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Short Communication

Twist contraction of jute multi-ply yarn –a theoretical approach

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Twist contraction is a critical phenomenon in ply yarn manufacturing. This study presents a theoretical model to predict the contraction factor of jute multi-ply yarns, accounting for the helical configuration of single yarns and the twist loss incurred during plying. The model integrates geometric parameters and twist mechanics to derive an expression for the contraction factor, incorporating both the helical path length and the incremental length change of single yarns due to untwisting. Theoretical predictions were validated through experiments using 2, 3, and 4-ply jute yarns of various counts and twist levels. Comparison between calculated and measured contraction factors demonstrated strong agreement, confirming the model's applicability.

Keywords: Helix, Jute, Ply yarn, Twist contraction, Twist loss

Introduction

Twist contraction is an important phenomenon in ply yarns, where twisting multiple single yarns together reduces the overall yarn length due to geometric and mechanical interactions among the constituents[1]. Expressed as the contraction factor, it strongly influences yarn texture, density, and dimensional stability [2,3]. During plying, single yarns are generally twisted in the opposite direction of their original twist, leading to twist loss and a corresponding increase in their length. Consequently, the actual single-yarn length within the ply differs from its ideal helical length, underscoring the need for accurate modelling of twist contraction.

In commercial plying operations, contraction directly affects bobbin capacity, yarn take-up, length uniformity, and maintenance of the intended linear density. The ability to predict contraction reliably helps minimise trial-and-error, reduce material waste, and optimise twist settings for desired yarn characteristics.

Twist mechanics of multi-ply yarns and related contraction behaviour have been examined by several researchers[4–7]. Woods[4] showed that single yarns undergo tortuosity during plying, causing a twist change of "2π sin α" radians per turn of doubling. Coulson and Dakin[7]explained differences between measured and calculated twist density in terms of single-yarn length increment and the resulting redistribution of ply twist, and further described negative and positive take-up behaviour based on the ply-to-single twist ratio. Salhotra and Dutta[8] investigated the residual twist in single yarns inside the ply and its influence on ply-yarn strength. Lin *et al*.[9]examined the influence of twist direction and thereby twist loss in single yarns on the physical properties of plied yarn produced from a rotor twister. Twist contraction in chenille yarn have also been derived by Ilhan S & Yarar[10]using mathematical and statistical approaches[10].

Although the mechanics of twisting and plying have been examined by several researchers, these works primarily focus on twist redistribution, torsional deformation, and qualitative explanations of length variation in multi-ply yarns. However, no previous study has presented a unified analytical model that simultaneously accounts for the geometric helical configuration of constituent yarns and the twist-loss-induced length increment occurring during plying.

The present study is an effort to address this gap by developing an integrated model combining helical geometry with twist-loss behaviour to predict the actual contraction of single yarns as they lie within a multi-ply structure. The accuracy of the model is evaluated using jute multi-ply yarns.

Theoretical Model

In actual cases, the structure of any yarn is highly complicated. In order to facilitate the model development, it is assumed that all the constituent single yarns are circular in cross section, have uniform radius and twist throughout the length, similar bending and torsional behavior and the axis of the each single yarn makes cylindrical helix around the ply axis. Let us now consider a S over Z twisted multi-ply jute yarn having the following parameters –

T_p Turns per inch in ply yarn
T_s Turns per inch in single yarn before plying
T'_s Turns per inch in single yarn in the ply

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H Pitch of one helix in the ply yarn

L Axial length of single yarn inside one complete helix the ply

L_1 Single yarn length in one ply helix as per helical geometric

L_2 Change in axial single yarn length per ply helix due to untwisting

l_y Pitch of fibre helix in single yarn when the yarn has T_s twist per unit length

l'_y Pitch of fibre helix in single yarn when the yarn has T'_s twist per unit length

Δl_y Single yarn length increment per turn of twist in case of twist loss ($T_s > T'_s$)

l_f Length of fibre per turn of single yarn yarn

α Ply helix angle

θ Surface fibre helix angle in single yarn before twist loss

θ' Surface fibre helix angle in single yarn after twist loss

R Radius of the single yarn axis from the ply axis

r Radius of single yarn

d Diameter of single yarn

C_y Ply yarn contraction factor

Let us consider a complete helix of the multi-ply yarn as shown in Fig. 1. As the contraction factor of ply yarn is the ratio of untwisted length single yarn to resultant twisted length of ply yarn, therefore, contraction factor (C_y) of the ply yarn can therefore be expressed by $C_y = L/H$ or $C_y = L.\ T_p$, as $T_p = 1/H$.

As single length gets changed during plying process, therefore the effective length of single yarn as it lies inside a ply yarn (L) can be given by $L = L_1 – L_2$ for a S over Z twisted multi-ply.Therefore to determine actual contraction of single yarn in ply, it is important to derive both heliacal length (L_1) as well as increment in single yarn length due to twist loss (L_2).

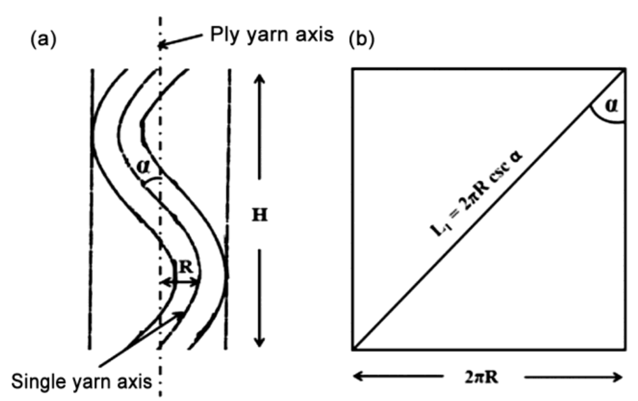

Fig. 1 — (a) A ply helix showing path of single yarn, and (b) Rectilinear representation of single and ply axes

Determination of Single Yarn Length Due to Geometric Configuration(L_1)

As the single yarn axis is at 'R' distance from ply yarn axis and both are making α angle, therefore, from Fig. 1(b) it can be derived that the helical arc length of single yarn (L_1) is

$$L_1 = 2\pi R \csc \alpha \qquad \text{... (1)}$$

Also, $$\tan \alpha = 2\pi R T_p \qquad \text{... (2)}$$

Determination of Single Yarn Length Increment Due to Untwisting (L_2)

As per woods, constituent single yarn loses '2π sinα' radians twist per turn of doubling which is equivalent to 'sinα' when considered in number of turns.The configuration of a helix (formed by the surface fibres) of the constituent single yarn is shown in Fig. 2.

From Fig. 2,

$$l_y = l_f \cos\theta = \frac{l_f}{\sqrt{1+(2\pi r T_s)^2}}, \quad \text{as } \tan\theta = 2\pi r T_s$$

and, $$l'_y = l_f \cos\theta' = \frac{l_f}{\sqrt{1+(2\pi r T'_s)^2}}$$

$$l_f = \sqrt{\left(\frac{1}{T_s}\right)^2 + (2\pi r)^2}$$

Therefore, $$\Delta l_y = l'_y - l_y$$

$$\text{or,}\Delta l_y = \frac{1}{T_s}\sqrt{1+(2\pi r T_s)^2}\left(\frac{l_f}{\sqrt{1+(2\pi r T'_s)^2}} - \right.$$

$lf1+ 2\pi rTs2$ ... (3)

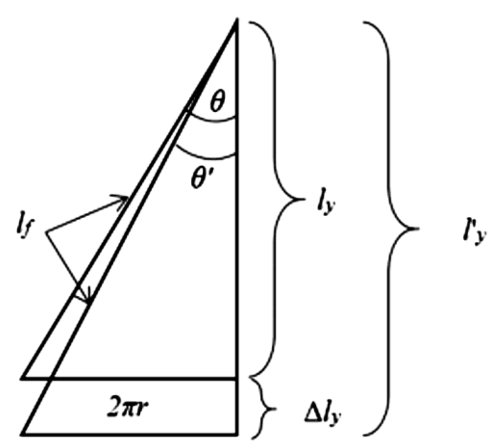

Fig. 2 — Representation of helical structure of single yarn before and after twist loss

As T_s is twist per unit length in the single yarn before plying, so total number of helix present in the L_1 length is 2πR cscα.T_s. Therefore total length increment of single yarn due to untwisting –

$$L_2 = 2\pi R T_s \csc\alpha \ .\Delta l_y \quad \text{... (4)}$$

Thus, putting the values of L_1 and L_2 from equation (1) and (4) respectively, length of single yarn as it lies in the ply (L) can be obtained as -

$$L = L_1 - L_2 = 2\pi R \csc\alpha - 2\pi R T_s \csc\alpha \ .\Delta l_y \quad \text{... (5)}$$

Thus, the actual contraction factor of single yarn (C^y) is –

$$C_y = L.T_p$$

$$\text{or, } C_y = 2\pi R T_p \csc\alpha \left(1 - T_s \Delta l_y\right)$$

Putting $\tan\alpha = 2\pi R T_p$ from equation (2), the relation can be simplified as –

$$C_y = \sec\alpha \left(1 - T_s \Delta l_y\right) \quad \text{... (6)}$$

In order to obtain theoretical values of contraction factor from measured ply helix angle, the theoretical values of r, R and T'_s needs to be obtained. As per Woodhouse and Alexander[11], the radius of single jute yarn is √G/84 inch, where G is the count of the yarn in grist (lb/14400 yds) system. The theoretical values of R and T'_s are described below –

Determination of Helix Radius (R)

Consider cases of 2, 3 and 4-ply yarns separately where each single yarn makes line contact with neighbouring single yarns. From geometry, the relation between R and r for 2, 3 and 4-ply jute yarn can be derived from the figures given in Fig. 3 as follows –

Determination of Twist Level in Single Yarn as it Lies in the Ply (T'_s)

After loosing ‘sinα’ turn form thatL₁length, the residual turns remain in the single yarn is(2πR$T_s$cscα – sinα). Therefore, the residual turns per unit length (T'_s) is –

$$T'_s = \frac{2\pi R T_s \csc\alpha - \sin\alpha}{2\pi R \csc\alpha}$$

Experimental Validation

In order to examine the validity and accuracy of the model, experiments were made to compare the calculated and measured values of contraction factor of 2, 3 and 4-ply jute yarns. Single yarns of 13.24 lb/spy (456 tex), 9.42 lb/spy (325 tex) and 6.95 lb/spy (240 tex) count spun with twist factor of 26 tex-tpc unit were used for preparation of 2, 3 and 4-ply jute yarns of approximately 27 lb/spy (930 tex) count. The ply helix angle of each type of yarn was measured using scanning electron microscope and the images are given in Fig. 4.

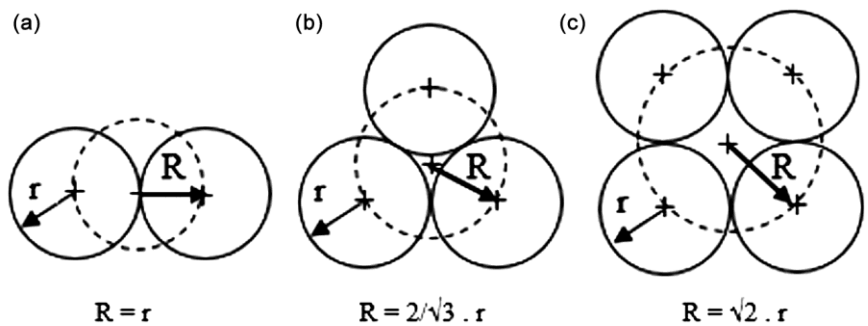

Fig. 3 — Schematic diagram of ply yarn cross-section

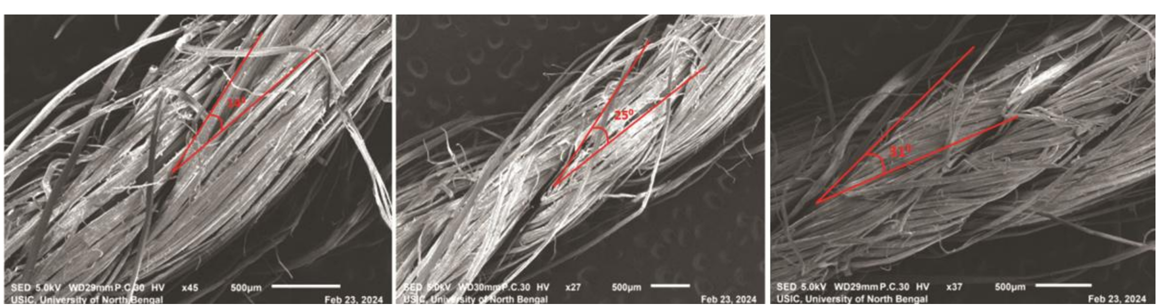

Fig. 4 — SEM images of 2, 3 and 4-ply jute yarn ply helix angle

Table 1 — Comparative theoretical and actual contraction factor of jute ply yarn

No. of Ply	Single yarn count, lb/spy, G	Single yarn tpi, T_s	Ply helix angle, α	Average C_y, Calculated	Average C_y, Measured	P - Value
2	13.24	3.1	14°	1.02	1.02	1.000
3	9.42	4.0	25°	1.05	1.04	0.847
4	6.95	4.4	31°	1.08	1.05	0.670

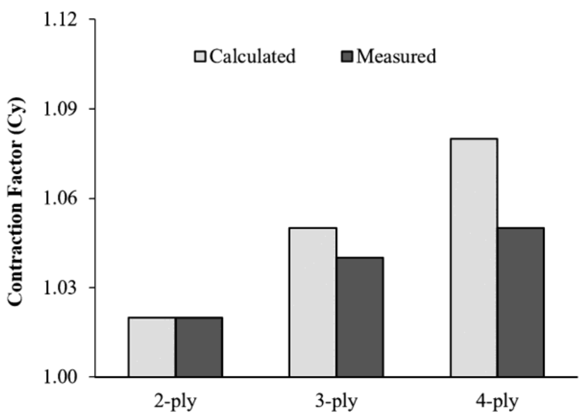

Fig. 5 — Comparative theoretical and actual contraction factor of jute multi-ply yarn

Table 1 shows the average parameters of five numbers of observations of each quality of single and ply yarn as well as measured and calculated value of contraction factor Fig. 5 illustrates the comparison between theoretically achieved (calculated) and actual (measured) contraction factors of 2, 3 and 4-ply jute yarns.

From Fig. 5, it can be seen that the calculated value of jute ply yarn contraction factor more or less near to the measured values for each type of ply yarn.Some insignificant deviation observed, especially higher value of calculated contraction factor than that of measured one may be due to consideration of the fact that the single yarns are circular in cross section and its axis makes cylindrical helix around ply axis, which may not be true always.

Conclusion

From the theoretical model developed for determination of contraction factor of jute plied yarn considering its helical geometry and twist loss in single yarn during plying due to tortuosity, it may be said that the model is more or less shows good agreement with the measured contraction factor, with extent of variability varies from 1 – 3% with respect to measured contraction factor. Considerable deviation between theoretical and actual results may be due to over simplification of the ply yarn structure assumed to develop the model.

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