Fibre migration in compact-spun yarns: Part I—Pneumatic compact yarn

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Fibre migration of regular ring-spun vis-à-vis compact-spun (pneumatic compact) combed cotton yarns has been studied using the tracer fibre technique for the different migration parameters. The yarn counts used were 40s and 52s Ne (14.8 tex and 11.4 tex). It is observed that the migration parameters for compact yarn are 10-25% lower than those of regular yarn in both 40s and 52s Ne counts. 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. Even though this causes significant change in degree of migration, its contribution is less in comparison to the tension gradient due to fibre occupying different radial positions. The diameter of compact yarn is found to be lower than that of regular yarn in both the cases 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 yarn strength.

Keywords: Cotton, Compact-spun yarn, Fibre migration, Mean fibre position, Mean migration intensity, RMS deviation, Tension mechanism

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1 Introduction
The mechanical properties of staple yarns depend not only on physical properties of constituent fibres but also on the yarn structure characterized by geometrical arrangement of fibres in yarn. Of the various structural properties for staple yarn, the relative fibre movements at the point of yarn formation and the resultant position of fibres in the yarn structure have a decisive influence on yarn properties, such as strength, C V of strength, elongation, hairiness and running performance. The relative fibre movement has been termed as 'fibre migration' by Morton and Yen. Fibre migration characteristic in staple yarns is, to a great extent, influenced by the factors such as spinning system adopted or fibre accumulation mechanism and the relative tension of fibres at the point of yarn formation apart from fibre characteristic such as length, fineness, crimp and cross section shape. You Huh et al. observed that among the widely used systems in the production of staple yarns such as ring, rotor and friction, the ring-spun yarn exhibits highest fibre migration followed by rotor-spun and then the friction-spun yarns, based on spinning tension and its variation. The compact yarn is spun with a significantly reduced spinning triangle to less than 20% of ring yarn (base of the triangle from 2-3mm to less than 0.5 mm) and hence a less variation in path distance among fibres of drafted stand is achieved. This results in less variation in tension among the fibres than in ring yarn and hence its migratory characteristic is expected to be less and it will remain somewhere between ring and rotor yarns. But the strength obtained in compact yarn is higher. This necessitated a study of migration, packing density and other related factors on compact yarn so as to correlate its structure with properties.

The literature reveals that since 1950 there have been many studies on structural analysis of yarn. Tracer fibre technique used by Morton and Yen in 1949 is still being followed by many researchers. The study of Morton reveals that the migration is due to tension differences resulting from different path length of fibres. He found that the interval of helix profiles decreases as the twist increases. Riding studied fibre migration using a new measurement.
method in which he simultaneously viewed yarn from two perpendicular directions.

In 1965, Hearle et al.⁵ established the theoretical basis for fibre migration and characterized migration behaviour of an ideal yarn by considering ribbon-twist model and suggested various migration parameters, such as mean fibre position, R M S deviation, mean migration intensity rate of fibre migration but to a lesser extent. In 1970, Gupta¹⁰ discussed the geometric mechanism of fibre migration and the influence of roving and drafting variables in detail. In 1971, Lord" emphasized that the frequency of migration is roughly constant in relation to frequency of twist.

In 1969, Gupta and Hamby⁹ emphasized that the migration behaviour of staple yarns is, to a large extent, dependent on their mean fibre position. They also concluded that the spindle speed and spinning tension influence rate of fibre migration but to a lesser extent. In 1970, Gupta¹⁰ discussed the geometric mechanism of fibre migration and the influence of roving and drafting variables in detail. In 1971, Lord" carried out work on structure of open-end spun yarn and in 1972, Hearle et al.¹² investigated fibre migration in OE yarns. They concluded that the low strength of rotor-spun yarns could be attributed to poor fibre alignment, inferior and shallower fibre migration within yarn body and fairly large number of folded fibres. In 1994, Alagha et al.¹¹ concluded that the difference in migration characteristic of yarn on different spinning systems is due to different twisting methods and different levels of tension developed during yarn formation. They also developed an image analysis system to assess the structural characteristics of friction-spun yarns, mainly fibre migration. In 2001, a three dimensional analysis of migration of staple yarns by You Huh et al.¹⁸ revealed the efficacy of 3-dimensional visualization with image analyzer for structural analysis of staple yarns.

While a considerable amount of information exists on fibre migration in ring-spun, rotor-spun and friction-spun yarns, no work seems to have been done on the migration of compact yarns. The present work was therefore aimed at studying the migration in pneumatic compact system yarn.

Literature²¹⁴ on instrumentation used for the study revealed that in place of projection microscope (Projectina), CCD camera or trinocular microscope with CCD camera is being used in recent years to magnify and capture the image of the tracer fibre in a computer, and the trajectory of tracer fibre is analyzed using software.

2 Materials and Methods

2.1 Materials

A cotton variety H-4 with a 2.5% span length of 29/30 mm and fineness of 4.0 µg/inch (1.58 dtex) was used to produce combed roving of 1.37 Ne (431 tex). A small proportion (1.0% by weight of above fibres) was black dyed and used as tracer fibres, which were introduced in the carding stage with the remaining undyed material. The yarn counts 40s Ne (14.8 tex) and 52s Ne (11.4 tex), which were produced by the mills on Suessen Elite Compacting System working on pneumatic compacting principles, were selected for the study. The tracer fibre incorporated roving was used in two spindles to produce compact yarn in a commercial machine. For the production of equivalent count ring yarns (40s and 52s Ne), the same spindles without compacting attachment was used while keeping the process parameters, such as spindle speed (13500 and 18500 rpm), twist factor [4.2α¸/127a_m and 3.95α¸/119a_m (1045 and 1120 t.p.m.)] and traveler weight, identical for both yarns.

2.2 Methods

2.2.1 Migration Study

The standard tracer fibre technique was used for the study. A few length of above yarn (0.15 m), selected at random, was fixed on a glass trough under 1 cN tension and immersed in liquid medium (methyl salicylate) having substantially the same refractive index as that of fibres concerned. The trough was mounted on the stage of projection microscope (Projectina × 40) fitted with CCD camera. The yarn, when examined under a microscope, shows that the un-coloured fibres appear transparent leaving the path of each tracer coloured fibre to be clearly visible. The tracer is seen against the faint background of yarn body as the wavy line representing the projection in one plane of helix. The present study is confined to
the unidirectional analysis of the projection. Using CCD camera, around 1.5mm of yarn is photographed at a time and the images are stored using a PC as the trough mounted on the stage is gradually moved. Then the photographed images are merged sequentially and analyzed using software for configuring the tracer fibre in the yarn body. The number of measured tracers per sample is 10. The number of trough/peak point measured per fibre is between 35 and 50 and corresponding yarn length is between 19mm and 26mm.

2.2.2 Configuration of Tracer Fibre
Parameters such as mean fibre position ($\bar{Y}$), R M S deviation ($D$), mean migration intensity ($I$), equivalent migration frequency defined by Hearle\(^5\) and Prementas\(^15\) and migration factor defined by You Huh\(^14\) were used for characterizing migration behaviour of the tracer fibre under microscope.

Mean Fibre Position
Mean fibre position ($\bar{Y}$) represents the overall tendency of a fibre to be near the surface or near the centre of yarn. It is calculated from the following equation:

$$\bar{Y} = \frac{1}{L} \int_0^L Y_dZ = \frac{1}{n} \sum_{i=0}^{n-1} Y_i$$

where $Y_i$ is equal to $\{r_i / R_i\}; i=0,1,2,...,n-1$, the sequence no. of observation; $R_i$, the yarn radius; $r_i$ the helix radius for the $i^{th}$ observation; $Z$, the length coordinate along the yarn; $L$, the total yarn length (observed); and $n$, the total number of observation.

Amplitude of Migration
Amplitude of migration is the magnitude of deviations from mean position represented by root mean square deviation ($D$). This is derived from the following equation:

$$D = \left[ \frac{1}{L} \int_0^L (Y - \bar{Y})^2 dZ \right]^{\frac{1}{2}} = \left[ \frac{1}{n} \sum_{i=0}^{n-1} (Y_i - \bar{Y})^2 \right]^{\frac{1}{2}}$$

Rate of Migration
Rate of migration is indicated by the mean rate of change of radial position, which is denoted as mean migration intensity ($I$). This is derived from the following equations:

$$I = \left[ \frac{1}{L} \int_0^L \left( \frac{dY}{dZ} \right)^2 dZ \right]^{\frac{1}{2}} = \left[ \frac{1}{n} \sum_{i=0}^{n-1} \left( \frac{dY}{dZ} \right)_i \right]^{\frac{1}{2}}$$

The modified form of the formula\(^15\) is:

$$I = \left[ \frac{1}{n} \sum_{i=0}^{n-1} \left( \frac{Y_{i+1} - Y_i}{z_{i+1}} \right) \right]^{\frac{1}{2}}, \quad z_i = Z_i - Z_{i-1}$$

where $z_1,z_2,...,z_{i+1}$ are the yarn axial distances between adjacent indications of peak and trough of tracer; $Z_1,Z_2,...,Z_{n+1}$, the cumulative distances; and $Y_i$ or $Y_{i+1}$ as defined earlier.

Equivalent Migration Frequency
Equivalent migration frequency is derived for the ideal migration cycle constructed from the calculated value of $I$ and $D$ as: $1/4D\sqrt{3}$.

Migration Factor
Migration factor (MF) is derived by multiplying R M S deviation ($D$) and migration intensity ($I$) values.

2.2.3 Measurements
The measurements\(^15\) of $a$, $b$, $c$ and $z$ were made at successive peak and trough of a tracer fibre image (Fig. 1). The $c_0$, $c_1$, $c_2$, $c$, and $a_0$, $a_1$, $a_2$, $a$, points are located at start and end of the body of tracer fibre image for the ‘$i=0,1,2,...,n-1$’ sequence number of observations, leaving aside the protruding and loosely held fibre end portions. The radius of yarn ($R_i$) for the $i^{th}$ observation in scale units is $\{(a_i - c_i)/2\}$. The helix radius ($r_i$) for that observation is given by $\{(a_i + c_i)/2 - b_i\}$, which is the offset of trough / peak from yarn axis.

Fig. 1 — Tracer fibre measurement
axis. The distance between adjacent trough and peak is $z_i, z_2, \ldots z_i$. In order to avoid effects due to change in yarn diameter, radial position of fibres is given by a ratio $r/R_i$, which is derived by $\{(a_i + c_i)/2-b_i\}/\{(a_i - c_i)/2\}$. Plot of $r/R_i$ against length along the yarn shows cylindrical envelop of varying radius around which fibres are following a helical path. Around 4-5 trough/peak of tracer are appearing in a image of about 1.5 mm yarn length captured at a time and stored in the PC. Using software the images were sequentially merged to track the full length of tracer fibre and measurements were taken subsequent to applying appropriate scale and calibration check.

3 Results and Discussion

Table 1 shows the migration characterization data obtained from the measurements taken each on tracer fibres of ring and compact yarns of 40s and 52s Ne combed cottons.

3.1 Mean Fibre Position, R M S Deviation and Mean Migration Intensity

It can be observed from Table 1 that the 40s Ne compact yarn shows 10.7%, 11.0% and 9.8% reduction in mean fibre position ($\bar{Y}$), R M S deviation ($D$) and mean migration intensity ($I$) respectively as compared to 40s Ne ring yarn. Similarly, there are reduction in mean fibre position ($\bar{Y}$), R M S deviation ($D$) and mean migration intensity ($I$) to the extent of 29.3%, 17.6% and 9.6% respectively for 52s Ne compact yarn as compared to 52s Ne ring yarn. T-test values reveal that the quantum of reduction is significant at 95% confidence level for $\bar{Y}$ and $D$ and not for $I$. The reason for the reduction is best explained by proper understanding of 'tension variation as mechanism of migration' and due to elimination of spinning triangle in the compact yarn spinning.

3.1.1 Tension Variation as Mechanism of Migration

Morton found that the fibres twisting along a long path on the outside of a yarn would develop a high tension, while the fibres following the shorter straight path in the centre would be under low tension. Similarly, in ring spinning due to the formation of spinning triangle, the corner fibre of the drafted strand that emerges from the front roller has to travel longer

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Yarn diameter, mm</th>
<th>Mean fibre position ($\bar{Y}$)</th>
<th>R M S deviation ($D$)</th>
<th>Mean migration intensity($I$), cm$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall mean</td>
<td>Compact (0.13384)</td>
<td>0.48030</td>
<td>0.26225</td>
<td>0.29479</td>
</tr>
<tr>
<td>S D of mean</td>
<td>Compact (0.00577)</td>
<td>0.10067</td>
<td>0.03597</td>
<td>0.03253</td>
</tr>
<tr>
<td>C V% of mean</td>
<td>Compact (4.31471)</td>
<td>0.00798</td>
<td>13.71671</td>
<td>11.03559</td>
</tr>
<tr>
<td>$T_{95%}F_{95%} &amp; T_{Act}/F_{Act}$</td>
<td>Compact 2.262</td>
<td>6.115</td>
<td>1.494</td>
<td>1.264</td>
</tr>
<tr>
<td>C V% individual</td>
<td>8.55680</td>
<td>7.67796</td>
<td>55.92123</td>
<td>55.75908</td>
</tr>
<tr>
<td>$T_{95%} &amp; T_{Act}$</td>
<td>1.96</td>
<td>19.033</td>
<td>2.017</td>
<td></td>
</tr>
<tr>
<td>Equivalent migration frequency, cm$^{-1}$</td>
<td>Compact</td>
<td>2.7441</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mignation factor, cm$^{-1}$</td>
<td>Compact</td>
<td>3.4202</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

When the calculated values exceed the limiting values, the difference between the two is significant at 95% confidence level.
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. The difference in fibre path distance of spinning triangle with 3 mm base is 0.5 mm only, whereas the difference in fibre path distance for the fibres located at core and surface is 2.6 mm for a 25 mm long fibre of 40s Ne yarn.

From this, one can understand that the difference in path experienced in spinning triangle, which gets eliminated in compact yarn, is significantly lower than the difference in path followed by fibres at different radial position (20% only). This is the reason for the lesser differences of around 10-25% in the migration characters \((\bar{T}, D, I)\) of compact yarn compared to ring yarn.

### 3.2 Yarn Diameter and Packing Density

Table 1 shows that there is an overall reduction of yarn diameter to the extent of 10.7% for 40s Ne and 16% in 52s Ne for the compact yarn as compared to respective ring yarn of the same count and a consequent increase in overall packing density is observed. This is due to the pneumatic compaction that is involved in the production of compact yarn, which is mainly responsible for the increase in strength apart from better integration of fibre. This can be visualized from in the CCD camera photos as shown in Fig. 2 for the ring and compact yarns.

### 4 Conclusions

4.1 The elimination of spinning triangle in compact spinning technology has reduced the migration parameters such as mean fibre position, RMS deviation and mean migration intensity to the extent of 10-25% only. This is due the lower differential path distance experienced by fibre in spinning triangle than due to differential path distance experienced by fibres at different radial position (20%).

4.2 Differential path experienced by fibres at different radial positions is a major factor which contributes to migration based on tension mechanism, apart from the geometric mechanism contribution to long-term migration.

4.3 In view of the above, the increase in strength of compact yarn can be attributed to the factors such as higher packing density and better integration of fibre to yarn body.

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### References