Influence of Twist and Thermal Treatments on Characteristics of Acrylic-Polypropylene Blended Yarns

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Yarns spun from a majority of polypropylene fibres showed high strength and low extension. The yarn breaking strength tended to increase after boiling-water treatment. Thermal treatments had no significant effect on either unevenness or imperfections. Boiling-water treatment caused a higher yarn residual shrinkage than heating at various temperatures.

Keywords: Acrylic-polypropylene yarn, Blended yarns, Fibre mobility, Residual shrinkage, Shrinkage potential, Strength utilization factor

1 Introduction

The characteristics of high-bulk yarns, mainly bulkiness, are affected by the shrinkage and spinning process. Factors conferring the desired bulk are temperature, shrinkage and yarn twist. Of the various relaxation methods, the use of steam or boiling water for developing bulk in acrylic goods has been considered to be more effective than dry heat. Acrylic yarns not set at the correct steaming temperature exhibit low yarn strength, causing a thin fabric with a limp handle, or not giving a permanent shape to the fabric, i.e. dimensional instability; the latter, however, may be improved by adding some components like polypropylene to the acrylic fibre mix. On the basis of various theoretical and experimental trials many researchers have accounted for the contribution of fibre denier, cut length, type of fibre and yarn twist towards the bulk characteristics of various yarns. However, it is well established that different yarns, if they are to be bulked, require different relaxation treatments, and that the yarn shrinkage, in turn, is governed by the characteristics of yarn and type of treatment.

This investigation was undertaken with a view to understanding the influence of fibre type, twist and boiling-water treatment on the physical and shrinkage characteristics of acrylic-polypropylene yarns. Because yarns spun from thermoplastic fibres are usually heat-set, addition of polypropylene with an acrylic made it necessary to investigate the influence of heating temperature. The change in the different characteristics of acrylic-polypropylene yarns spun from different blend compositions and twists, with special reference to the application of boiling water, was also examined.

2 Materials and Methods

2.1 Preparation of Yarn Samples

All the yarns were made from four different blends of 3.2 denier, 64 mm acrylic fibre and 4.0 denier, 64 mm polypropylene fibre (Table 1). For spinning the yarns of various twists, four twist factors (2.6, 3.0, 3.4 and 3.8) were used for each yarn spun from a specific blend.

2.2 Thermal Treatment

All the yarns were heat-set at three different temperatures (100, 120 and 140°C) in a laboratory curing-setting chamber. The yarns were also subjected to boiling-water treatment for 30 min.

2.3 Tests

Yarn tenacity and extension were measured, before and after the thermal treatments, on an Uster single-yarn tester. Yarn unevenness and imperfec-

<table>
<thead>
<tr>
<th>Fibre</th>
<th>Fibre denier</th>
<th>Fibre length mm</th>
<th>Breaking tenacity g/den</th>
<th>Breaking extension %</th>
<th>Softening temp. °C</th>
</tr>
</thead>
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<tr>
<td>Acrylic</td>
<td>3.2</td>
<td>64</td>
<td>1.8</td>
<td>36</td>
<td>200-280</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>4.0</td>
<td>64</td>
<td>4.0</td>
<td>22</td>
<td>150-155</td>
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</table>
Yarn diameter and hairiness were measured on a Projectina microscope and the residual shrinkage of yarns was estimated by the method mentioned in BSI handbook.

3 Results and Discussion

3.1 Breaking Strength and Extension

3.1.1 Effect of Twist

Table 2 shows that yarns spun from a majority of polypropylene fibres possess a high breaking strength due to the high tenacity of this fibre. The higher breaking strength of low-twisted yarns can be attributed to the effect of cohesion between the components, which outweighs the effect of obliquity; however, a further increase in cohesion with increase in twist no longer results in increase in strength as a majority of fibres breaks. Further, the breaking strengths of various yarns do not show a similar trend, which may be accounted for by the varying strength utilisation factor, which is a function of blend composition and ultimately depends upon fibre parameters. Besides, the optimum twist multiplier also changes with change in proportion of different fibres in the blend. The observed trend is expected because of the overwhelming effect of denier and tenacity of the polypropylene fibre.

On the other hand, the breaking extension is low in weak yarns and continues to follow the same trend as strength with yarn composition. Further, the breaking extension is considerably low in yarns spun from higher proportions of polypropylene fibre probably due to higher tenacity, low extension and high stiffness of polypropylene. The latter, however, is a function of its tensile modulus, its density, and above all its fineness. An increase in breaking extension with increasing twist at low twists may also be due to the variability in strains with twist. Apart from fibre parameters, twist depends upon subsequent contraction of under-strained length and causes an additional extension of centre core before it breaks, as a result of the buckling of the centre core.

3.1.2 Effect of Heating Temperature

An examination of test results shows an increase in yarn strength followed by a decrease with further increase in heating temperature, which may be accounted for by the decreased surface cohesion. The fibres, therefore, bend and their rearrangement still resists rupture. This accords with the observation of Cook, who stated that polypropylene fibre retains its flexibility at lower temperatures and a further increase in temperature below the softening point results in the deterioration in mechanical properties. Moncrieff also mentions 51% loss in strength of acrylic fibre when it is exposed to a temperature of 140°C or above.

3.1.3 Effect of Boiling-water Treatment

The results of the tenacity of various yarns show a marginal increase in breaking strength after boiling-water treatment. This increase in yarn
strength may be accounted for by an increase in cohesive energy between fibres owing to a significant change in structural order of bulked yarn matrix. Because polypropylene fibre does not suffer any noticeable degradation, the behaviour, at low twists, may be attributed to the differential shrinkage of acrylic fibres, which reorganizes and shifts them towards the core. Further, the high resistance to buckling at high twists is expected to decrease yarn strength.

3.2 Yarn Linear Density
3.2.1 Effect of Twist
Yarns spun from a higher proportion of polypropylene fibre exhibit a lower linear density owing to the low specific gravity of this fibre. Table 3 also shows an increase in yarn linear density followed by a decrease with increasing twist. This may be attributed to the reduction in segment length arising from increased contraction, which, in turn, increases with twist. However, the high extension of fibre components at high twists causes an additional extension of yarn segment, resulting in a lower linear density.

3.2.2 Effect of Heating Temperature
The results in Table 3 show that all yarns exhibit higher linear densities at low temperatures; however, an increase in temperature (140°C) causes a decrease in yarn linear density. The increase in yarn linear density is expected to be due to the shortening of fibre length brought about by the alteration in structural matrix of fibres.

3.2.3 Effect of Boiling-water Treatment
The linear density of all yarns tends to increase after boiling-water treatment. Further, yarns either spun from higher proportions of acrylic fibre or treated with boiling water do exhibit a higher linear density, which can be attributed to the higher shrinkage potential of acrylic and easier penetration of water molecules right up to the core of the yarns.

3.3 Yarn Diameter
3.3.1 Effect of Twist
Table 3 shows that the diameter of all yarns tends to increase with polypropylene content owing to the greater bulk and coarse denier of this fibre, resulting in low yarn packing density, which ultimately causes an increase in diameter. An increase in twist factor from 2.6 to 3.8, in general, leads to a significant reduction in diameter. The reduction in yarn diameter may be accounted for by the increased packing coefficient, which, in turn, reduces the yarn specific volume and diameter.

Table 3—Effect of Yarn Composition, Twist, Heating Temperature and Boiling-water Treatment on Yarn Linear Density and Diameter

| Yarn ref. No. | T.M. (A:P) | Parent yarn Linear density tex | Diameter mm | Heating temperature°C | Boiling-water treatment
<table>
<thead>
<tr>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100 120 140</td>
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<td></td>
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<td>Yarn diameter mm</td>
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<td>Yarn diameter mm</td>
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<tr>
<td></td>
<td></td>
<td>33.12 0.2347</td>
<td>33.78 0.2362</td>
<td>31.78 0.2302</td>
<td>34.07 0.2539</td>
</tr>
<tr>
<td>S₁ 100:0 2.6</td>
<td>30.0 0.2282</td>
<td>34.99 0.2289</td>
<td>35.69 0.2434</td>
<td>28.76 0.2208</td>
<td>29.96 0.2574</td>
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<td></td>
<td>30.0 0.2217</td>
<td>32.45 0.2212</td>
<td>28.45 0.2595</td>
<td>28.92 0.2217</td>
<td>29.14 0.2469</td>
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<td></td>
<td>30.0 0.2135</td>
<td>31.89 0.2172</td>
<td>31.94 0.2204</td>
<td>29.77 0.2212</td>
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<td></td>
<td>30.0 0.2217</td>
<td>30.22 0.2224</td>
<td>30.00 0.2347</td>
<td>28.29 0.2272</td>
<td>29.93 0.2564</td>
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<tr>
<td>S₂ 60:40 2.6</td>
<td>30.27 0.2243</td>
<td>30.98 0.2461</td>
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<td>31.88 0.2372</td>
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<td>30.18 0.2235</td>
<td>31.44 0.2354</td>
<td>32.28 0.2626</td>
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<td>30.31 0.2287</td>
<td>33.90 0.2469</td>
<td>34.78 0.2527</td>
<td>32.11 0.2342</td>
<td>33.03 0.2642</td>
</tr>
<tr>
<td>S₃ 40:60 2.6</td>
<td>30.00 0.2210</td>
<td>30.53 0.2530</td>
<td>30.78 0.2730</td>
<td>29.47 0.2522</td>
<td>29.58 0.2504</td>
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<td>30.15 0.2191</td>
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<td>32.44 0.2645</td>
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<td>30.79 0.2093</td>
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<td>29.31 0.2234</td>
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<td>32.79 0.2547</td>
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<td>S₄ 0:100 2.6</td>
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<td>32.79 0.2547</td>
<td>29.45 0.2342</td>
<td>32.58 0.2730</td>
</tr>
</tbody>
</table>

*Yarns S₁ - S₄ exposed for 1 min; "Yarns S₁ - S₄ exposed for 30 min
A - Acrylic fibre; P - Polypropylene fibre
3.3.2 Effect of Heating Temperature
The results show an increase in yarn diameter with increase in heating temperature (Table 3). This can be attributed to the increase in bending and buckling of fibre components with increasing temperature, resulting in the loosening of the structural matrix of yarn owing to the decrease in cohesive forces. Further, the increase in diameter is less marked in high-twist yarns, which, according to Hearle, is expected to be due to the increased frictional hold on fibres, thus preventing them from bending and buckling.

3.3.3 Effect of Boiling-water Treatment
Yarn diameter, after boiling-water treatment, reflects the same trend as the diameter with heating temperature (Table 3). Further, the increase in diameter appears to be more with boiling water in comparison with that after heating at different temperatures. The observed trend is expected to be due to the higher absolute shrinkage of acrylic fibre in boiling water owing to quick and easier penetration of water molecules right inside the core.

3.4 Yarn Evenness and Imperfections

3.4.1 Effect of Twist
Table 4 shows yarn evenness and imperfections as influenced by the twist and thermal treatments. Higher proportions of acrylic fibre give a more regular yarn, but a further increase in twist makes it uneven. Yarn evenness decreases because high twist adds higher crimp to the yarn, and hence imparts a wavy effect, leading eventually to a higher Uster value.

Further, the Uster values and the number of imperfections for 64 mm fibre appear to be high in this investigation. This can be attributed to the inevitable problems like card loading, excessive nep formation, and fibre damage owing to inappropriate length: denier ratio. A regular reduction in neps with increasing proportions of polypropylene may also be noticed probably due to the high resistance to nepping offered by this fibre.

3.4.2 Effect of Heating Temperature and Boiling-water Treatment
None of the parameters, viz. evenness, thick and thin places or neps, reflects any significant association with either heating or boiling-water treatment owing to the independent formation of individual yarn faults.

3.5 Yarn Hairiness

3.5.1 Effect of Twist
The results of yarn hairiness (Table 5) show a considerable increase in the number of protruding fibres for yarns spun from a majority of polypropylene fibres. The increase may be attributed to the high bending rigidity and the large diameter of polypropylene. Further, an increase in twist leads to an appreciable reduction in yarn hairiness. The
The reduction is expected to be due to the in-body of yarns. High twist enables the fibres to traverse towards the number of protruding fibres decreases because the decreased fibre mobility with increasing twist, however, is expected to cause a further collapse of fibres or lateral movement of fibre segments nearer to the yarn surface, resulting in decrease in the number of protruding ends.

3.5.2 Effect of Heating Temperature

Table 5 shows a consistent reduction in the number of protruding fibres for all twist levels. The reduction is expected to be due to the increased buckling tendency of fibres at higher temperatures. On the other hand, a greater reduction in the number of protruding ends in yarns spun with higher proportions of acrylic fibres may also be observed owing to change in shrinkage potential of acrylic with change in temperature. As a result, there is shortening of looped fibre length and decrease in the number of protruding ends.

3.5.3 Effect of Boiling-water Treatment

Table 5 shows that all yarns, after boiling-water treatment, exhibit a marginal reduction in hairiness irrespective of the choice of yarn composition and twist. This may be attributed to the increased clinging tendency of the fibres towards the main body of the yarn. Though no specific relationship between the number of protruding ends per unit length and yarn twist has been observed, the decreased fibre mobility with increasing twist, however, is expected to cause a further collapse of fibres or lateral movement of fibre segments nearer to the yarn surface, resulting in decrease in the number of protruding ends.

3.6 Assessment of Residual Shrinkage and Its Dependence upon Twist and Thermal Treatments

As may be observed from Table 5, yarn residual shrinkage appears to decrease with increasing twist, which according to Hearle may be attributed to the development of tangential and radial forces in fibres that tend to bind them together. Any imposed tension in yarn, therefore, generates an inward pressure from the outer layers to inside ones, leading to a close packing of fibres, which, in turn, offers more resistance to buckling of fibres.

The transient response of yarns with boiling-water treatment in comparison with that due to heating at different temperatures shows a marked increase in residual shrinkage irrespective of fibre proportion and twist. This is attributed to the combined effect of increased fibre mobility and optimum buckling with boiling water, which occurs because each single fibre is exposed to treatment.

4 Conclusions

4.1 Yarns spun from a majority of polypropylene fibres at all levels of twist are stronger. However, an increase in heating temperature results in increase in breaking strength and extension followed by a decrease with further increase in temperature. The increase in tenacity is more after boiling-water treatment.
4.2 Yarn diameter decreases with increase in twist; the former, however, increases after thermal treatments but the effect of boiling water is more prominent in comparison with that due to heating at different temperatures.

4.3 Yarns spun from higher proportions of acrylic fibre at all levels of twist are more regular. However, yarns with a higher twist, on the other hand, show deterioration in evenness.

4.4 Yarns spun with higher proportions of acrylic fibre give a greater number of nepes, while the number of thick and thin places do not show any specific trend.

4.5 Thermal treatments have no significant effect on either the unevenness or imperfections of acrylic-polypropylene yarns.

4.6 Yarns spun from higher proportions of polypropylene are more hairy. However, yarns with a higher twist, on the other hand, show consistent reduction in hairiness.

4.7 Thermal treatments result in a significant decrease in yarn hairiness but the effect of boiling water is more prominent in comparison with that due to heating at different temperatures.

4.8 Twist has a significant effect on yarn residual shrinkage. Yarn residual shrinkage increases with an increase in heating temperature and decreases thereafter with further increase in temperature. However, yarns subjected to boiling-water treatment, on the other hand, show a considerably higher shrinkage irrespective of twist.

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References