Structural and tensile properties of ring and compact plied yarns

S M Ishtiaque, P Subramani, A Kumar & B R Das
Department of Textile Technology, Indian Institute of Technology, New Delhi 110 016, India

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The effect of doubling on physical properties of regular ring-spun and compact yarns has been studied in terms of structural parameters, like fibre extent, spinning-in coefficient, fibre pair overlap length, packing coefficient and migration of fibres. The structural parameters, like fibre extent, spinning-in coefficient, fibre pair overlap length and packing density increase and migration parameters decrease after doubling for both the ring-spun and compact yarns. The percentage increase in tensile strength and percentage decrease in breaking elongation are found to be higher and lower respectively in ring-spun yarn than in compact spun yarn on doubling. Doubling process also reduces the hairiness of both ring-spun and compact yarns; the extent of hairiness reduction on doubling is higher for ring-spun yarn.

Keywords: Compact yarn, Fibre pair overlap length, Packing coefficient, Plied yarn, Ring yarn, Spinning-in coefficient

1 Introduction

Folded or plied yarns are used especially where single yarns are incapable of withstanding the demands made by them in manufacture or end-use. Hence, the folded yarn has continued to maintain its status in the production cycle despite occupying a disproportionate share of production costs. Plied yarns are widely used in many areas of textile industry due to their unique physical characteristics over single yarns. Double yarns are more uniform and have high strength, less hairiness, very smooth surface than the single yarns. They are used as sewing threads and are excellent choice for mittens, socks, and dress items. Doubling is the process of equalizing and compensating single-strand unevenness, thin and thick places. It is also reported that there is reduction in yarn hairiness after doubling due to entrapping of the protruding fibres between constituent yarns. Furthermore, ply-twisting of staple fibre yarns in the opposite direction, in almost all cases, results in increased tenacity and extensibility. The composite yarns display better recovery after the applied loads have been removed and show a correspondingly higher work of rupture. The highest strength is achieved when ply twist and spin twist are approximately equal, because a fibre arrangement that is almost parallel to the yarn axis makes maximum use of the inherent fibre strength. Plied yarn tenacity may surpass single-end tenacity by as much as 30%. For cotton yarns to obtain maximum folded yarn strength, the folding twist to spinning twist ratio should be equal to $3.253 \times n^{-0.345}$, where $n$ is the number of single components folded together. Although many endeavors have been made to compare the changes in physical characteristics of ring yarn on doubling, very little efforts have been made to understand these changes in terms of structural parameters.

Furthermore, many studies have been carried out to understand and analyze the comparative physical characteristics of ring and compact yarns in terms of internal structure parameters. The yarns spun on the compact spinning system are characterized by higher tenacity, higher elongation-at-break, smaller mass irregularity measured at short segments and significantly lower hairiness in comparison with yarns spun on the conventional ring spinning frame. It is reported that the migration parameters for compact yarn are 10-25% lower than those for the conventional ring yarn. The degree of migration is found to be lower in compact-spun yarn than in ring-spun yarn due to the reduction in size of spinning triangle and its consequence in the tension gradient. The diameter of compact yarn is found to be lower than that of regular ring yarn and this indicates that the packing densities are different. Higher packing
density coupled with better integration of fibres into the yarn body results in higher strength of compact yarn. The rate of fibre migration as well as the amplitude of migration are higher in compact-spun yarns. The former can be attributed to minimized spinning triangle in compact spinning and the latter could be the result of the higher density associated with these yarns. It is most likely that the higher rate and amplitude of fibre migration values are the source of higher tenacity values observed in compact yarns made from 100% cotton, but there are no structural studies covering the structural characteristics of plied conventional ring yarn and plied compact yarn. To understand the effect of doubling on ring-spun and compact yarns in a comprehensive manner, the present study has been undertaken to analyze this process in terms of changes in structural parameters like fibre extent, fibre overlap, migration parameters and packing density quantitatively. This will help in engineering and controlling different physical properties of plied yarn in a better way.

2 Materials and Methods

Polyester ring and compact yarns of 28\textsuperscript{s} Ne count were spun using polyester staple length of 32mm and twists/inch of 16.7. Single yarns having different tracer colours were doubled using TFO machine at 70% of single yarn twist (11.69 twists/inch). A small proportion (0.2% by weight) of coloured tracer fibres (red and green) were mixed after opening on the miniature card in the parent fibres separately and processed in the blow room stage. The mean length of opened tracer fibres was found to be 30.3 mm.

The yarn was immersed in benzyl alcohol having the same refractive index as that of polyester fibre to optically dissolve the grey fibres. Spinning-in coefficient, fibre pair overlap length and yarn migration parameters were measured by projection microscope using classical tracer fibre technique. Spinning-in coefficient was calculated using the following Kasparek’s formula:

\[
K_r = \sum_{i=1}^{n} \frac{L_i}{n} = \frac{L_o}{L} \quad \ldots (1)
\]

where \(L_i\) is the individual fibre extent; \(L_o\), the arithmetic mean of the projected length of individual fibres along the axis of the yarn; \(n\), the number of observation; and \(L\), the fibre length.

Fibre pair overlap length is the measure of the total projected overlapping length (along yarn axis) of two simultaneously overlapping tracer fibres. It gives a direct interpretation of total contact length between fibres. The combination of spinning-in coefficient and fibre pair overlap length explain the longitudinal structure of yarn. Migration parameters, such as mean fibre position (MFP), root mean square deviation (RMSD) and mean migration intensity (MMI), were measured using the following formulae:

- **Mean fibre position \((\bar{Y})\) – This represents the overall tendency of a fibre to be near the surface or near the centre of a yarn.**

\[
\bar{Y} = \frac{1}{Z} \int_{0}^{Z} Y \, dz = \frac{\sum Y}{n} \quad \ldots (2)
\]

where \(Y = (r/R)^2\); \(r\), the helix radius; \(R\), the yarn radius; \(Z\), the length along the yarn; and \(n\), the number of observations.

- **Amplitude of migration (RMSD) – The magnitude of the deviations from the mean position or the amplitude of the migration is root mean square deviation.**

\[
D = \left(\frac{1}{Zn} \left( \int_{0}^{Z} (y - Y)^2 \, dz \right)^{1/2} \right) = \left( \frac{\sum (y_i - Y)^2}{n} \right)^{1/2} \ldots (3)
\]

- **Rate of migration \((I)\) – The rate of change of radial position is represented by mean migration intensity.**

\[
I = \left( \frac{1}{Zn} \int_{0}^{Z} (dY/dz)^2 \, dz \right)^{1/2} = \left( \frac{\sum (y_i - y_{i-1})^2}{(z_i - z_{i-1})^2} / n \right)^{1/2} \ldots (4)
\]

The parameters needed for calculating packing density, like helix angle, helix twist and yarn diameters, were studied by using the classical tracer fibre technique. The packing density \((\mu)\) of the yarns was further calculated from the values of different structural parameters of the yarn using the following formula:

\[
\mu = \frac{2\pi nFZ^2}{(\sqrt{1 + (\pi D Z)^2} - 1)} \quad \ldots (5)
\]

where \(n\) is the number of fibres in the yarn cross-section obtained by multiplying theoretical number of fibres in yarn by cosine of helix angle \((\theta)\); \(F\), the cross-sectional area of cotton fibre used (mm\(^2\)); \(Z\), the
number of turns of twist in fibre helix per mm; \( D \), the yarn diameter (mm); \( d \), the helix diameter (mm); and \( \theta \), the helix angle (deg) = tan\(^{-1}(\pi d Z)\).

3 Results and Discussion

3.1 Fibre Extent and Spinning-in Coefficient

Fibre extent is one of the most important structural parameters, which directly influences the strength of the yarns. It indicates the degree of straightening of the fibres inside the yarn body. Mean fibre extent and spinning-in coefficient of the ring and compact yarns are given in Table 1. It is observed that the compact-spun yarns show higher mean fibre extent than the ring-spun yarn. This is due to the reduction in spinning triangle in the compact spinning which reduces the differential path of fibre in the yarn, so that the fibre follows smaller helical path in compact yarn than in ring yarn.

The mean fibre extent values of single yarns in a plied yarn were measured to access the influence of doubling on the said structural factor. The values of mean fibre extent and spinning-in coefficient of single yarns in a plied yarn are given in Table 1. The values of mean fibre extent and spinning-in coefficient of the ring and compact single yarns in a plied yarn are higher than their corresponding single yarns before doubling. Doubling operation inserts twist in the opposite direction to single yarn twist, which makes the fibres parallel to the yarn axis in the individual single yarns and the doubling tension in the yarn causes significant straightening of fibres. It is interesting to note that the increase in mean fibre extent of single yarn in a plied yarn is 27.42% for ring-spun and 20.89% for compact yarns as compared to their corresponding single yarns. The noted difference in the values can be explained by the fact that in case of compact yarn in a plied yarn, the plied yarn twist is not enough to untwist the single yarn as it happens in case of ring yarn which is mainly due to more compact structure of compact single yarn.

<table>
<thead>
<tr>
<th>Spinning type</th>
<th>Mean fibre extent, mm</th>
<th>Spinning-in coefficient</th>
<th>Mean fibre extent, mm</th>
<th>Spinning-in coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single yarn</td>
<td>Single yarn in plied yarn</td>
<td>Single yarn</td>
<td>Single yarn in plied yarn</td>
<td></td>
</tr>
<tr>
<td>Ring</td>
<td>17.5 (41.8)</td>
<td>22.3 (38.7)</td>
<td>0.58</td>
<td>0.74</td>
</tr>
<tr>
<td>Compact</td>
<td>20.1 (39.5)</td>
<td>24.3 (36.9)</td>
<td>0.66</td>
<td>0.82</td>
</tr>
</tbody>
</table>

Values in parentheses indicate the CV%.

3.2 Fibre Overlap

Fibre pair overlap length is one of the structural parameters, which influences the breaking strength and elongation properties of yarn. This indicates the degree of coherence among the fibres and how much a fibre is in contact with the neighbouring fibres in the yarn structure. The fibre pair overlap length values of single and plied yarns are respectively 9.51 mm & 11.28 mm for ring-spun yarns and 10.15 mm & 13.43 mm for compact yarns. Ring-spun yarn has lower value of fibre pair overlap length as compared to compact-spun yarn. Pneumatic compaction and positive condensation in compact spinning reduce the ribbon width at the front roller nip. Therefore, it gives smaller size of spinning triangle in the compact spinning. The smaller spinning triangle reduces the tension variation between middle and selvedge fibres which give better alignment of the fibres in yarn, resulting in higher fibre pair overlap length. The fibre pair overlap lengths are also measured for a single yarn in a plied yarn to access the influence of doubling operation on structural parameters. The fibre pair overlap length values for a single yarn in a plied yarn increase after doubling. This is due to straightening of fibres arising out of untwisting during doubling.

3.3 Fibre Migration

The migrational parameters, like mean fibre position, root mean square deviation and mean migration intensity, of ring and compact yarns have been measured (Table 2). It is observed that the mean fibre position of ring-spun yarn is higher than that of the compact-spun yarn. However, the compact yarn shows higher value of root mean square deviation and
mean migration intensity than the ring-spun yarns. The reason for lower mean fibre position of compact-spun yarn is best explained by proper understanding of ‘tension variation as mechanism of migration’ and due to reduction of spinning triangle in compact spinning. In ring spinning, due to the formation of spinning triangle, the selvedge fibre of the drafted strand that emerges from the front roller has to travel longer path than the one at the centre before it reaches the point of yarn formation, resulting in higher tension. The difference in tension among the fibres would cause an interchange of position of fibres and thus lead to a more or less regular migration. This is apart from the geometric mechanism that contributes to long-term migration based on roving twist and ring frame draft. From this, one can understand that the reduction of spinning triangle in compact spinning technology has reduced the mean fibre position in the compact yarn. This is due to lower differential path distance experienced by the fibre in spinning triangle than due to differential path distance experienced by fibres at different radial position. The higher value of root mean square deviation of the compact-spun yarn indicates the better spreading of the fibre helixes along the yarn diameter. The higher mean migration intensity of compact-spun yarns is due to the compromising effect of yarn radial position and buckling of the fibres at the yarn core. Smaller size spinning triangle of compact-spun yarn reduces the tension difference between the sheath and the core fibres, so more chances of buckled fibres at the yarn core. The favoured incidence of lower radial path traversed by the fibre helices along with buckled fibres in the yarn core increases the mean migration intensity of compact-spun yarns.

The migrational parameters of a single yarn get reduced after doubling process. This is due to the fact that fibres are getting parallelized in single yarn of a plied yarn, while twisting is carried out opposite to that of single yarn during plying operation. The individual yarn restricts the movement of the fibres during its tension compensation. The mean fibre position of single yarn in a plied ring yarn is higher than that of single yarn in a plied compact yarn. Ring yarn is having lower packing coefficient than compact yarn which results in more untwisting of single yarns during doubling operation. Higher mean migration intensity and root mean square deviation are observed in the case of single yarn in a plied compact yarn than in case of single yarn in a plied ring yarn. This is due to same explanation mentioned for the single yarns.

3.4 Packing Coefficient
The packing coefficients of single and plied yarns are respectively 0.518 & 0.612 for ring-spun yarns and 0.691 & 0.772 for compact yarns. It is revealed that the packing coefficient of ring-spun yarn is lesser than the compact-spun yarn. The spinning triangle in the ring spinning process cannot entrap all the fibres fed in this means, and hence the selvedge fibres in the spinning triangle are either lost or attached in a completely uncontrolled manner in the twisted yarn body. In other words, in ring-spun yarn, a certain portion of fibres protrude out of yarn body and make little or no contribution to the yarn strength. This leads to higher diameter of yarn and less packing coefficient value. In compact spinning, the width of the fibre stream is reduced, i.e. the spinning triangle is small due to the pneumatic compaction of fibre stream and the positive condensation process. Therefore, the fibres in the spinning triangle are collected and fully integrated in the yarn body. This gives compact structure to the twisted yarn and lower yarn diameter. The higher values of root mean square deviation and mean migration intensity of compact-spun yarns enhance their packing density.

The packing coefficient of the single yarn in plied ring-spun and compact yarns was also measured. It is indicated from the measured values that the packing coefficient of single yarn in plied ring-spun and compact yarns increases significantly. The packing coefficient of single yarn increases after doubling process, because untwisting and twisting in reverse direction during doubling reduce the air volume between the fibres in the yarn. In addition, the flattening of fibres and compression of fibres in yarn structure caused by doubling twist increase the packing coefficient of single yarn in plied yarn.

3.5 Yarn Tenacity and Breaking Extension
The yarn tenacity and breaking extension of ring and compact yarns are given in the Table 3. The higher tensile strength and breaking extension of compact yarn as compared to ring yarn are due to higher spinning-in coefficient, fibre pair overlap length, root mean square deviation, mean migration intensity and packing density. After doubling, the fibre extent increases in both the cases, which results in higher tenacity and lower breaking extension. However, in the plied ring yarn, the increase in tenacity (15.24%) is more than that of plied compact yarn (12.47%). This is due to the fact that the change in fibre extent in a plied ring yarn (27.42%) is higher
than in compact plied yarn (20.89%) corresponding to their single yarn. Further, it can be noted that the decrease in elongation-at-break is 18.5% in case of ring plied yarn and 19.8% in case of compact plied yarn than their corresponding single yarns.

In plied yarn, the migrational parameters of single yarn change significantly. This results in an increase in fibre extent and packing coefficient of single yarn in a plied yarn. However, the percentage of migrational parameters change is more in the case of single yarn in a plied ring yarn than in case of single yarn in a plied compact yarn, i.e. the reduction in mean fibre position in single yarn in a plied ring yarn is 60.41% and in the single yarn in a plied compact yarn it is around 54.05%. This is due to lower packing coefficient of ring yarn. Because of this, a higher change in structural parameters gives more increase in tenacity in single yarn in a plied ring yarn (27.42%) than in plied compact yarn (20.89%). Despite lesser improvement after doubling, the tenacity and breaking extension remain lower for resultant double compact yarn.

### 4 Conclusions

Compact yarn displays higher fibre extent and spinning-in coefficient than regular ring-spun yarn. Fibre extent and spinning-in coefficient increase after the doubling operation. Fibre extent is increased by 27.42% for single regular ring-spun yarn and 20.89% for compact yarn after doubling. The fibre pair overlap length values increase after doubling in both regular ring-spun and compact yarns. Compact-spun yarn shows lower mean fibre position but higher root mean square deviation and mean migration intensity. After doubling, the mean fibre position, root mean square deviation and mean migration intensity values are reduced. Packing coefficient increases by 18.14% for regular ring-spun yarn and 11.72% for compact yarn after doubling. Compact single yarn has higher tensile strength and breaking extension than regular single spun yarn. The increase in tensile strength on doubling is more in the case of regular ring-spun yarn than in compact yarn. But decrease in elongation-at-break is more in the case of compact-spun yarn on doubling. Hairiness of compact yarn is lower than that of regular ring yarn. Doubling process reduces hairiness but reduction in hairiness at all measured lengths due to plying is more in case of ring yarn than in corresponding compact yarn.

### Industrial Importance

The relationship established between yarn structural changes on doubling with the plied yarn mechanical properties will facilitate in engineering and controlling the doubling process. The manufacturing variables can be manipulated to achieve a particular degree of fibre disposition in yarn body to decide the plied yarn mechanical properties.
The yarn structure dependent doubling twist concept may be implemented in industrial process instead of the conventional way of deciding the optimum twist for better engineering and controlling of the doubling process.

References