Influence of Residual Twist in Single Yarns on the Tensile Strength of 2-Ply Yarns

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The strength of ply yarns is determined by the tensile contribution of the constituent singles and the enhanced inter-fibre cohesion due to spiralling of the singles around one another. It has been shown that these two components determining the strength of the ply yarns are dependent, to a large extent, on the fibre length and its variability, as also the direction of the ply twist in relation to the direction of twist in the singles.

It is often necessary to twist two or more single yarns together to form a ply yarn to meet a particular end-use requirement like sewing threads, heavy weight fabrics, selvedge yarns, etc. The ply yarns give enhanced yarn regularity. They also result in increased yarn tenacity if the twist levels and direction for singles and ply yarns are suitably chosen. The tensile strength of a plied yarn is a function of the tensile strength of the constituent single yarns. During ply twisting, each single yarn rotates about its own axis, resulting in a change in its twist. Hence, the twist in the singles (as they lie in the ply yarn) becomes important, since the single yarn would not be expected to behave in the same manner in the plied state as it would behave outside the plied structure. An estimation of the residual twist in the singles can be of great value in determining the contribution of the singles strength towards plied yarn strength. The present work is concerned with the study of this contribution of singles towards the tensile behaviour of plied yarns.

Materials and Methods

California cotton (staple length, 27 mm) and viscose rayon fibres (denier, 1.5 and staple length, 37 mm) were used for spinning the yarns of the following specifications: linear yarn density, 30 tex for cotton and 19 tex for viscose rayon; and tex twist factor, 39 for cotton and 30 for viscose rayon. All these yarns were spun with S twist. The single yarns were plied employing both S and Z direction of twist, i.e. similar to and opposite to that of singles twist. The ply twist factors were varied from 0.6 to 1.5 times the singles twist factors.

Tensile strength—Single yarns and ply yarns were tested for tensile strength on the Instron using a gauge length of 30 cm. Twenty readings were taken for each sample.

Influence of varying twist on the tensile strength of single yarns—This study was undertaken with a view to finding out the strength of single yarns at the level of twist they will have after being plied. For this, the twisting head of a Goodbrand twist tester was fixed in an aluminium clamp. This clamp was then mounted on a stand which was kept on the base of Instron tensile tester. The twisting head was so fixed on the stand that the distance between the upper jaw of Instron and the jaw of the twisting head was 30 cm. The yarn was fixed in this condition in the lower jaw of Instron. Before completely tightening the lower jaw, the 'pen' was switched on and a pretension of 1/100 of full scale load was given to the sample. Ten readings at each twist level were taken. The twist was then gradually removed in steps of 1 turn/cm until the yarn showed practically zero breaking load.

The same procedure was repeated by adding twist in the direction of single yarn twist in steps of 1 turn/cm. In this way, a complete picture of yarn strength at various twist levels was obtained (Figs 1 and 2).

Calculation of residual singles twist—Various workers have studied the relationship between the initial singles twist, ply twist and the residual twist in single yarn. Notable among them are the derivations by Merrill, Freeston et al., Zurek and Godon, Matukonis, Platt et al., Woods and Schwarz. The equation given by Wood and supported by Schwarz has generally been accepted as the most logical and suitable one. If the single yarn had originally \( T \) turns
per unit length, the residual twist $T_0$ in singles is given by the expression:

$$T_0 = T_1 \pm \cos^2 \theta_1$$  \hspace{1cm} (1)

where $\theta_1$ is the twist angle of the ply yarn.

The plus sign is used when plying twist is in the same direction as the singles twist and the minus sign when it is in the opposite direction.

**Contribution of single yarn strength to the ply yarn strength**—The contribution of the single yarn strength to ply yarn strength was calculated using the expression:

$$S_p = 2S \cos \theta_1$$  \hspace{1cm} (2)

where $S_p$ is the contribution of single yarn strength to ply yarn strength; $S$, the yarn strength corresponding to the residual twist; and $\theta_1$, the twist angle of the ply yarn.

The residual twist was determined using Eq. (1) and the value of $S$ was read off against this twist from Figs 1 and 2 for cotton and viscose rayon yarns respectively.

**Results and Discussion**

The effect of relative twist on the tensile strength of ply yarn is shown in Figs 3 and 4 for cotton and viscose rayon respectively. In Fig. 3, the ratio of ply yarn strength to single yarn strength has been plotted against the ratio of ply yarn twist factor to the single yarn twist factor. Curve 1 depicts the behaviour of ply yarn strength when the direction of twist during ply twisting is same as that of twist in the singles. Curve 2 shows the same when the ply twist is in the reverse direction. Curve 1 shows a maximum in the strength ratio at the twist factor ratio of 0.86. This indicates that increase in the twist of single yarns during ply twisting in the same direction as the singles twist results in considerable increase in the inter-fibre cohesion reflected in increased ply yarn strength which more than offsets the effect of reduction in the strength of the singles due to the obliquity effect. This can be seen from the steady increase in the contribution of the
strength of single yarn to the ply yarn strength (Fig. 5). However, beyond the maximum, there is a gradual decrease in the ply yarn strength when the effect of obliquity overrides any further increase in strength due to increase in inter-fibre cohesion resulting from the greater transverse forces. It is possible that beyond the twist factor ratio of 0.86, the increase in strength due to increase in inter-fibre cohesion is very small, subsequently reaching a saturation point. Curve 2 shows an interesting phenomenon in that the yarn strength ratio remains practically unaltered with increase in twist factor ratio. The reverse ply twist causes the fibres in the constituent single yarns to have reduced twist angle and hence increased contribution to the yarn strength, i.e. the strength loss due to obliquity effect is reduced. However, this increase is counteracted by the reduction in strength due to a drop in the inter-fibre cohesion resulting from the decrease in the twist in the single yarn. Ply twisting counteracts this reduction in inter-fibre cohesion in the singles due to the increase in cohesion between the two single yarns spiralling around each other. A net reduction in inter-fibre cohesion is, however, expected and is likely to be higher for yarns made from cotton due to the presence of short fibres which fail to contribute much to the yarn strength. This conclusion is further strengthened by the results on single yarn strength contribution to the ply yarn strength as shown by curve C in Fig. 5. The second difference between the curves 1 of Figs 3 and 4 is the rate of drop in the ply yarn strength which is much higher for the viscose rayon yarns. For cotton yarns, the drop is not that steep because of the continuous increase in strength due to the increased inter-fibre cohesion even at high twist levels.

Curves 2 of Figs 3 and 4 are completely different. The curve for cotton shows a complete balance between the gain in strength (due to decreasing fibre obliquity) and the loss in strength (due to decreasing inter-fibre cohesion). On the other hand, the viscose rayon yarn shows a minimum in strength ratio at the
twist factor ratio of 0.8 and then a steady increase, which starts levelling off at the twist factor ratio of 1.22. A possible reason for the initial decrease could be that the initial untwisting of the single yarns due to the twisting of ply yarn in the opposite direction causes a much higher drop in strength due to an overall decrease in inter-fibre cohesion (due to lessening of transverse forces) than could be compensated by the slight gain due to reduced fibre obliquity. The subsequent increase beyond the minimum could be attributed to two factors: (1) The drop in inter-fibre cohesion due to reduction in twist is compensated by a corresponding increase in cohesion between the two single yarns due to ply twisting, causing a net increase in inter-fibre cohesion, and (2) the fibre strength utilization improves because of lower loss due to fibre obliquity.

The contribution of single yarn strength to the ply yarn strength is shown in Fig. 5, which brings out some interesting facts. The yarns spun from the cotton fibres, which are short and highly variable in length, show that the contribution of single yarn strength to the ply yarn strength is greatly influenced by the direction of ply yarn twist, the contribution being highest when the ply twist is in the same direction as the singles twist and minimum when it is in the opposite direction. On the other hand, the yarns spun from viscose rayon fibres, which are long and of uniform length, show very little dependence on the direction of twist. This is evident from the fact that the values of contribution for viscose rayon for both the directions of ply twisting fall in between those for cotton.

**Conclusion**

The tensile strength of 2-ply cotton yarns having plying twist in the same direction as that of singles is higher than in the case of yarns in which the direction is opposite. This, however, is not true for 2-ply viscose rayon staple yarns having ply-to-single twist factor ratio beyond 0.94. At higher ply twist factors, the fibre strength utilization is far better in S over Z than S over S twisting, evidently due to reduced effect of obliquity.

For S on S twisting, the major portion of ply yarn strength is contributed by the single yarns for cotton. On the other hand, for viscose rayon, the S on Z twisting brings out a higher contribution from the singles. The behavioural difference between the yarns spun from these two fibres, viz. cotton and viscose rayon, is, therefore, attributable to the differences in their staple length and the length variability.

**References**