Core-spun yarns incorporating a textured nylon multifilament core were prepared by introducing the multifilament core along with a drafted ribbon of fibres as the latter entered the nip of the front rollers of a ring frame. The geometrical disposition of the core was altered by changing the twist multiplier, pre-tension and the type of feeding of the sheath material, and the effects of these changes on the tensile properties were evaluated. Comparison of the stress-strain curves for the core-spun yarns with those for the continuous filament and cotton yarns of the same counts spun under identical conditions highlighted the behaviour of the components in a core-spun yarn undergoing strain. The contribution of the cotton components to core-spun yarn strength was assessed by the study of cotton fibre breakage at various levels of yarn strain. The results from the Instron tensile tester reveal the mode of strain distribution along the length of the yarn. The process of rupture of the core-spun yarns has also been studied in detail.

The development of the spinning processes to produce stronger yarns at a faster rate resulted in the introduction of continuous filamental yarns. But staple fibre structures predominate over the continuous filamental yarns for their improved use characteristics such as easy care, comfort, bulk, etc. To produce a yarn with improved use characteristics, an idea was conceived which would embody rational utilization of the properties of both the continuous filamental yarn and the staple fibre yarn. This resulted in the introduction of core-spun yarns, which consist of a blend of a number of components wherein one of the components, usually a continuous filamental yarn, is constrained to lie permanently at the core, while the remaining components act as the covering fibres around the central core.

A special feature of the core-spun yarn is the different properties in its inner and outer regions. The choice and exploitation of the various properties in the inner and outer regions of the yarn commend their usage for specific applications, namely tarpaulins, tentages, hose pipes, belting ducks, sewing threads and other industrial applications. The continuous filament incorporated at the central axis of the yarn contributes mainly towards the strength, while the surface characteristics of the composite yarn provide properties of adhesion, heat insulation, bulk, etc. These properties are exploited in the manufacture of belting, tarpaulins, hoses, etc., which demand an after-treatment with chemicals. Further, the production of light-weight apparel fabrics, hitherto not possible by ordinary methods, can be done using a soluble core. Much of the bagginess in wear can be eliminated by incorporating elastomeric core-spun yarns into cuffs, neck bands of sweaters, collars, etc., and such types of yarns find extensive applications in apparel fabrics, slacks, creepers, leisure wear, underwear, knitted garments, etc. Also, by using a continuous filament core, breakages in spinning and cloth manufacture can be reduced substantially.

Several methods for the manufacture of core-spun yarns, their merits and demerits, along with the end uses, have been reported. A critical assessment of the merits of core-spinning through a comparison of the strength and extension of core-spun yarns with those of all-staple yarns was made by Balasubramanian and Bhatnagar. Bhatia investigated the influence of some of the processing parameters on the properties of core-spun yarns. New methods for the production of core-spun yarns more rapidly and without the limitation of the staple length have been reported.

Mechanical properties are of prime importance for yarns meant for industrial applications. The mechanical properties of core-spun yarns depend upon the load-elongation characteristics of the components. So a study of the tensile behaviour of such yarns would contribute to a better understanding of the mode of strain distribution along the length of the yarn and the contribution of the components to the core-spun yarn strength.

The production and properties of core-spun yarns composed of a 40 den textured nylon multifilament core are reported in this paper. Detailed studies were made only on one count, namely 26 tex, where the filament formed 17% of the yarn. Pre-tension and type of feeding were suitably selected to alter the geometric disposition of the filament in the composite yarn. The...
effect of these changes on the tensile properties was evaluated over a range of twists.

Materials and Methods

Production of core-spun yarns—The method for producing core-spun yarns consists in introducing the filamentary yarn along with the drafted ribbon of fibres at the nip of the front rollers in a ring frame. If the filament is delivered at the same speed as the staple fibre material, the filamentary yarn always exceeds in length that of the composite yarn and is not likely to stay at the core only, but is found to migrate, from time to time, to the surface of the core-spun yarn. The two different methods for obtaining a reduced delivery rate to the core are differential twist retraction and pre-tensioning, the latter being the more commonly used method.

The core material, namely textured nylon multifilament, was taken from the supply package around suitable guides to facilitate smooth unwinding. It was then drawn through a suitable tensioning device capable of providing a wide range of tensions. A disc type of tensioning device mounted on the top of the drafting zone was used. The suitably tensioned filament was then drawn over a porcelain guide roller to enable the filament to be positioned accurately at the centre of the drafted ribbon of fibres. The filament was finally drawn through the eye of a sewing machine needle, mounted just above the drafted ribbon of fibres and just behind the nip of the front rollers to ensure that the position of the filament remains unaltered throughout the production of the core-spun yarn. The traverse mechanism for the roving guides was also disengaged to ensure the same.

The cotton sheath was processed through the same set and sequence of machines under similar conditions to reduce the variations as far as possible to a minimum. The roving from the roving bobbins was passed over suitable guides and through a special arrangement made at the cradles for double end feeding. The drafted ribbon of fibres entered the nip of the front rollers along with the suitably tensioned and positioned core. To take advantage of the natural fold and hence to obtain a better cover, the filament was fed at the left side of the drafted ribbon of fibres in the case of single end feeding arrangement, while in the case of double end feeding rovings were fed separately and the filament was fed at the centre to ensure better cover and good strength.

The present investigation was carried out on similar lines as that by Balasubramanian and Bhatnagar with a few changes. A textured nylon multifilament 40 den (4.4 tex) was used as the core and cotton suitable for spinning 60's Ne (9.84 tex) was used as the sheath. Core-spun yarns of 26 tex were produced whereby the filament formed 17% of the yarn. Two extreme tension levels, namely 4 g and 20 g pre-tensions, were selected to vary the geometrical disposition of the filament and hence to study the effect of the same on the tensile behaviour. It was found that an initial tension of 4 g was necessary to remove all the kinks in the textured core and an optimum tension of 20 g was needed to ensure that no buckling of the staple fibres takes place during spinning. Four different twist multipliers were selected to investigate the influence of twist on the tensile behaviour so as to cover the usual range of twist multipliers employed in normal practice. Further, the effect of the feeding type was studied by making use of multipliers employed in normal practice. Further, the effect of the feeding type was studied by making use of both single and double end feeding arrangements. The same rovings were employed to spin 100% cotton yarns to be used for comparison purposes, by corresponding manipulation of the spinning draft. The spindle speed, traveller size and other particulars were kept the same for either method of spinning. The twist was varied over a selected range, and core-spun and cotton yarns were spun under similar conditions.

Testing procedure—Goodbrand, Scott and Instron tensile testers were used for tensile testing of yarns. The conditions of testing were as follows:

Goodbrand tensile tester:
Test length, 48.5 cm;
and rate of traverse, 30 cm/min.

Scott tensile tester:
Test length, 50 cm;
and rate of loading for most of the tests, 1000 gf/min.

Instron tensile tester:
Gauge length, 8 cm
for most of the tests;
and rate of extension 60%/min.

From the load-elongation curves obtained, the tensile behaviour of the core-spun yarns was assessed by studying the (a) stress-strain relations, (b) cotton fibre breakage, and (c) the process of rupture.

Results and Discussion

Stress-strain relations—Core-spun yarn is a composite yarn composed of a continuous filamental core and a staple fibre covering, the former providing support to the latter. Since the filament and the staple fibre material, namely cotton, are of different materials, the tensile properties of the composite yarn depend, as in the case of blends, on the load-elongation characteristics of the components. Comparison of the stress-strain curves of the core-spun and cotton yarns
of the same count, spun under identical conditions, highlights the behaviour of the components in a core-spun yarn undergoing strain. The load-elongation curves for core-spun, all-cotton and nylon multifilament were obtained by a method similar to Kemp and Owen method. The stress-strain curves for core-spun, all-cotton and nylon multifilament were derived from the load-elongation curves. On the assumption that cotton and nylon behave in a similar manner in the case of both core-spun and conventional yarns, the stress-strain curves for core-spun yarns were derived. A method similar to the one followed by Balasubramanian and Bhatnagar was employed to obtain the predicted curves for the core-spun yarns.

The stress-strain curves (predicted and actual) for core-spun yarns, prepared with cotton yarn and nylon multifilament drawn up to the point of the first breakage, are included in Fig. 1. The core-spun yarns were prepared with 20 g pre-tension using single feeding arrangement over a varied range of twists. It is observed that at any given extension level, the stress borne by the core-spun yarn is less than the predicted stress. This indicates a small reduction in the realization of strength from the components. This feature was noticed in the case of core-spun yarns prepared with both 4 g and 20 g pre-tension using single and double feeding arrangements at all twist levels. This slight fall in strength realization may be attributed to the differences in geometric disposition and hence the cohesion between the components of the composite yarn. At any given extension level below the point of rupture, the stress borne by the core-spun yarn (actual) is less than that of the components. This may be attributed to the serigraphic effect by virtue of which in a composite yarn comprising cotton and nylon, which vary widely in their stress-strain characteristics, the maximum load at any given extension below the point of rupture of cotton component is shared by the cotton component, while the incorporation of the nylon multifilament in the composite yarn does not contribute in any way to higher strength realization. This also accounts for the lower tenacity of the core-spun yarns prepared using double feed, than that of the equivalent cotton yarns, at all twist levels. The same feature was noticed for core-spun yarns prepared using single feeding arrangement, except at low twists. The presence of the continuous filament in the latter case reduces the slippage of the cotton fibres and hence accounts for higher strength realization. The breaking extension of the core-spun yarns was found to be slightly higher than that of the equivalent cotton structures. The effect was found to be more pronounced in the case of core-spun yarns prepared using single feed than double feed.

The stress-strain curves for the core-spun yarns prepared with 4 g and 20 g pre-tension over a varied range of twists are shown in Fig. 2. The slope of the stress-strain curves was found to reduce progressively with the twist multiplier. The stress borne by the core-spun yarns at any given extension level, in general, increases progressively with reduction in the twist multipliers. In addition, core-spun yarns prepared with higher twist multipliers have higher breaking extension values. This may be attributed to the fact that the increased obliquity in the lie of fibres with the increased twist multiplier allows the highly extensible core to take the load and extend.

The stress-strain curves for core-spun yarns prepared with 4 g and 20 g pre-tension using a single feed are shown in Fig. 3. It is seen that the breaking stress values for core-spun yarns prepared with 20 g pre-tension are greater than those prepared with 4 g pre-tension at all twist levels. The same feature was noticed in the case of core-spun yarns prepared using a double feeding arrangement. These results show that
the pre-tension certainly influences the geometric disposition and hence the strength of the yarn. This may be attributed to the fact that the filament lies close to the core and is in contact with the sheath material over a greater surface area as a result of higher pre-tensioning, thereby improving the resistance to slippage. This improved resistance to slippage makes the yarns spun with 20 g pre-tension even with the lowest twist multiplier to exhibit a single sharp break in contrast to core-spun yarns prepared with 4 g pre-tension.

The stress borne by the core-spun yarns, at any given extension level, is more for 4 g pre-tension at 3.0 and 4.1 twist multipliers. But the core-spun yarns prepared with 20 g pre-tension are found to have a higher stress at any given extension level at 5.4 and 6.5 twist multipliers. A similar feature was observed in the case of core-spun yarns prepared with a double feeding arrangement.

The stress-strain curves for core-spun yarns prepared with a pre-tension of 20 g using both single and double feeding arrangements over a varied range

Fig. 2—Stress-strain curves for core-spun yarns [(1) core-spun yarns prepared with TM = 3.0; (2) core-spun yarns prepared with TM = 4.1; (3) core-spun yarns prepared with TM = 5.4; and (4) core-spun yarns prepared with TM = 6.5. (A) Core-spun yarns prepared with 20 g pre-tension; (B) core-spun yarns prepared with 4 g pre-tension using double feed; (C) core-spun yarns prepared with 20 g pre-tension; and (D) core-spun yarns prepared with 4 g pre-tension using single feed]
of twists are shown in Fig. 4. The stress-strain curves for the core-spun yarns prepared using a double feed have greater slope than those prepared using single feeding arrangement. Further, the stress borne by the core-spun yarns prepared by a double end feeding arrangement is more than that in the case of yarn prepared by the single end feed at any given extension level below the point of rupture. This feature, in general, was also observed in the case of core-spun yarns prepared with 4 g pre-tension over a varied range of twists. This may be attributed to the better cover and hence cohesion developed as a consequence of the double end feeding employed. The improved binding between the cotton fibres and nylon filament in the core-spun yarns prepared with double feed does not allow relative movement and slipping of the cotton component and hence a higher stress is developed at a given strain with such yarns than with single feed core-spun yarns.

The breaking stress values for core-spun yarns prepared using double feed were found to be higher than those for the core-spun yarns prepared using single feed for twist multipliers 3.0 and 4.1. The breaking stress values, for single end feeding arrangement, further increased as the twist multiplier was increased to 5.4 and 6.5 compared to the corresponding yarns obtained using double end feeding arrangement. The better cover of the core-spun yarns as a result of double end feeding results in improved resistance to slippage and consequently higher strengths were realized in such yarns at low twists. The benefits from this source seemed to be outweighed by other considerations and hence, instead of improvement, drop in strength was found at higher twists in the case of double end feed. This is due to increased obliquity and non-simultaneity in the occurrence of breaks in the cotton component, which is the direct outcome of higher inter-fibre cohesion. This non-simultaneity in the occurrence of breaks does not permit the equalization of strains along the length of the migrating fibres. This effect is likely to be more pronounced in the case of double feed as a consequence of greater cohesion and hence would result in strength deficiencies at higher twist multipliers.

**Cotton fibre breakage**—The behaviour of the cotton component in the core-spun yarn during straining of the yarn to extensions below and beyond the breaking extension of all-cotton yarns highlights the contribution of the sheath component to the core-spun yarn strength. An insight into the contribution of the components to the core-spun yarn strength could be obtained by comparing the length-frequency distributions of cotton fibres removed from core-spun yarns strained to different extensions below and beyond the breaking extension of all-cotton yarns. This would give a clear understanding of the process of cotton fibre breakage during straining of the composite yarn. Detailed investigations were made on core-spun yarns prepared with a pre-tension of 4 g using double feed with a twist multiplier of 3.0. A method similar to that followed by Kemp and Owen was adopted. The material was strained to the desired extent on a Goodbrands single thread strength tester. Two ink marks spaced at a distance of 8 cm were marked at a randomly chosen place on the strained yarn. The ink marks on the strained yarn were cut and the specimen was slightly untwisted and all the cut (inked) fibres were removed. To assist this operation, the specimen was held firmly between two glass plates with a small length protruding beyond the glass plates with a weight on the top of them. After the removal of cut fibres, length measurements were made on 400 fibres pooled from several specimens selected along the length of 8 cm, and length-frequency distributions of cotton fibres obtained from core-spun yarns strained to 0, 10, 20 and 30% extensions were drawn. The mean length, coefficient of variation of length and the % of fibres broken deduced from the mean length are given in Table 1.

The length-frequency distributions for cotton fibres in core-spun yarns extended to different extents are depicted in Fig. 5. It is seen that the modal value shifts towards the origin with increase in strain on the core-spun yarns. As expected, with increase in strain beyond the breaking extension of all-cotton yarn, greater number of fibres continue to break, which is indicated by the shift in the modal value towards the left. It is clear from Table 1 that the cotton fibres continue to break even at strains beyond that at which all-cotton yarn ruptures. A value above the maximum value of 100 for the percentage of cotton fibres broken indicates that a portion of the fibres break more than once at 30% strain. The sufficiently higher cohesion between the sheath and the core component makes the cotton fibres continue to contribute to the load in the yarn even after the first break. This is further accentuated by the higher surface area available on the core component as a consequence of the presence of multifilaments in the core as well as the textured character of the core.

<table>
<thead>
<tr>
<th>Table 1—Percentage of Cotton Fibres Broken at Different Levels of Yarn Extension</th>
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<tr>
<td><strong>Material</strong></td>
</tr>
<tr>
<td>Core-spun yarn, 0% extension</td>
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<tr>
<td>Core-spun yarn, 10% extension</td>
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<td>Core-spun yarn, 20% extension</td>
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<td>Core-spun yarn, 30% extension</td>
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The process of rupture—Most of the specimens of core-spun yarns prepared with a pre-tension of 4 g and a twist multiplier of 3.0 using both single and double feeds were found to have breaking extensions somewhere between the breaking extension of all-cotton yarn and that of the nylon multifilament. These specimens were found to take the load up to a certain extent, beyond which higher extensions were realized for a slight increase in the load and did not exhibit a single sharp break. Further, from the cotton fibre breakage study, the percentage of fibres broken exceeded 100 for yarn strains beyond 30%, indicating the occurrence of multiple breaks. A study of the mechanism of breakage of the components would contribute to a better understanding of the contribution of the components to the core-spun yarn strength. The contribution of the components to the core-spun yarn strength can be obtained by studying the load on the specimen at different levels of strain. An electronic tensile tester would measure the load on the specimen at different levels of yarn strain. Any drop in the load would also be recorded on such an instrument. Detailed tests were made on core-spun yarns spun with 4 g pre-tension using double feed with a twist multiplier of 3.0. Initial tests on an Instron tensile tester at gauge lengths of 50 and 30 cm gave load-extension curves similar to those obtained on Goodbrand and Scott seriplane testers, the record showing a single sharp break. However, when the specimen length was reduced to 8 cm, the break was of a different kind, the specimen showing stepwise breaks. In such specimens, the load-extension curve proceeded smoothly up to the first breakage at which a sharp fall in the load on the specimen was noticed, this being followed by a series of stepwise breaks continuing to much higher extensions.

Fig. 6 shows some typical load-extension curves obtained from an Instron tensile tester. For core-spun yarns prepared with a pre-tension of 4 g using double feeding arrangement, the load dropped by 20-135 g at the time of the first break, but the residual load on the specimen was still much higher than that of nylon at this extension level, from which it can be inferred that the cotton component contributes substantially to the load in the yarn. Further, with increase in the strain, the load on the specimen was found to increase to a certain extent until the point of second break, after which a drop in the load on the specimen was noticed. This stepwise break continued to the point of final rupture lying somewhere around the breaking extension of the nylon multifilament. In most cases, the loads on the specimen at the subsequent breaks were less than the load at the time of first break. The stepwise rise and fall of load on the specimen may be attributed to the multiple breaks in the cotton component and the stick and slip effects. This accounts for a value over and above 100% for cotton fibres broken at 30% strain observed under cotton fibre breakage. The final rupture point was found to be highly variable, lying somewhere around the breaking extension of the nylon multifilament. Even the breaking extension of the nylon multifilament was found to be highly variable, depending upon the variations between and within the component filaments.
At the time of the first break, the inter-fibre frictional forces between the cotton fibres and the nylon multifilament were sufficiently high. If the specimen length is more, these high inter-fibre frictional forces do not permit the high tension developed in the specimen to be dissipated in portions in the form of fibre slippage, as a result of which the break spreads across the cross-section at the place of breaking. This is why at larger specimen lengths, the first break could not be distinguished from the rupture point. Contrary to this, at short specimen lengths and at lower twist multipliers, the inter-fibre frictional forces are insufficient, and this allows the tension on the specimen to fall in portions as a result of fibre slippage in the case of lower twist multiplier; the insufficient stored energy available in the case of short specimen lengths causes the break to be completed instantaneously.

Core-spun yarns prepared with a pre-tension of 20 g showed noticeable differences from yarns prepared with 4 g pre-tension. With core-spun yarns prepared with 20 g pre-tension, more specimens were found to have a sharp drop in the load on the specimen at the time of first break, though it was of less predominating type in the latter. The extent of drop at the time of first break was remarkable, lying anywhere in the range 20-135 g as against 20-50 g for specimens prepared with a pre-tension of 4 g. Differences in geometric disposition and hence the cohesion between the components may account for this disparity. The contribution of cotton fibres to the load on the specimen by stick-slip effects was also reduced in the case of specimens prepared with 20 g pre-tension.

Conclusions

(1) Comparison of the stress-strain curves for the core-spun yarns with those for the continuous filament and cotton yarn of the same counts spun under identical conditions highlights the behaviour of the components in the core-spun yarns undergoing strain. At any given extension level, the stress borne by the core-spun yarn is less than that predicted from the components, indicating a small reduction in the realization of strength from the components.

(2) In general, the tenacity of core-spun yarns is less than that of equivalent cotton yarns and the nylon multifilament.

(3) The breaking extension of the core-spun yarns is slightly higher than that of equivalent cotton structures and is more pronounced in the case of core-spun yarns prepared using single feed.

(4) The slope of the stress-strain curves decreases progressively with increase in the twist multiplier. Hence, the stress borne by the core-spun yarns at any extension level, in general, increases progressively with reduced twist multipliers.

(5) Pre-tensioning certainly influences the geometric disposition of the filament and hence improves the strength of the composite yarn by constraining the filament to lie close to the core.

(6) The stress borne by the core-spun yarn below the point of rupture is more for core-spun yarns prepared with double feed than for yarns prepared using single feed. The effect is more pronounced at higher pretensions.

(7) The relative merits of single and double feeds with respect to the tenacity of the yarn vary with the twist multiplier employed. A double end feeding is advocated for core-spinning at lower twist multipliers.

(8) Study of the length-frequency distributions of cotton fibres obtained from core-spun yarns strained below and beyond the breaking extension of all-cotton yarns shows that the modal value shifts from right towards left, indicating increase in fibre breakages with increased strain. Cotton fibres continue to break even at strains beyond that at which all-cotton yarn ruptures and a portion of fibres break more than once.

(9) At any given extension level, the load borne by the core-spun yarn is greater than that of the nylon multifilament, which indicates a substantial contribution of the sheath component.

(10) Core-spun yarns like cotton yarns show a single sharp break, except at short specimen lengths and low twists. For short specimen lengths at low twists, a sharp drop in the load followed by a series of stepwise multiple breaks due to stick and slip effects continuing to much higher extensions can be observed.

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