35th INTERNATIONAL COTTON CONFERENCE BREMEN 2021

PAPER

Session:

Textile Processing 1 (T1)

Presentation Title:

New insert reduces yarn hairness of fine count ring spun yarns

Speaker:

Stuart Gordon, CSIRO Agriculture and Food, Waurn Ponds, VICTORIA

Presentations are available on the conference archive:

https://baumwollboerse.de/en/cotton-conference/lectures/

Conference Organization
Faserinstitut Bremen e.V., Bremen, Germany. E-Mail: conference@faserinstitut.de
Bremer Baumwollboerse, Bremen, Germany. E-Mail: info@baumwollboerse.de

NEW INSERT REDUCES HAIRINESS OF FINE COUNT RING SPUN YARNS

C. Singh[1], S. G. Gordon[2] and X. Wang[1]
[1]Deakin University Institute of Frontier Materials, Waurn Ponds VIC Australia
[2]CSIRO Agriculture and Food, Waurn Ponds VIC Australia

ABSTRACT

Reported in this paper are results of systematic studies of spinning triangle (ST) dynamics using tracer fibres (Singh et al, 2018) and a new reflective imaging method (Singh et al, 2019) that provided new insight into the design of an offset spinning insert device (Singh et al, 2017). The new device both condenses and directs the ST along a diagonal path to the drafting zone to improve yarn hairiness. A novel aspect relates to the equidistant control of twist that the insert provides to the spinning triangle. This control is achieved by offsetting the spinning triangle of a Z-twist yarn to the right using the insert, which is positioned at the exit of drafting zone. The insert allows the twist (or pre-twist) to travel into the middle of the spinning triangle, which in turn reduces the distance that edge fibres in the spinning triangle need to travel to be incorporated into the yarn core. The shorter distance reduces fibre loss and the period of dynamic movement (from side-to-side of the triangle), which in turn reduces opportunities for fibres to be moved out of alignment with the yarn core. The insert significantly reduces yarn hairiness, which in turn results in improvements in other yarn properties and in processing after spinning, e.g., improved sizing and weaving efficiencies.

INTRODUCTION

Yarn hairiness control is a key focus of research into ring spinning. Significant effort has been devoted to the study of yarn hair generation and methods for its control. Methods typically involve minimizing the ST width to incorporate and reincorporate protruding hairs into the yarn body. Several methods have been used. These include condensing the roving during drafting (e.g., compact spinning), untwisting and then retwisting the spun yarn using swirling air-jets (e.g., JetRing spinning) and splitting roving into multiple small roving strands (e.g., Solospun™ system). Of these, compact spinning is the most popular and widely used. However, this technology comes with significant additional cost in terms of the compacting unit (pneumatic or mechanical), maintenance during spinning and limitations in its ability to reduce yarn hairiness. There is, therefore, still significant demand from spinning mills for new methods of hairiness reduction that require minimum investment costs.

The ST occurs in the zone where roving is converted into yarn and is the site where hair generation occurs as a result of fibres located along the edge of the drafted fibre strand not being incorporated into the yarn body. The geometrical dimensions of the ST are critical in controlling the hair formation tendency of the fibre strand. However, until the concept of changing the overall symmetry of the ST was suggested by Chang and Wang (2003) the ST width was the only geometric parameter considered in the research on reducing yarn hairiness. In their work, Chang and Wang reported improvement in worsted yarn hairiness after introducing a diagonal offset in the yarn path as the fibre strand emerged from the front roller nip (see Figure 1).

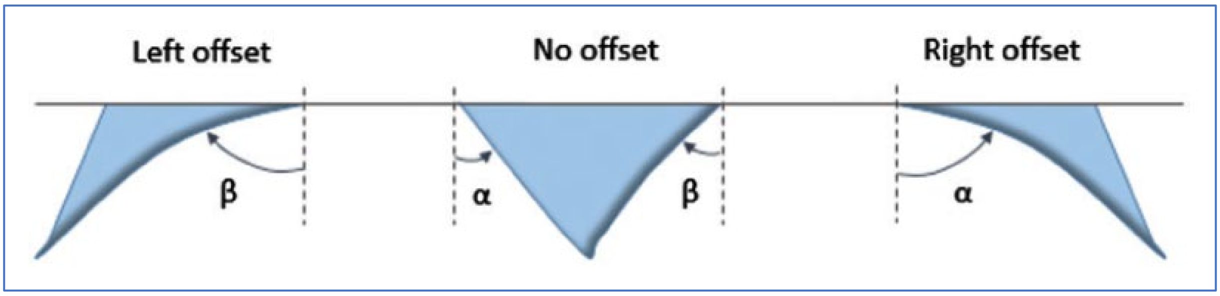


Figure 1. Effect of yarn path offset on the geometry of the spinning triangle. α and β represent the vertical angle made by the left and right-hand edges of the spinning triangle respectively. With right-hand and left-hand offset spinning the spinning triangle no longer remains symmetrical and is shifted towards the offset direction.

The benefit of this technique was later reported in cotton yarns using both theoretical and experimental investigations. In Z-twist yarns, right-hand offsetting (RO) of the ST reduced yarn hairiness compared to normal or no offset (NO) spinning, while left-hand offsetting (LO) had an opposite effect. The judgement was the RO resulted in an increased amount of pre-twisted fibres on the righthand edge of the ST, which was effective in binding fibres into the yarn body. It was also suggested that left-hand edge fibres are already under tension while the lowered fibre tension on the right-hand edge is compensated by pre-twisting.

However, studies by Xia et al (2015) and Thilagavathi et al (2005) supported the contrary, i.e., the use of LO spinning. Their work proposed the left diagonal path reduced the distance travelled by fibres on the left-hand side of the ST, which leads to better fibre incorporation, while fibres on the right-hand side are controlled by the pre-twist. But the actual dynamic change in fibre path and tension distribution due to diagonal offsetting was not investigated experimentally in any of these studies. This is due to two reasons. One, the dynamic nature of the geometry of a staple fibre ST in which tension is distributed unevenly across the width presents a limitation for theoretical investigations and two, the lack of visibility in the ST region restricts determination of the fibre tension path and ST geometry relationship. The lack of visibility also provides a limitation to experimental studies in understanding fibre migration in and out of the yarn core.

Understanding the migration of fibres within the dynamics of the ST is of absolute importance. If the fibres were merely twisted in concentric layers, the resulting yarn structure would be highly susceptible to abrasion and tensile failure. Fibre migration provides a self-locking characteristic to the yarn structure, which enables the yarn to withstand significant tensile loads (see Figure 2). The extent of fibre migration is dependent on several factors and the study of its underlying mechanisms is reasonably complex.

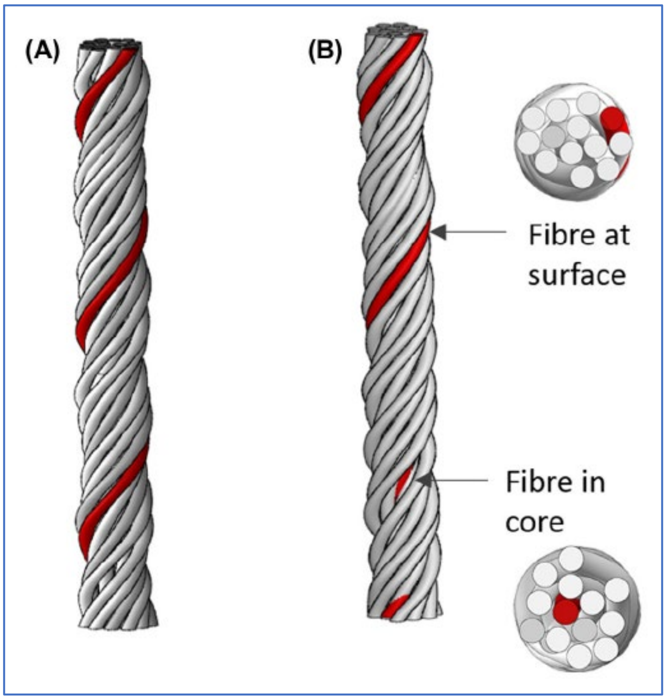


Figure 2. (A) an idealised concentric layered yarn structure, and (B) actual yarn structure with radially migrating fibres.

The first concepts of fibre migration in spinning were proposed nearly six decades ago with major contributions from Pierce (1947), Morton and Yen (1952), Hearle and Bose (1965), Hickie and Chaikin (1960), Onions et al (1960), Townend and Dewhirst (1964), Gupta (1970) and others. The first mention by Pierce (1947) considered the main reason behind structural integrity of a twisted yarn was fibre migration. Pierce proposed fibres on the surface of a spun yarn have one end tucked inside the yarn body and that this occurred in a random manner. Morton and Yen (1952), and Morton later in 1956, proposed the term migration to express the change in radial position of a fibre within yarn body. The first mechanism of migration was due to differences in tension on the fibres as result of different path lengths followed by fibres entering the ST zone (see Figure 3). They proposed at any given instant, fibres lying on the ST edges are under higher tension due to their longer path length, which causes them to move towards lower tensioned core positions. Under this process, edge fibres can displace core fibres with the slacker core fibres moved out towards the surface. Their ‘tension mechanism’ explained a regular migration behaviour but the ‘random tangle theory’ proposed by Pierce remained unanswered.

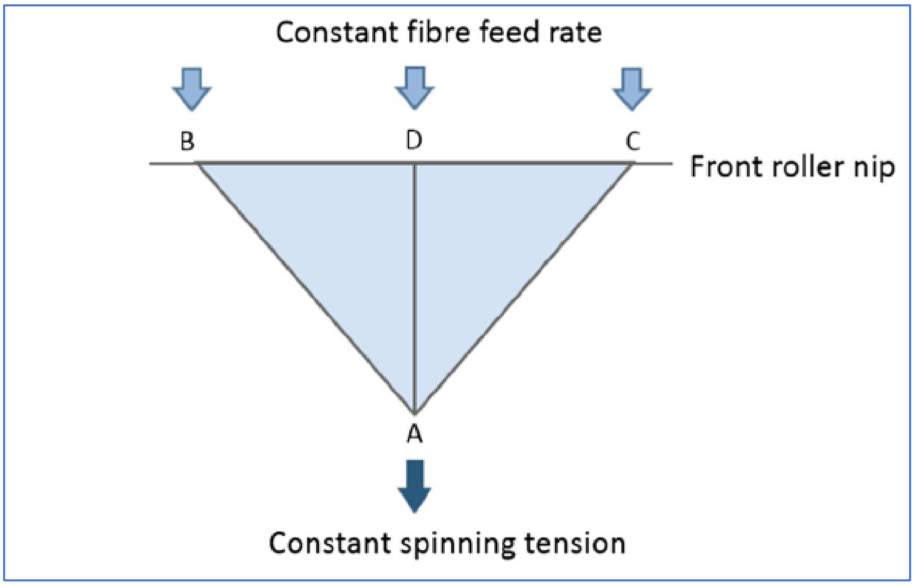


Figure 3. Schematic of the tension mechanism of fibre migration.

The tension mechanism of migration was partially accepted by Hickie and Chaikin (1960) who debated the unexplained ‘invisible force’, which causes low tensioned or slack fibres from the core to move outside. They proposed there should be a force outside the tension mechanism in the ST acting upon the fibre. Townend and Dewhirst (1964) also questioned the ‘tension mechanism’ reason behind the tendency of a low-tension fibre (core) to move into a high tension (edge) state. Centrifugal forces were disregarded, as they were too small to be of any significance. The possibility of an inward moving edge fibre displacing the core fibre was also rejected, as this should result in overall inward movement of all fibres with little, if any, outward movement. In the end, Hickie and Chaikin proposed the inward and outward movement of a fibre on the hypothesis that fibre strain could vary along the length of the fibre. The portion of fibre under high strain tends to move closer to yarn axis compared to the rest of the length. They then postulated that any migration was primarily due to inward movement of fibres only. Imperfection in the twisting (travel) mechanism was suggested to be the reason behind variable strain along the fibre length.

Hearle and Merchant (1962) proposed another condition for migration based on experiments using a seven-ply filament structure. They suggested fibre (filament) migration takes place when the tension in the yarn core has fallen to zero or below. Thus, when the spinning tension is high enough to maintain the core tension above zero, no migration is possible. They found once the spinning tension fell below a certain level, the supply of excess fibre caused slackness to accumulate in the core, resulting in migration. In their experiment slackened filaments moved outwards until the slack was consumed. The chief mechanism of migration here also was the displacement of core filaments by edge filaments, when the former became slack. It has been shown experimentally that spinning tensions are typically (and dynamically) lower than the tension required to prevent migration in staple yarns (Hearle and Gupta, 1965 and Townend and Dewhirst, 1964).

El-Sheikh and Backer (1972) partially accepted the theory of slack formation but suggested that this mechanism only caused outward migration in an open structure. That is, when fibres in the ST are not in contact with each other, which is not the case in a real ST, where fibres provide mutual support to each other and thus prevent slack. Instead, they proposed that compressive buckling (of fibres) causes outward migration, which meant that the central fibre buckles either, statically, due to compressive strain or, dynamically, due to sudden release of trailing end from the front roller nip. Hearle and Bose proposed the geometric mechanism of migration, according to which fibres follow a different path in the yarn depending on their position in the roving (Hearle & Bose, 1965; Hearle, Gupta, & Goswami, 1965). They claimed that this mechanism can either combine or replace the tension mechanism. Geometric mechanism was proposed to give a regular migration because of regularity of roving twist, while tension mechanism was suggested to result in random migration in staple yarns. Gupta contributed to this mechanism by suggesting that it is only the remaining amount of twist in the drafted roving which influences migration in staple yarns (Gupta, 1970). He also added that fibre length irregularity plays a decisive role in influencing geometric arrangement of fibres in the drafted roving. Hickie and Chaikin's (1960) approach received limited attention and research works to date unanimously accept the tension and geometric mechanisms of migration.

The axis of rotation of a spinning yarn also plays an important role in controlling the tension and determining the path of individual fibres while integrating to form the yarn structure. It is not difficult to contemplate the yarn axis of rotation always passes through the tip of ST (see Figure 4). However, the idea of considering a pre-twist zone as a continuation of the yarn axis into the ST has not been clearly conceptualised. A brief account on the role of pre-twist in ST was mentioned by Morton (1956) who proposed fibres in the pre-twist region tend to occupy the core position in the final yarn. It was suggested that in a z-twist yarn, fibres on the right-hand side of ST are under the control of the pre-twist in yarn formation; whereas, obstruction due to the bottom roller surface does not allow the left-hand fibres to do the same. This results in a yarn with right-hand edge always containing core and left-hand edge fibres preferentially in surface layers. However, previous trials using tracer rovings have reported random radial distribution of fibres from both edges (Balasubramanian, 1970 and Morton, 1956). Therefore, detailed visual investigation of pre-twist zone becomes an important task before proceeding to any conclusions on its role in yarn structure.

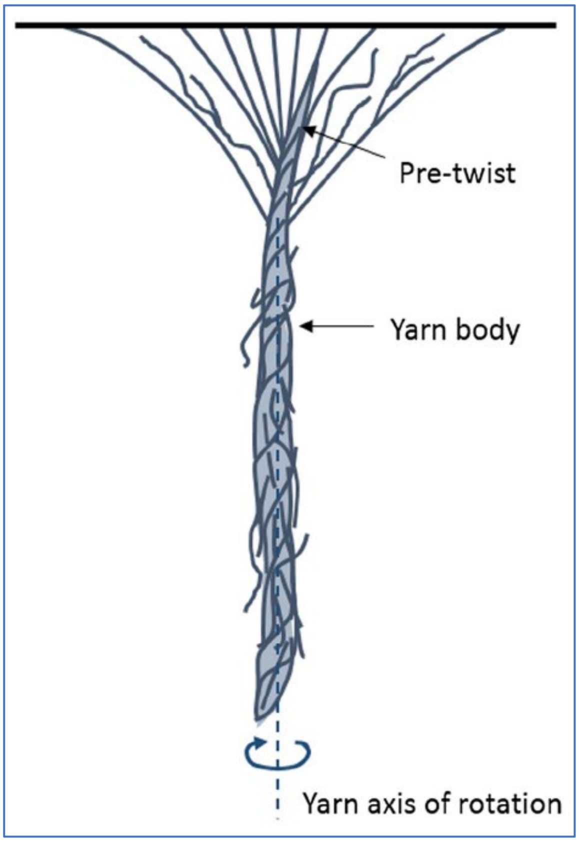


Figure 4. Graphic showing pre-twist zone as continuation of yarn axis of rotation into the spinning triangle.

One major reason why the role of pre-twist in determining yarn structure has been overlooked is the inability of conventional imaging techniques to distinguish the pre-twist region from the rest of the ST during spinning. A staple fibre ST assembly has an extremely rough surface, which causes both specular and diffuse reflection of incident light. The information obtained from diffusely reflected rays is just sufficient to analyse shape and size of the ST. Multiple overlap of fibres creates diffused reflectance surface that blurs the details within the ST. Apart from imaging constraints, the laboratory scale experimental setups reported previously e.g., Hearle and Merchant (1962) considered only monofilament strands. The wide spacings (>1 mm) between adjacent filaments does not allow the formation of any pre-twist region to be properly modelled, as happens in staple spinning due to frictional contact between adjacent fibres. The application of pre-tensioning weights further limits the scope of these studies (to be used as models) by restricting any dynamic changes in tension between individual filaments as per the staple fibre spinning scenario. There is therefore a lack of information on ring yarn structure and fibre migration from a practical spinning perspective. Thus, an aim of this research was to observe the dynamic behaviour of the ST and provide reasons for the radial-changes in staple fibre paths during spinning, with a view to understanding and limiting hairiness in the final yarn (fibre properties, e.g., high short fibre content, notwithstanding).

The first step towards the above goal was to confirm the effect of offset spinning on the ST and the directional benefit for hairiness reduction. Theoretically, the offset direction that performs better in one twist direction should worsen hairiness when the twist direction is changed. Therefore, spinning trials were conducted by changing the twist direction (Z and S) and comparing the yarns for changes in hairiness. Using tracer fibres in equal proportion allowed the effect on the ST to be observed. The second step was to understand the mechanism behind fibre movement (migration) and hairiness control via imaging techniques that allow the ST to be examined *in situ* and thus in greater detail. Evidence gathered from these experiments allowed the authors to develop a mechanism for improving yarn utilizing an offset ST with an angled condensing spinning insert. Details of the resulting insert are provided in the discussion.

EXPERIMENTAL

Table 1 provides a summary of experiments and treatments undertaken in this investigation. Note the order of experiments proceeded as listed in the Table. Development of the reflective system followed the benchtop apparatus.

Table 1. Summary of experiments, yarn specifications and treatment details

Experiment	Count and twist Ne (tex) and αe	Treatments
Control and treatment yarns Zinser 351 ring frame Effect of offset spinning	60 (10) αe = 3.6 40 (15) αe = 4.4	700 tex roving S-twist and Z-twist with no offset (NO), right offset (RO) and left offset (LO)
Tracer fibres Zinser 351 ring frame Effect of offset spinning	40 (15) αe = 4.4	White roving = 400 tex Black roving = 400 tex Z-twist with no offset (NO), right offset (RO) and left offset (LO)
Tracer fibre imaging Benchtop spinning system Effect of offset spinning	40 (15) αe = 4.4	White roving = 400 tex Black roving = 400 tex Z-twist with no offset (NO), right offset (RO) and left offset (LO)
Reflective imaging Zinser 351 ring frame Dynamic movement in ST + effect of condensation	50 (12) αe = 4.0	700 tex roving with 1% black tracer fibres Z-twist with no offset (NO) Constricted ST with condenser
Insert development	Summary of results provided	

Control and treatment yarns: Australian long staple cotton (micronaire = 4.03 and upper half mean length = 31.93 mm) was used as the raw material. The fibre was opened and cleaned through a Truetzschler 'blow-room', which incorporated an Inclined Lattice Bale Feed and CVT3 Opener and Cleaner to remove trash and open the fibre. The fibre was then carded using a Truetzschler DK903 machine to produce to a 5.2 ktex sliver. Carded sliver was then subjected to one passage of a Truetzschler HSR1000 draw-frame before lapping and combing through a Vouk CM400/S combing machine. The combed sliver was then drawn a second time through the same but reset draw-frame. The combed sliver (4.46 ktex) was then converted to roving (700 tex) on a Zinser 660FU fly roving machine. Yarns (10 and 15 tex) with 1108 turns per metre were spun on a Zinser 351 ring frame machine.

For each yarn count, six types of yarn samples were spun: S-twist (NO, RO and LO) and Z-twist (NO, RO and LO), where NO, RO and LO represent No Offset, Right Offset and Left Offset, respectively. The degree of offset was defined by offset angle parameter (the angle between the yarn path and vertical axis). This angle of 35 degrees was maintained for all the offset trials in this study.

Tracer fibres: A blended yarn (15 tex, Z-twist) was also spun using a combination of white cotton roving (400 tex), prepared later using the same fibre source, and a black coloured tracer roving (400 tex) on the Zinser ring frame (see Figure 5). The relative position of both rovings was kept the same (white cotton: left and black tracer: right) for all spun samples. The yarns were spun in three different conditions (NO, RO and LO). The purpose of this trial was to observe the change in fibre wrapping behaviour in yarn and fabric from both sides of the ST during offset spinning.

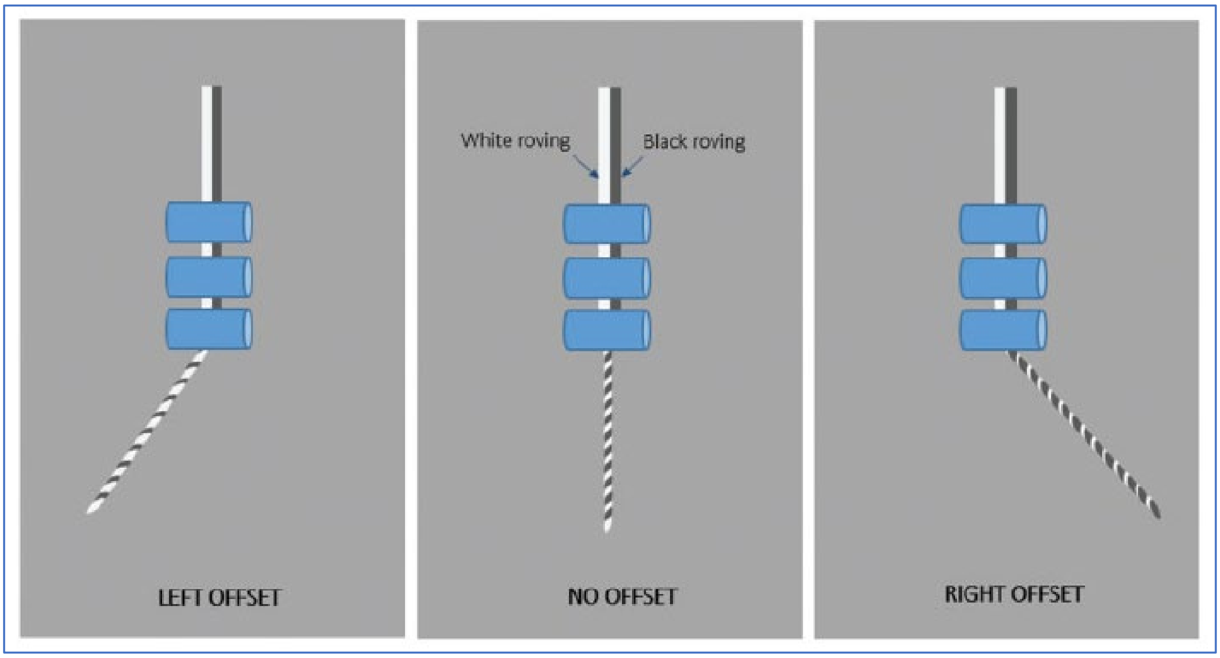


Figure 5. Schematic showing the blend yarn spinning using white cotton and black tracer roving.

Tracer fibres (benchtop): Figure 6 illustrates the benchtop system used to image the ST. A replicate ring spinning front roller assembly fitted with a mini-microscope camera was built using two rollers, a rubber bottom roller and a clear plastic top roller, both with the same dimensions (diameter = 30 mm, length = 100 mm). The loading of the top roller was done by means of springs and the rotational motion was imparted through a crank lever. A finely drafted roving strand was fed from the back end and twisted after emerging from the front end using a motorised twisting unit. The offset (a 35 degrees angle to the vertical axis) to the ST was introduced by moving the position of the twisting unit relative to the nipping point of the roving in the rollers. The height of the twisting unit was kept lower than that of the roller nip line in order to achieve a similar contact surface of the ST with the bottom roller, as in an actual ring spinner. The microscope camera was fixed on top of the clear roller to capture high magnification images of the ST region. The purpose of this trial was to record the relative movement of black and white fibres streams into the ST. Note this work preceded and informed the following reflective imaging experiment.

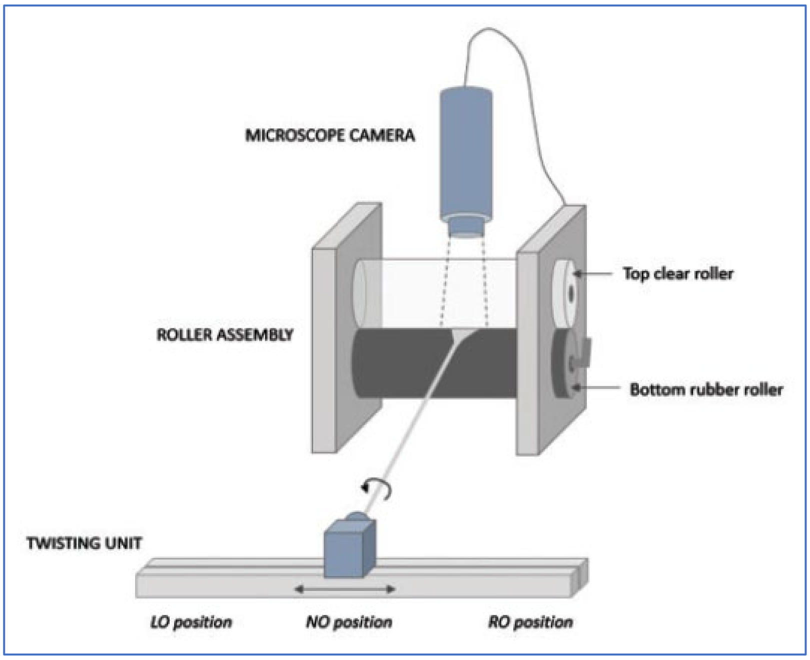


Figure 6. Schematic of the benchtop replicate of the ring spinner front roller assembly. LO: left offset, NO: no offset and RO: right offset

Reflective imaging: The extraction of fibre arrangement information by imaging ST directly on the ring spinning machine is a challenging task. The most important requirement for obtaining an informative image is the precise orientation of camera with respect to the lighting source used to view the object. This work makes use of a reflective imaging technique, which overcomes the limitation of normal imaging in providing structural details of non-uniform and rough objects like textile fibre assemblies. Reflectance transformation imaging is a photographic method in which a composite image is created from multiple digital photographs of the object shot from a stationary camera but with different light source directions. This produces a series of images of the same object with varying highlights and shadows which enable interactive re-lighting of the object from any direction. In the current study, we have utilised only a part of this technique and used the light source direction which provided the highest specular enhancement of the ST and hence the most detailed fibre arrangement information inside it. For this, the camera was placed in line with the light rays reflected from a very smooth reflective surface (100% specular reflection), so that the diffused reflection from an intermediate object gets subtracted and a clear shadow image of this object is obtained. The bottom steel roller of the drafting system was used as a smooth reflective surface, while the ST fibre assembly on its surface acted as the intermediate object (see Figure 7). The spinning region was recorded in continuous video format (Canon DSLR camera: EOS 70D; frame speed = 1/40th second) during spinning of a 100% cotton yarn as per Table 1. Images were then extracted from the video footage for analysis.

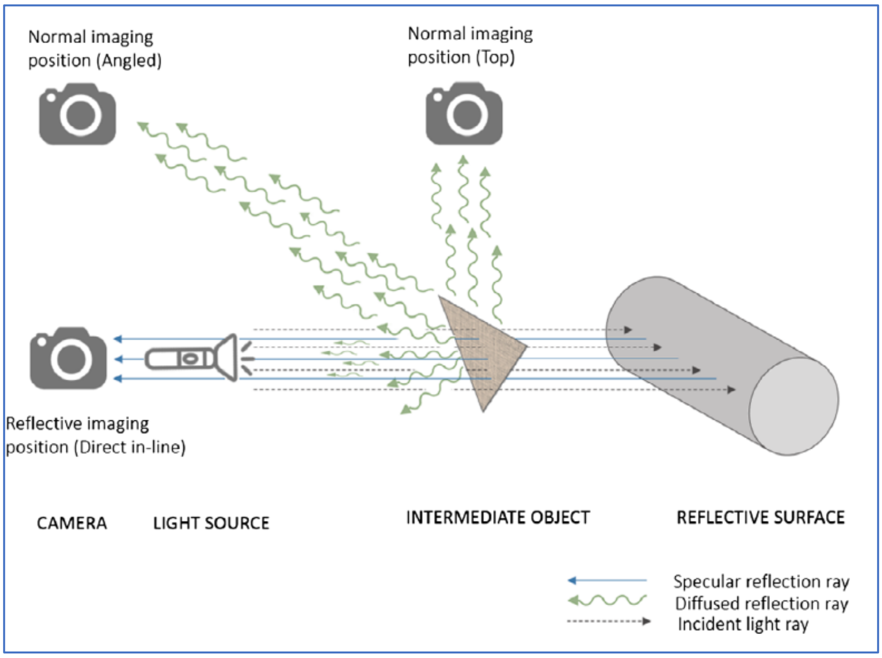


Figure 7. Schematic showing experimental setup for reflective imaging of spinning triangle and its comparison with normal imaging positions.

Effect of condensation on ST: In order to analyse the effect of ST geometry on fibre migration, cotton yarns were spun in normal (normal ST width) and mechanically constricted (reduced ST width) conditions. Mechanical constriction was achieved with the use of a purposely designed roving condenser. The condenser units were 3D printed using ABS (acrylonitrile butadiene styrene) polymer and secured magnetically to the apron supporting arm in the main draft zone of the Zinser 351 spinning frame (see Figure 8). The units were fitted on the same spindles as normal spinning in order to keep all other spinning parameters identical for comparison. Yarns (normal and condensed) were spun as per the **control and treatment yarns** with and without addition of 1% black coloured tracer fibres.

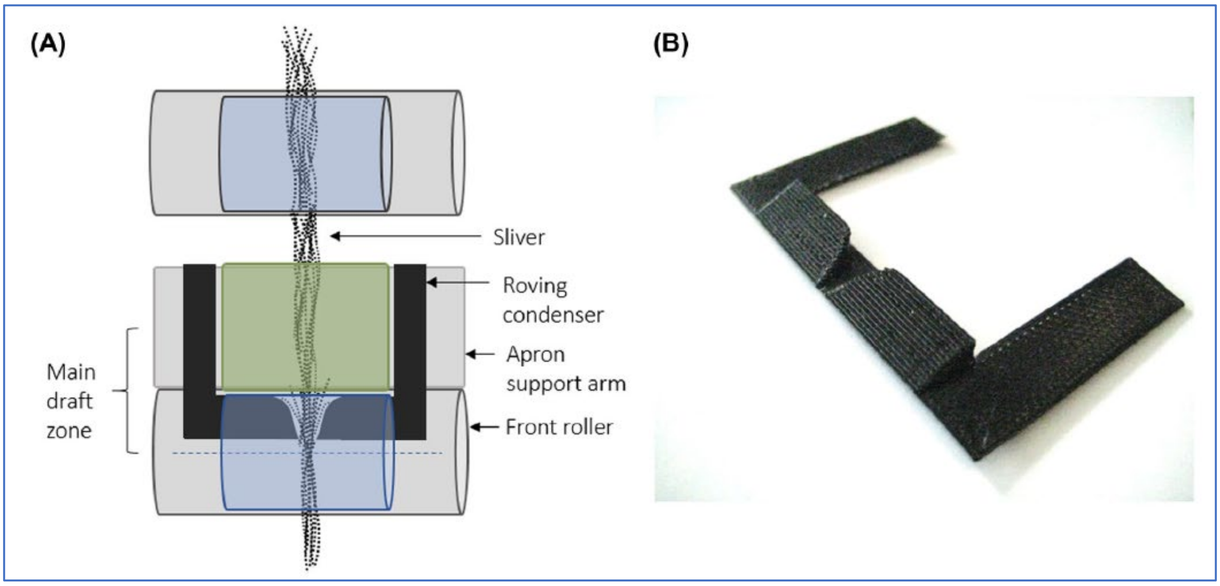
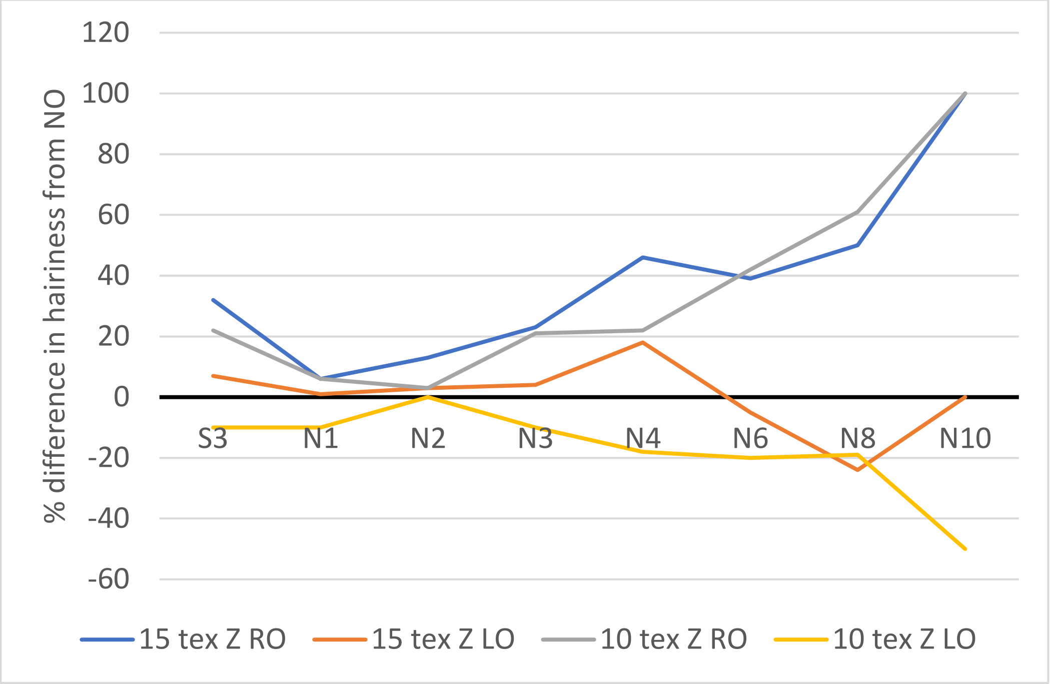


Figure 8. (A) Schematic of top view of drafting system showing the setup for achieving mechanical constriction of spinning triangle using a (B) 3D printed roving condenser.

Yarn testing: Yarn quality testing involved hairiness, evenness and tensile testing. Before testing, bobbins were first oven dried (eight hours) and later conditioned (48 hours) under standard conditions, i.e., 65% ±2% RH and 20^{o}C ±2^{o}C. Hairiness results were obtained from a Zweigle Tester HL400 at a testing speed of 400 m/min over a testing length of 400 m per test. Evenness testing (CV%) was performed on an Uster Tester-4 at 400 m/min with a testing time of one minute. Tensile testing (tenacity cN/tex, breaking elongation %) was performed at 250 mm/min on an Uster Tensorapid-3. All yarn quality results reported represent an average of 20 bobbins.

RESULTS AND DISCUSSION

The hairiness results presented in Figure 9 show proportional differences in hairiness values as measured by the Zweigle HL400 Tester, i.e., S3 (hair length ≥ 3 mm) values plus each hair-length category (N1 = 1 mm, N2 = 2 mm, N3 = 3 mm, N4 = 4 mm, N6 = 6 mm, N8 = 8mm and N10 = 10 mm) for RO and LO yarns relative to NO yarns in both twist directions. A positive change (y-axis upwards) in the graph indicates improvement or reduction in hairiness while a negative change (y-axis downwards) indicates an increase in hairiness. As expected, the results indicate hairiness was very similar irrespective of twist direction in both yarn counts. Although in Z-twist yarns, RO yarns showed better improvement than LO yarns. As hypothesised, the change in twist direction (Z to S) resulted in a reversed effect of RO and LO on yarn hairiness.



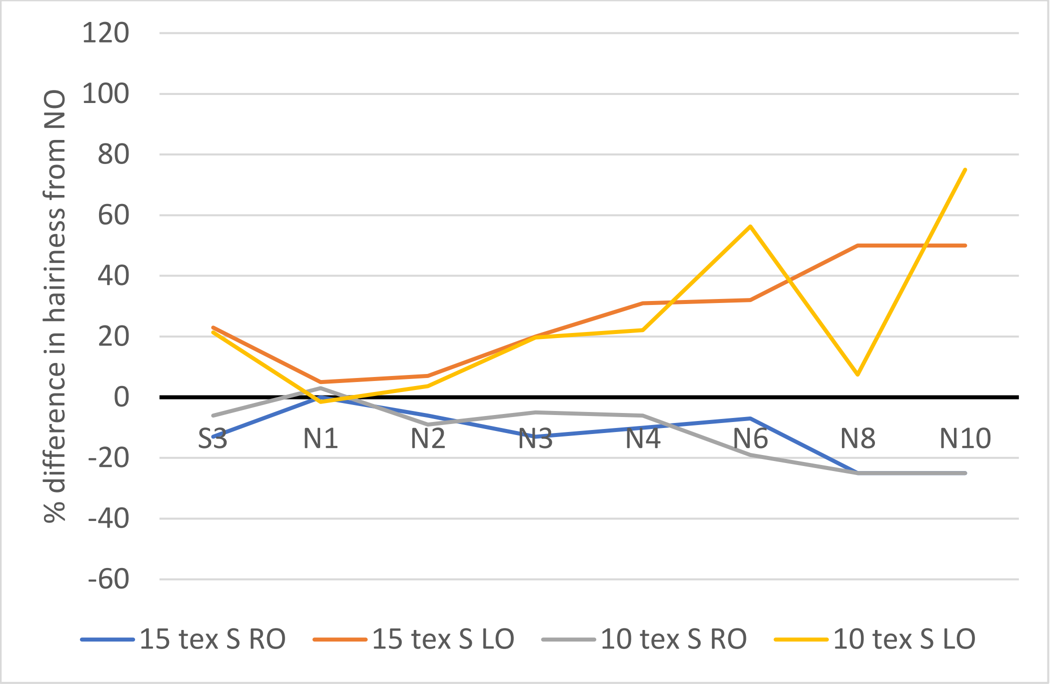


Figure 9. Hairiness results for different count and twist (top = Z-twist, bottom = S-twist) direction categories shown as a percentage improvement or deterioration with respect to normal (NO) yarn hairiness results. RO = right offset and LO = left offset. S3, N1, N2, N3, N4, N6, N8 and N10 denote the hair length categories as measured by the Zweigle HL400 Tester.

Table 2 lists other yarn properties measured on the above Z-twist yarns. Yarn evenness (CV%) deteriorated slightly with offsetting of the ST, which is related to the change in tension profile of the ST with the offset yarn path. The effect is more significant in LO yarn than in RO yarn, which indicates that LO and RO tend to change the fibre path into the ST in different manners. The test results for strength and elongation parameters indicate the role of better incorporation of fibres into the yarn body in a RO yarn compared to NO and LO yarns. This can be a reason why, even with slightly higher unevenness (CV%, thick, thin), the RO yarn demonstrated higher strength than the NO yarn. On the other hand, the increase in unevenness (thick and thin places) along with the higher number of hairs in a LO yarn appears to contribute towards the corresponding decrease in yarn strength.

Table 2. Quality parameter comparison between normal (NO) and offset (RO and LO) spun (Z-twist) yarns.

Quality parameter – Z-twist yarns						
Sample	**CV %**	**Thin pl. -50%**	**Thick pl. +50%**	**Neps +200%**	**Ten. cN/tex**	**Elong. %**
15 tex						
NO	16.8	30	769	1537	16.19	5.29
RO	17.2	49	813	1545	16.21	5.43
LO	17.9	76[a]	865[a]	1648[a]	15.36[a]	5.19
10 tex						
NO	17.8	35	773	1522	15.55	5.41
RO	18.1	56	803	1538	15.93	5.67
LO	19.1	70[a]	844[a]	1580[a]	15.80[a]	5.18

[a] *Statistically significant ($p<0.05$) difference from normal yarn*

Images of coloured (tracer) fibre spun yarns showed that during offset spinning, fibres from both edges tend to significantly change their wrapping behaviour (see Figure 10). During NO spinning conditions, the surface of the yarn appeared randomly divided into black and white regions. As the yarn path was offset towards the left direction (LO), the left-hand edge fibres (white) started to appear more on the surface, as depicted by the increased length of the white fibre bands. On the contrary, the right-hand edge fibres (black) showed maximum coverage on the yarn surface in the RO yarn.

The image results provide important information about the changes in fibre directional movement during offset spinning. However, the reason behind improvement or deterioration in hairiness was still not evident as both LO and RO showed similar changes in fibre wrapping behaviour, although in different directions. Therefore, the next step was a detailed analysis of fibre movement within the ST. The images captured on the benchtop twisting setup were utilized for this purpose. These provided more informative than images recorded during the industrial-scale ring spinning (see Figure 11).

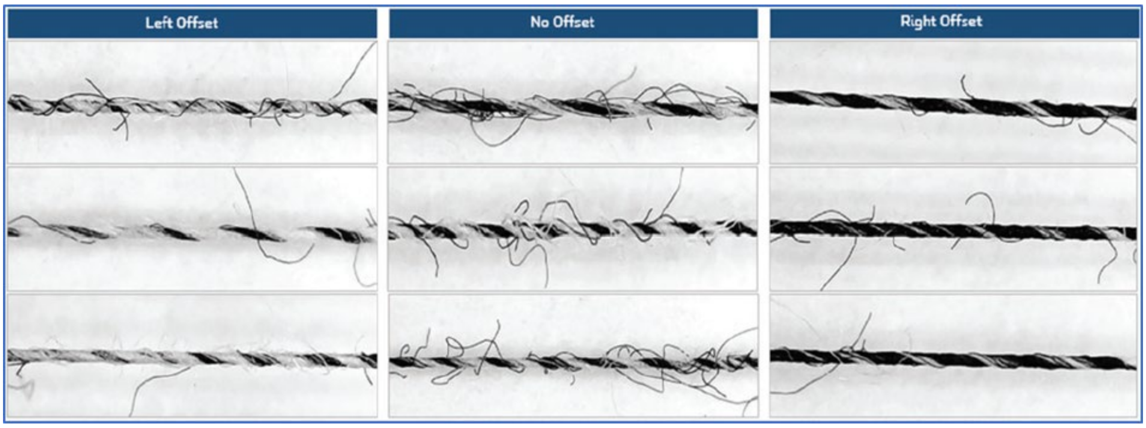


Figure 10. Macroscopic images of tracer blend yarns produced with and without offset conditions. Roving position: left = white and right = black as per Figure 5.

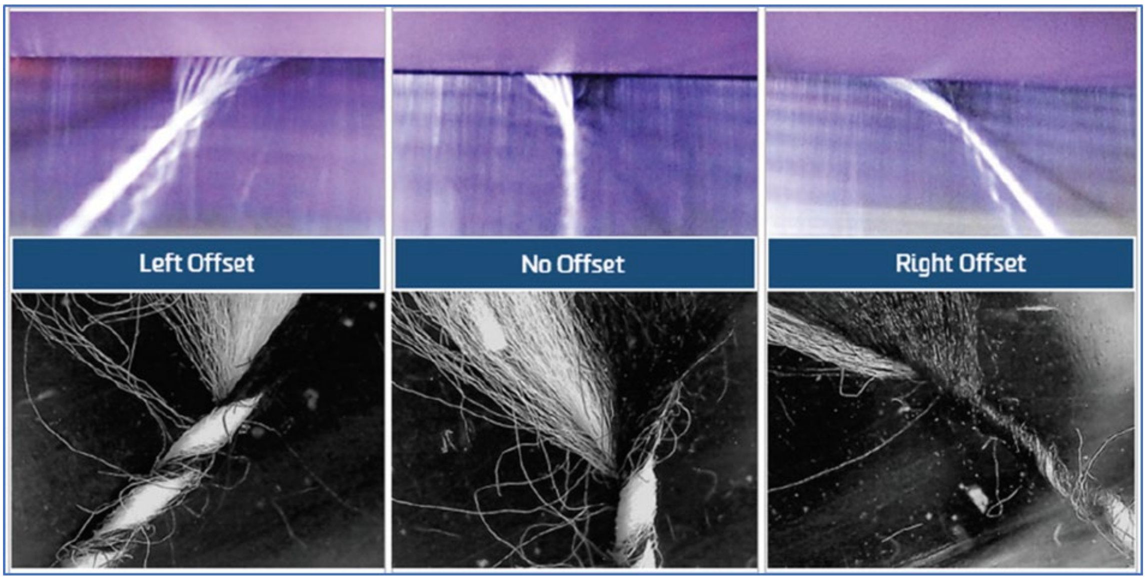


Figure 11. Imaging of the spinning triangle during (top) actual spinning on the industrial ring frame and (bottom) on the benchtop imaging setup. Material specification: tracer roving yarn (Z-twist).

The NO configuration of the ST shows the pre-twist, i.e. the spinning twist able to run up through the ST to the nip of the roller, on the right-hand edge (black) fibres while the left-hand edge (white) fibres are slightly more slack, resulting in an asymmetric ST (as per Figure 11). In the case of the LO configuration, the tension distribution becomes more uneven as the pre-twist now runs fully up to the roller nip line along the right-hand edge. The combined effect of the pre-twist tension (rotational) along with the spinning tension (axial) causes width-wise compaction of the right-hand edge (black) fibres. The corresponding decrease in tension on the left-hand edge (due to the absence of pre-twist) makes the white fibres slacker than in a NO configuration. The white fibres thus get loosely wound around the black fibres, resulting in an increased number of protruding hairs, which were predominantly white. The ST configuration during RO spinning was different. In RO spinning the left-hand edge (white) fibres were under tension and formed a concentrated core which was bound compactly by taut right-hand edge (black) fibres. The preferential surface appearance of black fibres in a RO yarn was due to the difference in their alignment angle with the yarn axis compared to the left-hand edge (white) fibres. Interestingly, the pre-twist region was observed to shift near the centre of the ST and did not follow the right-hand edge, as proposed in previous studies on offset spinning. These observations were seen in other subsequent spinning trials. It was concluded this geometrical phenomenon, therefore, is a decisive factor in limiting hair generation in a RO ST.

Following these analyses, a reflective imaging technique was used to provide information about the dynamic arrangement of fibres in the ST. It was observed that the pre-twist did not occupy a single location in the ST and changed its position frequently. The frequency of this oscillation was high and variable (20–40 movements/sec) and the span of this movement covered the whole width of the ST (see Figure 12). From these observations the dynamic variability in the tension profile across the ST is witnessed. A fibre will remain taut within the ST so long as its leading and trailing ends are gripped in the pre-twist and front roller nip respectively. Fibre tension drops as soon as the trailing end is released from the roller nip and fibre-fibre frictional grip is no longer able to provide any hold on the fibre. This moment can be termed as a ‘discontinuity event’ for a single fibre location in the ST. When all the fibres in the ST are considered, there are multiple discontinuity events happening at a given instant of time; the spatial distribution of such events across the ST width is random.

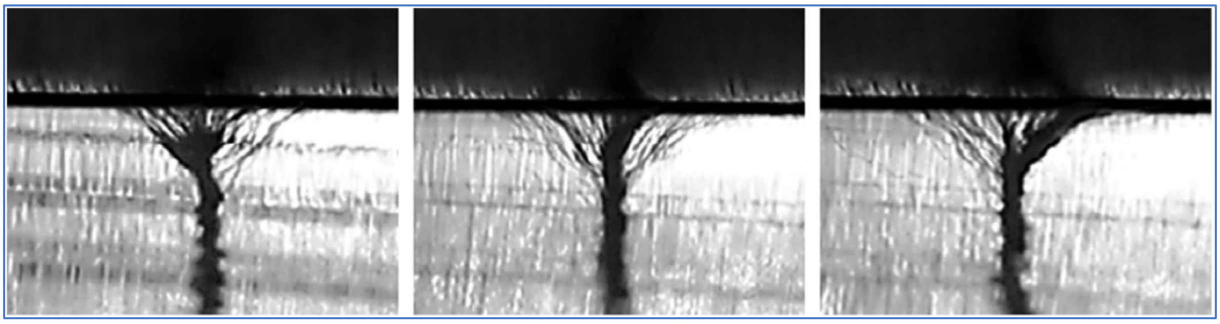


Figure 12. Three different locations (left, middle and right) of pre-twist zone observed within 0.15 seconds. The pre-twist is seen to stop midway on left edge due to the frictional obstruction from the surface of bottom roller during Z-twist spinning.

In order to be twisted together, fibres must satisfy two important conditions. They must be; (i) relatively taut than most of the fibres in ST and (ii) in proximity of other fibres satisfying the first condition. Such fibres together constitute the pre-twist and occupy the core position in the yarn but for a given instant of time. Meanwhile, other fibres travel in a continuum of discontinuity events. Therefore, fibres that start to form the yarn core will usually have their remaining length twisted near the surface in the next moment. In this way fibres will continue to migrate radially within the yarn body due to change in pre-twist location. This mechanism also explains the observation made by Morton in 1956. He observed there was no significant difference in radial position of tracer fibres when the tracer roving was fed either from right or left-hand side in a Z-twist yarn. The tension mechanism requires the ST region to have an open structure that allows both inward and outward movement of fibre, which is not the case in practical spinning. The pre-twist-based explanation of fibre migration answers this from a new perspective. The group of fibres incorporated in the pre-twist become aligned along the yarn axis due to the spinning tension, while fibres in the rest of the ST are subject to the continuum of discontinuity events and can be twisted around this 'internal' axis of rotation.

As soon as the pre-twist changes its location, the 'internal' axis of rotation also changes, and low-tension fibres start moving towards the new axis location. This means that fibres with lower tension do not make their way out of the core but start twisting around the 'newest' core, which is essentially the pre-twist zone composed of fibres with relatively higher tension. In other words, it is not the fibres that move in or out of the core but the core (or pre-twist zone) that adjusts its position according to the dynamic tension distribution across the ST. The pre-twist zone is the 'internal' axis of rotation at any given moment and fibres inside this axis of rotation always remain under higher tension than remaining fibres, irrespective of their location within the ST (edge or middle).

The relative parallelisation of fibres in the delivered drafted roving, is also important in understanding the pre-twist-based migration mechanism. Fibres that are delivered in a criss-cross manner add more complexity in the tension profile of the ST. As a result, more than one pre-twist bands can be observed in the ST. This phenomenon happens when the dual conditions of pre-twist formation exist, i.e., high fibre tension and proximity of fibres, at more than one location across the ST width. Each such location is separated from the neighbouring location by discontinuity events, which prevent them from joining together as a single pre-twist.

The role of pre-twist in influencing fibre migration was assessed by constricting its movement using a roving condenser in the main draft zone. The oscillation of convergence point of ST was observed to stop after this, which was an indicator of a stable and constricted pre-twist zone. The imaging results showed an increase in fibre packing density in the ST, without any distinguished pre-twist region (see Figure 13). This meant the majority of fibres in the ST were under the pre-twist control and hence the effect of any discontinuity event on their tension profile was minimized.

In the case of fibre blends with fibre length difference, longer fibres will tend to have lower discontinuity events than shorter fibres and, hence, tend to occupy the core predominantly. The influence of this factor on migration has been proved earlier by Balasubramanian, 1970; Onions et al., 1960 and Townend & Dewhirst, 1964. In case of a blend differing in fibre fineness, finer fibres have lower fibre-fibre slippage and, hence, will undergo discontinuity events less frequently than coarser fibres. This will result in finer fibres contributing more to pre-twist and occupying positions closer to the core than coarser fibres.

A new insert: Figure 14 illustrates a fibre guide device the authors have realised from this work for use in ring spinning utilizing a horizontally offset, typically RO, yarn spinning technique (Singh et al, 2017). As per the evidence presented the insert provides a guide device suitable for mechanically compacting a horizontally offset fibre strand thereby facilitating improved quality, particularly yarn hairiness. The fibre channel is angled to accommodate the horizontally modified path of the offset fibre assembly. It allows manipulation of the spinning triangle geometry according to the effects of RO spinning for improved fibre incorporation of fibres whilst also guiding and compacting the fibre strand to further reduce the occurrence of unincorporated fibres.

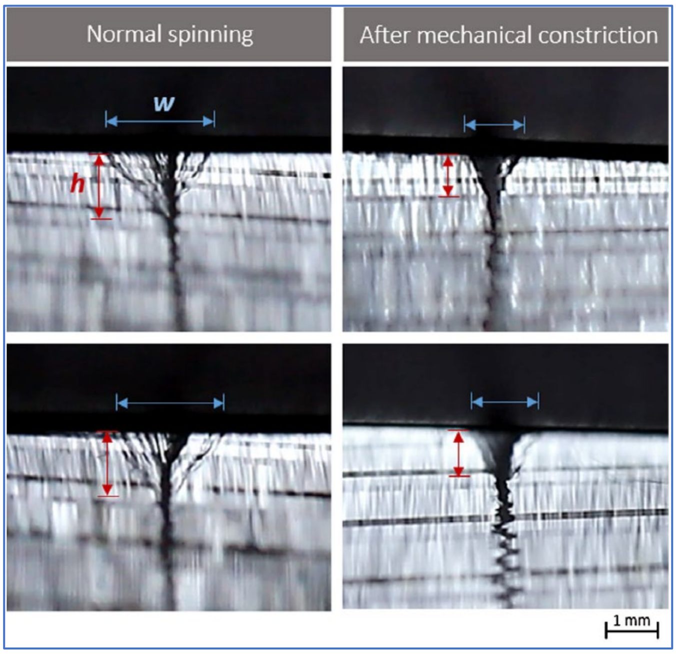


Figure 13. Reflective images showing difference in ST dimensional parameters during normal spinning and after mechanical constriction (condensing). w = width, and h = height.

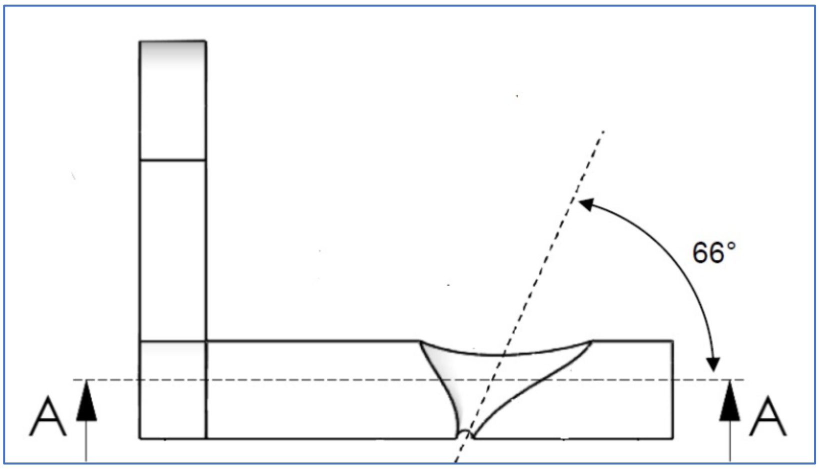


Figure 14. Fibre guide (condensing) device for use with a ring spinning machine in a horizontally offset yarn spinning technique.

CONCLUSION

Offset spinning is a simple geometric modification of the ST for producing yarns with reduced hairiness. However, the direction of offset plays an important role in determining this effect. A RO is effective in reducing hairiness for a Z-twist yarn while LO deteriorates hairiness results. An opposite effect is observed when the twist direction is changed. Fibres from both edges of the ST undergo significant change in their wrapping behaviour depending on the direction of the offset. Image analysis of the ST revealed that edge or biased positioning of the pre-twist region during LO spinning (Z-twist) distributes the twist tension unevenly across the ST width. The right-hand edge position of pre-twist during LO spinning causes slackness and delayed incorporation of left-hand edge fibres, which ultimately occupy the peripheral surface layers of the yarn, leading to increased hairiness. This observation was in contrast to RO spinning (Z-twist), in which equidistant positioning of pre-twist from both edges subjects all the fibres, irrespective of their incoming direction, to nearly similar twist tension and reduced travel distance to become incorporated into the yarn body. The primary factor which decides the position of the pre-twist is the ease of twist propagation into the ST.

Imaging of the ST revealed the pre-twist region within the ST does not assume a fixed position as had been generally considered but oscillates continuously across the ST width. At a given instant, fibres (with both ends gripped) constituting the pre-twist region form the core while rest of the fibres (with one end gripped or un-gripped) wrap around it to form the successive peripheral layers. The random change in gripping locations due to fibre length discontinuity causes the pre-twist to oscillate across the ST, which also changes the shape symmetry of the ST. During this process a fibre can enter and leave the pre-twist region (or core) multiple times, which is ultimately observed as its radial migration through the yarn body. This study offered a new insight into the dynamic fibre migration behaviour in ring spinning. It showed that fibre migration and yarn hairiness are integrally related for ring spun yarns. These insights led to the development of a new guide, which can be used in offset spinning to further reduce yarn hairiness.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the technical support provided by Mark Freijah and Phil Henry (retired) from CSIRO Manufacturing.

This work was sponsored by the Australian Cotton Research and Development Corporation.

REFERENCES

Balasubramanian, N. (1970). Effect of processing factors and fiber properties on the arrangement of fibers in blended yarns. Textile Research Journal, 40(2), 129–141

Chang, L. and Wang, X. Comparing the hairiness of Solospun and ring spun worsted yarns. Text Res J 2003; 73: 640–644

El-Shiekh, A. and Backer, S., (1972). The mechanics of fiber migration: Part I: Theoretical analysis. Textile Research Journal, 42(3), 137–146.
Gupta, B. S. (1970). Fiber migration in staple yarns: Part II: The geometric mechanism of fiber migration and the influence of the roving and drafting variables. Textile Research Journal, 40(1), 15–24.

Hearle, J. W. S., & Bose, O. N. (1965). Migration of fibers in yarns: Part II: A geometrical explanation of migration. Textile Research Journal, 35(8), 693–699.

Hearle, J. W. S., & Gupta, B. S. (1965). Migration of fibers in yarns Part III: A study of migration in staple fiber rayon yarn. Textile Research Journal, 35(9), 788–795.

Hearle, J. W. S., Gupta, B. S., & Goswami, B. C. (1965). The migration of fibers in yarns: Part V: the combination of mechanisms of migration. Textile Research Journal, 35(11), 972–978.

Hearle, J. W. S., & Merchant, V. B. (1962). Interchange of position among the components of a seven-ply structure: Mechanism of migration. Journal of the Textile Institute Transactions, 53(12), T537–T552.

Hickie, T. S., & Chaikin, M. (1960). The configuration and mechanical state of single fibres in woollen and worsted yarns. Journal of the Textile Institute Transactions, 51(12), T1120–T1130.

Onions, W. J., Toshniwal, R. L., & Townend, P. P. (1960). The mixing of fibres in worsted yarns: Part II—Fibre migration. Journal of the Textile Institute Transactions, 51(2), T73–T79.

Peirce, F. T. (1947). Geometrical principles applicable to the design of functional fabrics. Textile Research Journal, 17(3), 123–147.

Singh, C., Gordon, S. & Wang, X., (2019). The mechanism of hairiness reduction in offset ring spinning with a diagonal yarn path. Textile Research Journal, 89(8), 1546–1556.

Singh, C., Gordon, S. & Wang, X., (Oct 2017). Fibre guide device for offset yarn spinning, Australian Provisional Patent Application Filing, Application No. 2017904357.

Singh, C., Gordon, S., Zhang, S. & Wang, X., (2018). A new insight into the dynamics of fibre migration in ring spinning, The Journal of The Textile Institute, 110(4), 552-561.

Thilagavathi, G., Gukanathan, G. and Munusamy, B., Yarn hairiness controlled by modified yarn path in cotton ring spinning. Ind J Fib Text Res 2005; 30: 295–301.

Townend, P. P., & Dewhirst, J. (1964). Fibre migration of viscose rayon staple-fibre yarns processed on the bradford worsted system. Journal of the Textile Institute Transactions, 55(10), T485–T502.

Xia Z, Liu H, Huang J, et al. A study on the influence of a surface-contacting spinning strand on yarn appearance during Sirofil spinning. Text Res J 2015; 85: 128–139.