular than the equivalent Z-ply yarns. If one looks at the association of mass irregularity with ply twist factor, the yarns produced with higher ply twist factors display lesser reduction than the equivalent S-ply yarns. A decrease in yarn unevenness could be attributed to the formation of kinks in the ply yarn at the higher ply twist factors due to its snarling tendency.

Table 5 shows a constant reduction in the incidence of imperfections on plying. This is because the variations introduced in strands at earlier stages of the spinning process are modified by being overlaid by others in the strands with which they are plied. However, the reduction in thick places is more marked in S-ply yarns. As regards the contribution of plying to the nep content, the yarns with Z-ply twist show slightly greater number of Nep.

### 4 Conclusions

### 4.1 Both the direction and amount of ply twist play a key role in influencing fibre and yarn structural parameters. When the direction of Z-wrapped surface fibres is coincident with the direction of ply twist, the helix angle and helix diameter are high, but the mean fibre extend is very low. The increase in ply twist factor results in larger helix angle, larger helix diameter and lower fiber extend. There is also a marked decrease in extent and number of hooks on plying, but no consistent trend is observed.

### 4.2 The plying of MJ S yarns offers significant advantages in respect of yarn properties. Twist direction of plying yarn has the greatest influence on yarn tenacity, breaking extension, evenness and abrasion resistance. All these characteristics improve to different degrees, depending upon the amount and direction of ply twist. A plying yarn produced by twisting in the direction opposite to the direction of wrapping of surface fibres is stronger, less rigid, more regular, and has higher abrasion resistance, but this yarn also has lower breaking extension.

### 4.3 Z-ply yarns exhibit higher flexural rigidity than the equivalent S-ply yarns. An increase in ply twist factor further reduces the degree of flexural rigidity of Z-ply yarns. In the case of S-ply yarns, the flexural rigidity initially decreases when the ply twist factor increases and then increases thereafter as the ply twist factor is further increased beyond this limit.

### 4.4 There is a marked reduction in yarn hairiness on plying. The reduction, however, is more marked in Z-ply yarns and it increases with the increase in ply twist factor.

### 4.5 Yarn unevenness and imperfections of S- and Z-ply yarns show a significant reduction over the corresponding single yarns. The reduction decreases with an increase in the ply twist factor.

### References

9 Lorenzo R R C, Text Prog, 16 (1973) 59.