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Migration characteristics of Eli-Twist yarn and its comparison with Siro yarn

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An attempt has been made to investigate the migration characteristics in polyester and cotton Eli-Twist yarn. Three different counts (39.4, 29.5 and 23.6 tex) from each composition have been produced maintaining 40 twist factor for each. For comparative study, the 29.5 tex yarn of two compositions from cotton and polyester are produced on Eli-Twist and Siro spinning systems. The mean fibre position for Eli-Twist polyester yarn is found to be less than that of cotton yarn. Both root mean square deviation and mean migration intensity in Eli-Twist yarn are found to be higher, while mean fibre position is lower as compared to Siro yarn.

Keywords: Cotton, Eli-Twist yarn, Mean fibre position, Mean migration intensity, Polyester, Root mean square deviation, Siro yarn

1 Introduction

Fibre is the structural unit of a spun yarn. Besides its inherent properties, the configuration and arrangement play significant role in influencing the properties of yarn. For characterisation of the structural mechanics of a yarn, it is necessary to understand both internal and external structures. The external structure primarily influences the aesthetic behaviour, while internal structure governs the mechanical properties. Any applied force has to be shared by the constituent fibres. The resistance to failure may be influenced by the nature of distribution and dissipation of applied load and structural integrity.

A yarn fails either due to slippage, breakage or the combination of both of the constituent fibres. Localization of applied load increases the possibility of failure. An even distribution of load to the neighbouring fibres reduces the possibility of failure both in slippage and breakage mode. Such sharing of load reduces the load per fibre. However, a non-uniform distribution of fibre may create an imbalance in load transfer. Ideally, a uniform distribution is desired for uniform load sharing. Thus, fibre packing and its distribution in yarn cross section has important role in the structural mechanics of spun yarn[1]. The structural integrity of a yarn is decided by the degree of cohesion between the fibres. The cohesion can be influenced both by the surface characteristics of the fibres and their interlocking in the structure. A mechanism which facilitates non-linear path of fibres while maintaining appropriate tension can result in interlocking and the phenomenon is known as migration[2].

Migration induced interlocking of fibres is dependent on the yarn manufacturing technique. Hearle *et al.*[2] suggested that the pattern of fibre migration within a yarn influences its properties. An appropriate control of migration is thus a possible way of influencing yarn properties. The lateral movement of fibre in the twisting zone leading to migration depends on the level of tension developed in each during twisting. The difference in the mechanism of twisting and path of travel of fibres in different spinning system is different. The variation of path may be measured by its deviation from the yarn axis and is called axial migration[3]. For characterization of axial migration, it is necessary to measure the geometrical parameters. Figure 1

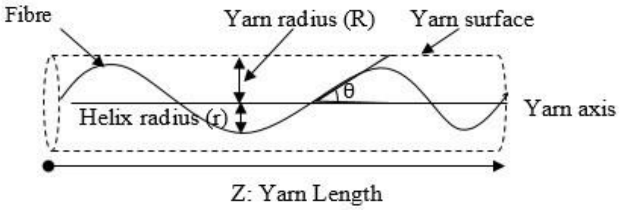

Fig. 1 — Typical fibre movement in yarn

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shows typical path variation of a fibre in a yarn, where radius of the yarn is represented by R while the helix radius is r.

Ring spinning is the oldest spinning system and still dominating the market[4]. In the quest of improved product performance, people had been looking for new technologies. During the current decade, Eli-Twist spinning system, introduced by Suessen, has started penetrating the yarn market[5, 6].

Basal and Oxenham[7] reported higher RMSD in compact spun yarns, leading to better dispersion of the fibre helices along the yarn radius. Natarajan and Subramaniam[8] reported an increase in strand spacing that leads to an increase in fibre migration in Siro-spun yarn. Work of Soltani and Johari[9,10] demonstrates highest fibre migration for Siro yarn followed by compact and conventional ring-spun yarns.

Straight and parallel arrangement of fibre can contribute most in load sharing. Parallel arrangement of fibres in a staple yarn is not desired, while a straight configuration of fibre offers additional contact points[11]. A straight fibre can cover longer path and hence possibility of more contact points with neighbouring fibres exists. In a staple yarn, good structural integrity can be achieved through interlocking of fibres. In this study, the migratory behaviour of fibres in Eli-Twist yarn has been investigated and an assessment is made in comparison with Siro yarn.

2 Materials and Methods

2.1 Materials

In this study, regular polyester and Indian cotton were used. During the production of yarns, 1% dyed tracer fibre was added in the mixing. The detail of sample preparation plan for Eli-Twist yarn production is given in Table 1.

For comparative study of migratory behaviour polyester and cotton yarns of 29.5 tex were produced on Sıro system, maintaining 40 twist factor. The Eli-Twist yarns were produced on Lakshmi ring spinning machine with attachement of Suessen Elite compact set. Sıro spun yarns were spun on the same machine after removing the compact set.

2.2 Method of Yarn Analysis

The tracer fibre technique was used to study the path of fibres in each yarn. The cotton yarns were immersed in methyl salicylate (refractive index 1.53) and polyester yarns in benzoyl alcohol (refractive index 1.54) to optically dissolve the grey fibres so that the dyed tracer fibre could readily be observed.

Table 1 — Material and process parameters

Parameters	Values
Fibre length, mm	
Cotton (H-4)	30 (UHML)
Polyester	38
Fibre fineness, den	
Cotton (H-4)	1.5 (4.2 micronaire)
Polyester	1.2
Yarn composition (polyester/cotton)	100/00 and 00/100
Dyed fibre content, %	01
Linear density produced, tex	23.6 (25 Ne), 29.5 (20 Ne), 39.4 (15 Ne)
Twist factor, turn/cm × tex$^{1/2}$	40
Tropical conditioning atmosphere	
Temperature, °C	27±2
RH, %	65 ± 2
Time, h	24

Fig. 2 — Typical path of a tracer fibre in yarn

Migration behavior of fibres in yarns was examined under Leica stereo microscope image analyzer. The images were captured and processed using the image processing software. For each yarn, 10 tracer fibres were observed and at least 20 readings were taken for each (Fig. 2). Characterization of axial migration was made with the following parameters:

- Mean fibre position (MFP)
- Root mean square deviation (RMSD)
- Mean migration intensity (MMI)

2.2.1 Mean Fibre Position

This represents the overall tendency of a fibre to be near the surface or center of a yarn, as defined by following relationship:

$$\bar{Y} = \frac{1}{Z_n}\int_0^{Z_n} Y\,dz$$

$$= \sum \frac{Y}{n}$$

where $Y=(r/R)^2$; r, the helix radius; R, the yarn radius; Z, the length along the yarn; and n, the no. of observations

2.2.2 Root Mean Square Deviation

It represents the deviation from the mean position and is expressed by the following formula:

$$\mathrm{RMSD} = \sqrt{\frac{1}{Z_n}\int_0^{Z_n}(Y - \bar{Y})^2\,dz}$$

$$= \sqrt{\frac{\sum(Y - \bar{Y})^2}{n}}$$

2.2.3 Mean Migration Intensity

The rate of change in radial position is expressed by the MMI using the following formula:

$$\mathrm{MMI} = \sqrt{\frac{1}{Z_n}\int_0^{Z_n}\left(\frac{dY}{dz}\right)^2 dz}$$

$$= \sqrt{\sum\frac{(\mathrm{dY/dZ})^2}{\mathrm{n}}}$$

$$= \sqrt{\sum\frac{(Y_2 - Y_1)^2/(Z_2 - Z_1)^2}{\mathrm{n}}}$$

3 Results and Discussion

Fibre migration is defined as the variation in fibre path within a yarn. In a spun yarn, coherence in fibre assembly plays vital role for conversion of discontinuous assembly of fibres into a continuous yarn. Besides raw material factors, twist increases the frictional forces between fibres and prevents the fibres from slipping over one another while fibre migration ensures partial interlocking of fibres in the yarn structure.

3.1 Observations on Tracer Fibres

The images of the yarns with tracer fibre are given in Fig. 3. For polyester yarns, the surface fibres are less evident in comparison to cotton yarns. The path of the fibres is distinctly visible. A close examination of the images reveals that spiral path followed by fibres in a polyester yarn is more regular than that in the cotton yarn. The spiral pitch becomes closer as the yarn becomes finer.

3.2 Comparison of Migration Parameters of Eli-Twist Yarns

The migration parameters of polyester and cotton Eli-Twist yarns are shown in Table 2. The influence of linear density on migration parameters has been

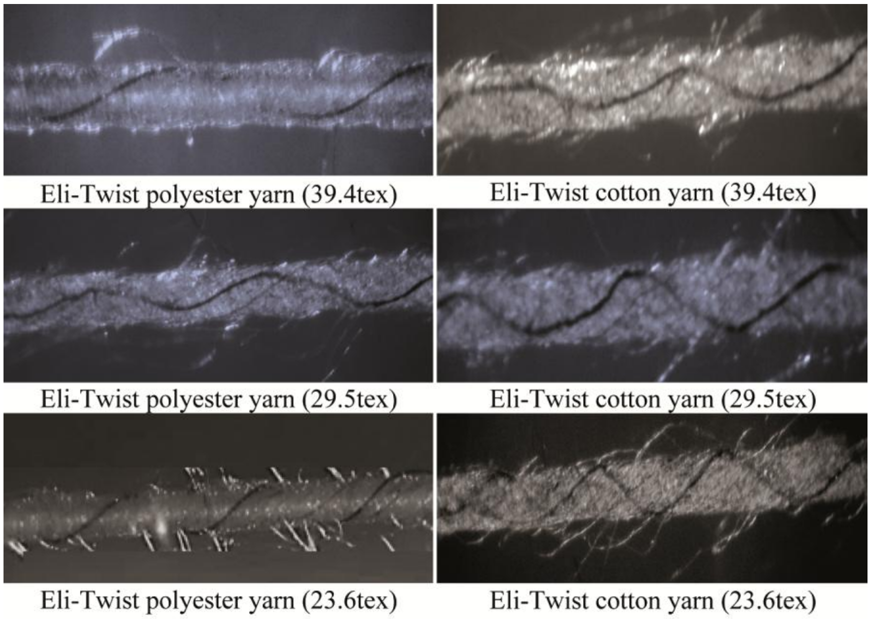
Eli-Twist polyester yarn (39.4tex)
Eli-Twist cotton yarn (39.4tex)
Eli-Twist polyester yarn (29.5tex)
Eli-Twist cotton yarn (29.5tex)
Eli-Twist polyester yarn (23.6tex)
Eli-Twist cotton yarn (23.6tex)

Fig. 3 — Fibre position in polyester and cotton Eli-Twist yarn

Table 2 — Migration parameters of polyester and cotton Eli-Twist yarns

Linear density, tex	Yarn composition	MFP	RMSD	MMI, mm	Helix angle, deg
39.4	Polyester	0.483	0.239	0.270	16.98
29.5	Polyester	0.452	0.224	0.312	17.93
23.6	Polyester	0.439	0.203	0.334	18.41
39.4	Cotton	0.546	0.217	0.218	17.72
29.5	Cotton	0.535	0.201	0.238	18.67
23.6	Cotton	0.511	0.192	0.262	19.15

MFP -Mean fibre position, RMSD -Root mean square deviation and MMI -Mean migration intensity analysed statistically. The results of ANOVA are presented in Table 3.

3.3 Mean fibre position in Eli-Twist yarn

The mean fibre position represents the overall location of fibres with respect to the axis of yarn. The mean fibre positions are shown in Table 2. It is observed that the mean fibre position in cotton Eli-Twist yarn lies between 0.51 and 0.54 and that in polyester yarn between 0.43 and 0.48. Thus, the mean fibre position for Eli-Twist polyester yarn is less than that of Eli-Twist cotton yarn. The mean fibre position is found to increase as the yarn becomes coarser.

Mean fibre position of 0.5 indicates uniform distribution of fibre length across the cross-section of the yarn, i.e. a given fibre length is equally distributed in all concentric layers across yarn cross-section. The packing of fibres is to be uniform across cross-section.

A value<0.5 implies that the fibres are on an average located closer to the yarn axis (asymmetric packing, i.e. fibres are packed near the yarn core and less near the surface) while a higher value of 0.5 implies more fibre length portions near the yarn surface and less near the core.

3.4 Root Mean Square Deviation in Eli-Twist Yarn

The root mean square deviation indicates the magnitude of the deviation from mean position of fibre. Ideally, high value of RMSD helps the constituent fibres to get interlocked at many points across yarn cross-section subject to the availability of sufficient length of fibre. The interlocking is necessary to achieve coherence in the structure. Table 2 shows the variation in root mean square deviation with linear density for polyester and cotton Eli-Twist yarns.

It is observed that the root mean square deviation for Eli-Twist polyester yarn lies in between 0.20 to 0.26 and for cotton yarn in the range of 0.19 to 0.22. Thus, the average value of RMSD for polyester yarns is higher. The value of RMSD significantly increases as the yarn becomes coarser.

3.5 Mean Migration Intensity in Eli-Twist Yarn

Mean Migration Intensity signifies the rate of change of radial position of fibre with respect to the yarn axis. It is observed from Table 2, that the mean migration intensity is higher for polyester yarns than cotton yarns.

It is observed from the Table 2 that the average value of MMI in cotton yarn is significantly lower than that in polyester yarn and the mean migration intensity decreases as the yarn becomes coarser.

3.6 Helix Angle of Fibres in Eli-Twist Yarn

The average helix angle for polyester and cotton yarns is represented in Table 2. It is observed that the helix angle increases when the yarn becomes finer. Effect of linear density and composition of yarn on helix angle is statistically significant and cotton fibre shows higher helix angle as compared to polyester fibre.

As the linear density decreases, the turns per unit length in the yarn increases which is the manifestation of higher helix angle as yarn becomes finer. The helix angle $\propto$ is related to yarn diameter and twist as shown by the following formula:

$$tan \propto = \pi dT$$

where *d* is the yarn diameter; and *T*, the yarn twist.

Therefore, helix angle will be a function of diameter at a given twist factor. Polyester yarn has lower diameter as fibres can pack well easily being circular. Thus, it shows lower helix angle in comparison to cotton. The differences in migration parameters can be explained on the basis of following:

Migration is the result of path differences of fibres within the cylindrical yarn following twisting process. All fibres are delivered at the twisting point at constant rate. The spiral paths they are made to follow varies, depending upon location of the fibres within the yarn. As a result, the fibres experience tension due to mismatch between length delivered and spiral path length required to follow. The fibres try to relieve their tension by continuously adjusting their position within yarn by moving toward and away from the yarn centre. All fibres try to occupy minimum energy configuration through mutual exchange of their positions, which is manifested as migration.

The ultimate destination of any segment of fibre depends upon radial component of fibre tension favouring inward movement against the frictional

Table 3 — ANOVA Analysis of migration parameters for Eli-Twist yarn

Factor	MFP	RMSD	MMI	Helix angle
Linear density, tex	Significant (0.049099)	Significant (0.029984)	Significant (0.050000)	Significant (0.000023)
Yarn composition	Significant (0.006261)	Significant (0.044953)	Significant (0.011894)	Significant (0.000030)

forces with neighbouring fibre segments opposing it. As a result, while being incorporated within the yarn, different segments of the same fibre will be at different locations and at different tension level. Once the fibre reaches the centre or close to the centre, the rest of the length can't settle there. There will be another fibre adjacent to it, which will push the previous fibre segment and occupy its position in order to relieve its own tension. Thus, a cyclic movement is expected amongst all fibres.

Count Difference

With coarser yarn, the wave length of helical path becomes longer as twist factor remains same. At the same time, the competing fibres are also more in number. The path length difference experienced by the fibres is also less. As a result, migration becomes less vigorous. This results in lowering mean fibre position in coarser yarn.

All migration parameters are interlinked, as they are as a result of same phenomenon. Finer yarns will not only show closer placement near yarn core but also vigorous migration manifested by mean migration intensity and greater helix angle. Less number of fibres in finer yarn will also facilitate better fibre movement across yarn cross-section, resulting in less deviation in their movement.

Fibre Differences

Length and fineness differences in polyester fibres being less, polyester yarn is more uniform. The helices formed by the fibres due to twisting are more regular. While migrating across the cross-section, the fibres, being circular, will be able to slide past each other better in comparison to non-circular fibres. Thus, the possibility to occupy the core area of the yarn is greater in case of polyester fibre and this is manifested in lower value of mean fibre position.

Cotton, on the contrary, lacks homo geneity, i.e. the length, fineness and cross sectional area differences are more in cotton. The mass variation in cotton yarn is also more. Therefore, the migratory path followed by cotton fibres is more variable and random in nature. As a result, incomplete migration (Fig. 4) and lesser RMSD are observed in cotton yarn.

Even though count is same, the diameter of the two yarns will not be same. Polyester yarn will be thinner than cotton yarn. The relationship between helix angle and count is shown below. Specific volume of polyester will be less than cotton. Hence, the

$$\tan\alpha = 0.0112 v_y^{\frac{1}{2}} C^{\frac{1}{2}} T$$

where α is the helix angle; $v_{y,}$, the specific volume of yarn; *C*, the count of yarn (tex); and *T*, the twist (turns/cm).

Specific volume of polyester is less than that of cotton as it's a more compact yarn. Hence, helix angle for polyester yarn is less than that of cotton for all counts.

Migration intensity of polyester is more as most fibres are long and participate in full migration. For cotton, partial migration has been observed in many cases, which could be due to length variation in cotton.

3.7 Comparative Assessment of Migration Characteristics of Eli-Twist and Siro Yarns

Fibre migration in a spun yarn plays major role in influencing its structural mechanics. The migration parameters of yarns from Eli-Twist and Siro spinning systems have been studied. The experiential results for the migration parameters are given in Table 4.

For a given fibre, the orders in which migration parameters for different yarns change for both spinning system are shown below:

- MFP : Eli-Twist <Siro
- RMSD : Eli-Twist >Siro
- MMI : Eli-Twist >Siro
- Helix angle : Eli-Twist <Siro

In Eli-Twist spinning, the two limbs prior to the twisting point are twisted in the same direction as that of the final twist. For the twist in the same direction, the yarn becomes compact. The compaction of fibres initiates in advance in Eli-Twist spinning system before reaching the spinning triangle. The interfacial

Fig. 4 — A typical single fibre movement in cotton yarn (incomplete migration)

Table 4 — Migration parameters in Eli-Twist and Siro yarns

Spinning system	Yarn composition	MFP	RMSD	MMI mm	Helix angle, deg
Eli-Twist	Polyester	0.452	0.224	0.312	17.93
Siro	Polyester	0.529	0.202	0.293	18.28
Eli-Twist	Cotton	0.535	0.201	0.238	18.27
Siro	Cotton	0.569	0.196	0.213	19.04

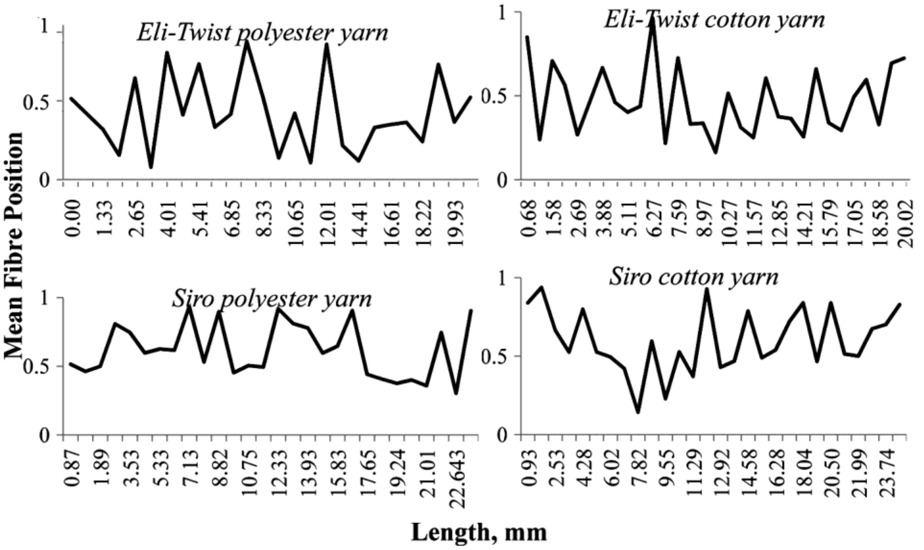

Fig. 5 — Fibre position along yarn length both in Eli-Twist and Siro spun yarn

pressure in the two limbs of the yarn at the apex point, leads to closer packing of fibres near the centre of the yarn and thus lowers the mean fibre position.

The higher RMSD in Eli-Twist yarn is due to the fact that the two twisted limbs of the yarn maintains their identity in the final structure, as the twist directions in the limb and the final yarn are same. The direction of twist in the limb and final yarn being same, the migration intensity is more in Eli-Twist yarn. The Eli-Twist yarn shows lower helix angle as compared to Siro yarn as its specific volume will be less being thinner than Siro yarn.

3.8 Fibre Position along Yarn Axis

Typical fibre path for Siro yarn (Fig. 5) suggests that it never reaches the yarn core, indicating the core to be less packed as compared to Eli-Twist yarn. The movement of fibre segments is more haphazard for cotton fibre in comparison to that for polyester due to variability in intrinsic properties of cotton fibre. The variation in segmental positions is less for Siro yarn, which is also seen from RMSD values.

4 Conclusion

The present work aims to provide a better understanding of migratory behaviour of yarns under study. From the study, following inferences are drawn:

4.1 The mean fibre position for Eli-Twist polyester yarn is less than that of Eli-Twist cotton yarn. The mean fibre position for polyester Eli-Twist yarn is near to 0.45-0.53, which is lower than that in Siro spun yarns. Low MFP of polyester yarn implies its higher consolidation.

4.2 The fibres show a tendency to be located near the core as the yarn becomes finer.

4.3 The deviation from average path followed by fibres is fibre dependent. The root mean square deviation for Eli-Twist polyester and cotton yarn varies from 0.20 to 0.26 and 0.19 to 0.22 respectively.

4.4 The Eli-Twist yarn shows higher RMSD and MMI as compared to Siro yarn. Higher RMSD results in more interlocking of fibres and hence better structural integrity.

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