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# Analysis of structural properties of cotton/milkweed blended ring, compact and rotor yarns

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This study has been conducted to explore the relationship between yarn structure and yarn characteristics of cotton/milkweed (C/M) blended yarns. The fibre migration index values reveal that the milkweed fibres are predominantly in the yarn sheath of C/M 80/20 yarn, whereas it occupies the yarn core in C/M 60/40 and 40/60 combinations as small clusters. Fibre migration studies reveal that the compact spun yarns have higher fibre migration factor which is responsible for their tenacity followed by ring- and rotor-spun yarns. The effective packing density of C/M blended yarn decreases with the increase in milkweed blend proportion due to less cohesiveness and poor self locking structure of fibres in the yarn cross-section.

**Keywords**: Cotton-milkweed, Migration index, Migration factor, Packing density, Tracer fibre, Yarn diameter

## 1 Introduction

The yarn structure is a function of many factors, such as fibre property as the yarn structural component and its mechanical properties; fibre distribution along the yarn cross-section and its migration properties; and relationship between yarn structure elements determined by the spinning system, level of twisting, or subsequent chemical processing[1]. The mechanical properties of staple yarns depend not only on the physical properties of the constituent fibres, but also on the yarn structure characterized by the arrangement of the individual fibres in yarn cross-section[2-4]. The mechanics of tensile deformation in staple spun yarns is influenced by the tensile properties of the constituent fibres, their migration and packing density. Many properties, such as yarn strength, extensibility, appearance, compactness, as well as uniformity of the structure, are related to fibre distribution along yarn cross-section[5-6].

Blending of dissimilar fibres results in an irregular distribution throughout the yarn cross-section, leading to preferential migration depending on the fibre properties and spinning system. The properties of blended yarns cannot be explained merely in terms of their characteristics and proportions of the different component fibres in the blends; the arrangement of the fibres in the yarn must also be taken into account[7]. Since the milkweed fibres are having different properties compared to cotton, their behavior and arrangement inside the yarn have been analysed while blending with cotton fibre and to relate them with the yarn characteristics.

The yarn characteristics of cotton/milkweed blends in ring, compact and rotor spinning systems and optimization of process parameters in ring and rotor spinning have already been reported by the authors[8,9]. In this study, the structures of ring-, compact- and rotor-spun cotton/milkweed (C/M) blended yarns have been characterized in terms of fibre migration, packing density and migration index to analyse the influence of yarn structure on yarn characteristics.

## 2 Materials and Methods

### 2.1 Materials

Medium grade cotton (S-4) and milkweed fibres were selected for the production of cotton/raw milkweed blended yarn.

### 2.2 Yarn Production

The spinning trials were conducted on a micro-spinning line (Trytex, India)[10]. The slivers were prepared for yarn production on a miniature model carding and the draw frame machine. The slivers were then processed through speed frame (LF4200, Lakshmi Machine Works, Coimbatore, India) and ring frame (LR6, Lakshmi Machine Works, Coimbatore, India) to produce 29.5 tex yarn for producing a normal ring yarn. After the second passage draw frame, the sliver was processed in miniature rotor spinning machine (Trytex, India) to produce the rotor yarn.

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### 2.3 Yarn Migration Study

For characterizing the structure of C/M blended yarns produced from the ring, compact and rotor spinning systems, a fibre migration study was carried out using classical tracer fibre technique[11]. The fibre migration studies were carried out based on Treloar's theory[12]. A small proportion (1% by weight) of red dyed tracer fibre for milkweed and blue color tracer for cotton fibres were introduced in carding stage and the yarn was produced. The yarns were then immersed in methyl salicylate having the same refractive index as that of the component fibres so that dyed fibres could be readily observed through an image analyzer. The yarn structural parameters, namely mean fibre position, root mean square deviation, mean migration intensity, were then calculated as per Hearle[13] and Primentas[14] definitions.

### 2.4 Evaluation of Yarn Packing Density

The yarn packing density was analysed based on the Internal Standard No. 22-103-01/01, characterized by Neckar's theory[15]. For packing density analysis, the yarn cross-sectional images need to be obtained to provide input data for computations. As a result, different sample preparation was required. Samples were prepared according to the IN 46-108-01/01 standard under soft section method. Motic Image Plus 2.0 software was used for the packing density analysis.

#### *2.4.1 Evaluation of Fibre Packing Density*

The cross-sectional image of a yarn sample was imported onto the software and then divided into ten concentric circles of equal radius to calculate the fibre packing density[16,17]. Afterwards, fibres in each radial ring were selected using the measure tool, and the fibre area in each zone was calculated using the software.

$$\text{Fibre packing density in yarn} = \frac{\text{Total area of fibres in yarn cross - section}}{\text{Total area of yarn cross - section}}$$

The total area of the yarn cross-section was calculated from yarn diameter.

### 2.5 Hamilton Migration Index

The Hamilton fibre migration index based on the calculation of the moment distribution of fibres in the yarn cross-section is a common method to calculate and analyze the distribution of fibres in blended yarn cross-section (Hamilton 1958). The Hamilton fibre migration index was calculated based on the literature[18,19].

## 3 Results and Discussion

### 3.1 Analysis of Fibre Disposition Distribution of Blended Yarns

During the twisting process, the properties of fibres and the process parameters have an influence on the migration behavior of fibres. To understand this mechanism, fibres with a radial distribution across the cross-section of blended yarns have to be investigated. The yarn cross-section was chosen at random for the experiment. The calculated values of migration index of different blended spun yarns are given in Table 1.

In C/M 80/20 blended yarns, the longer cotton fibres have a tendency to migrate towards the core of the yarn pushing the shorter milkweed fibres towards the surface. According to the transfer law of fibres in blended yarns, the longer, finer and higher initial modulus fibres will migrate towards the core and vice versa[20]. Though the milkweed fibres are finer and having a higher modulus compared to cotton, the higher proportion of longer cotton fibres pushes the shorter milkweed fibres towards outside in C/M 80/20. In case of C/M 60/40 and 40/60 blended yarns, the opposite phenomenon happens. The finer and high modulus milkweed fibres have a tendency to migrate inwards, pushing the coarser and low modulus cotton fibres towards the surface. The strong effect of fibre fineness and modulus overcomes the differences in staple length due to local clustering of finer milkweed fibres.

Considering the effect of spinning system on migration index, it is observed from Table 1 that the ring-spun blended yarns have a stronger inward or outward migration of fibres followed by compact- and rotor-spun blended yarns. In conventional ring spinning system, fibre migration is very obvious due to the combination of tension and geometric mechanism of migration. In case of compact spinning, though the same trend is noticed in all the blend ratios, the extent of transfer is found lesser as compared to that in conventional ring spinning. The compact spinning virtually have a very minimum spinning triangle area before the fibres enter the front roller. The absence of

Table 1—Migration indices of milkweed fibres at different blend levels

| Yarn | Hamilton migration index, M% | | |
|---|---|---|---|
| | C/M 80/20 | C/M 60/40 | C/M 40/60 |
| Ring | + 14.465 | - 6.398 | - 10.256 |
| Compact | +8.544 | - 4.136 | - 7.194 |
| Rotor | + 5.209 | - 2.934 | - 5.930 |

(-) shows inward and (+) shows outward migration.

spinning triangle results in better migration of fibres and even fibre distribution in yarn cross-section[21]. In case of rotor spinning, the fibre migration index values are, lower which show that the fibre distribution in the cross-section is more homogeneous due to low spinning tension during yarn formation[22].

### 3.2 Influence of Milkweed Blend Proportion on Fibre Migration

Fibre migration can be defined as a variation in fibre position within the yarn. The various fibre migration profiles of C/M blended yarns are shown in Fig. 1. The measured fibre migration parameters of ring-, compact- and rotor-spun blended yarns are shown in Table 2.

#### *3.2.1 Influence of Milkweed Blend Proportion on Mean Fibre Position*

The mean fibre position represents the overall tendency of fibres to be located near the surface or near the centre of the yarn. It is clear from Table 2 that the rotor-spun blended yarns show the lowest mean fibre position followed by compact- and ring-spun yarns. The fibre tension during spinning has a significant influence on mean fibre position. Lesser the fibre tensions, smaller is the value of mean fibre position[22]. As the twist flow is from core to sheath in rotor yarn, the fibres falling on the tail integrate to the yarn structure and have less freedom to move out towards the sheath due to the differential radial twist structure of rotor yarns. This finding is in agreement with the findings of Das[23]. The compact-spun blended yarns exhibit considerably lower values of mean fibre position as compared to ring-spun yarns but higher than rotor-spun yarns. This can be explained by 'tension variation as a mechanism of migration' and also due to reduction of spinning triangle in compact spinning[24,25].

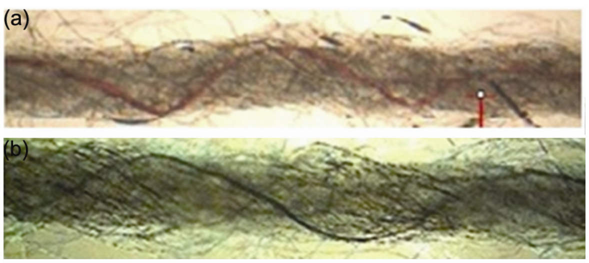


Fig. 1—Fibre migration profiles of C/M blended yarns (a) milkweed fibre and (b) cotton fibre

The introduction of milkweed component increases the average mean fibre position of blended yarns. Though the milkweed fibres are having a higher modulus and finer than cotton, longer length of cotton fibres pushes the milkweed fibres towards the outside in C/M 80/20.With further increase in milkweed proportion, the higher initial modulus of milkweed fibres pushes the cotton fibres outside gradually in the C/M 60/40 and 40/60 blends. A similar trend is also noticed in the ring-, compact- and rotor-spun blended yarns.

Table 2 — Migration parameters of C/M blended ring yarns

| Yarn type | Ring yarn | | | Compact yarn | | | Rotor yarn | | |
|---|---|---|---|---|---|---|---|---|---|
| | MFP | RMSD | MMI | MFP | RMSD | MMI | MFP | RMSD | MMI |
| **100% Cotton** | | | | | | | | | |
| Average | 0.462 | 0.268 | 8.571 | 0.434 | 0.310 | 11.053 | 0.407 | 0.232 | 6.834 |
| CV% | 10.84 | 8.26 | 12.23 | 11.42 | 9.71 | 14.38 | 10.14 | 9.36 | 11.35 |
| **C/M 80/20** | | | | | | | | | |
| Cotton | 0.449 | 0.265 | 8.566 | 0.447 | 0.302 | 10.977 | 0.402 | 0.227 | 6.818 |
| Milkweed | 0.492 | 0.286 | 7.724 | 0.476 | 0.322 | 9.837 | 0.444 | 0.242 | 6.286 |
| Average | 0.458 | 0.269 | 8.398 | 0.453 | 0.306 | 10.749 | 0.410 | 0.230 | 6.712 |
| CV% | 11.79 | 8.84 | 11.82 | 12.07 | 9.23 | 14.98 | 11.38 | 8.99 | 11.21 |
| **C/M 60/40** | | | | | | | | | |
| Cotton | 0.471 | 0.273 | 8.264 | 0.459 | 0.305 | 10.498 | 0.432 | 0.234 | 6.533 |
| Milkweed | 0.473 | 0.279 | 7.919 | 0.462 | 0.309 | 10.264 | 0.430 | 0.239 | 6.380 |
| Average | 0.472 | 0.275 | 8.126 | 0.461 | 0.307 | 10.404 | 0.432 | 0.236 | 6.472 |
| CV% | 12.83 | 9.38 | 14.38 | 14.72 | 10.25 | 16.35 | 14.37 | 10.89 | 15.37 |
| **C/M 40/60** | | | | | | | | | |
| Cotton | 0.482 | 0.279 | 7.417 | 0.463 | 0.313 | 9.678 | 0.442 | 0.244 | 5.720 |
| Milkweed | 0.434 | 0.278 | 8.223 | 0.452 | 0.308 | 10.632 | 0.434 | 0.238 | 6.697 |
| Average | 0.453 | 0.278 | 7.901 | 0.457 | 0.310 | 10.250 | 0.437 | 0.240 | 6.306 |
| CV% | 14.47 | 8.29 | 15.38 | 14.12 | 9.83 | 14.96 | 12.30 | 9.74 | 11.38 |

MFP – Mean fibre position, RMSD -Root mean square deviation, MMI – Mean migration intensity.

#### *3.2.2 Influence of Milkweed Blend Proportion on Root Mean Square Deviation (RMSD)*

The root mean square deviation (RMSD) indicates the migration amplitude and in turn, dispersion of fibre helical path across the yarn body. The high dispersion of the helical path assists the fibre to be interconnected by many numbers of fibres across the yarn cross section and stitches the helical assemblage of the fibres into a single unit. It is clear from Table 2 that the rotor yarns show lower value of RMSD followed by ring- and compact-spun blended yarns. The lower value of RMSD of rotor-spun yarns is due to the constraint imposed by the differential twist insertion. This shows that the fibre in the rotor yarn structure tends to be positioned in the yarn core throughout its yarn length.The RMSD values of compact-spun yarns are higher than those of ring- and rotor-spun blended yarns. The higher value of compact spun yarns shows better dispersion of the fibre helixes along the yarn radius, indicating a better migration[25].

From Table 2, it is clear that the average value of RMSD increases with the increase in milkweed content for C/M 80/20 and 60/40 in ring-, compact- and rotor-spun blended yarns. The higher modulus and finer milkweed fibres generate higher tension compared to the low modulus and coarser cotton fibres. This would lead to more variation in their radial position and hence show higher RMSD values with the increase in milkweed content. Though the milkweed components have higher RMSD values, the shorter length of fibres is not able to stitch more number of fibre bundles across the yarn cross-section, leadnig to less coherent and less dense packing of fibres in the yarn. In such a yarn structure, fibre slippage will be expected as the dominant failure mode[26].

#### *3.2.3 Influence of Milkweed Blend Proportion on Mean Migration Intensity*

Mean migration intensity (MMI) indicates the rate of change in fibre radial position along the yarn axis. It is observed from Table 2 that the MMI is higher for compact-spun blended yarns followed by ring and rotor blended yarns. In ring spinning, when the fibres come out of the front roller nip, the edge fibres are under tension and those at the centre are under low tension. According to the minimum potential energy of deformation law, the fibres under stress change their position with fibres under buckling strain. The same mechanism is present in the compact spinning system, but the whole thing happens in a very short length due to the absence of spinning triangle. The preferential incidence of lower radial path traversed by the fibre helices along with the buckled fibres in the yarn core increases the mean migration intensity of the compact-spun yarns as compared to conventional ring-spun yarns. In rotor spinning system, due to the lower spinning tension during yarn formation, it leads to lower mean migration intensity compared to ring- and compact-spun yarns.

From Table 2 it is observed that the average value of MMI decreases with the increase in milkweed blend proportion, which is lower than that of 100% cotton fibres in all the cases. Further, the MMI of cotton fibre decreases and milkweed fibre increases with the increase in milkweed blend proportion. At C/M 80/20 and 60/40 blends, the cotton fibre MFP is lower than that of milkweed fibres, indicating that the cotton fibres are in the core and milkweed fibres in sheath. But in the case of C/M 40/60 blends, the average value of MMI is higher due to reversal of positioning of milkweed fibres in the core and cotton fibres in the sheath. Further, the MMI of cotton fibre is found lower as compared to milkweed fibres in that blend. The presence of finer milkweed fibres in the core leads to higher buckling of finer milkweed fibres as compared to cotton, thus favoring higher MMI value.

### 3.3 Influence of Milkweed Blend Proportion on Yarn Packing Density

The evaluation of yarn packing density provides insight about the radial distribution of fibres in yarn structure for various milkweed blend proportions. The typical views of yarn cross-section of the different milkweed blend proportions in ring-, compact- and rotor-spun blended yarns are shown in Fig.2. As can be seen, compact-spun blended yarns possess more compact yarn structure and fibres are not scattered as much as in conventional ring- and rotor-spun yarns, leading to more circular cross-sections. The radial packing density results of ring-, compact- and rotor-spun blended yarns from core to surface of the yarn are shown in Fig.3.

Figure 3 reveals that a definite distribution pattern is being followed. To visualize the distribution of fibre compactness of different blended yarns, fitting of the parabolic function is done to the experimental data. The packing density is low around the yarn axis and rises continuously to reach its maximum, which is located around one third or one fourth from the yarn axis. Beyond this peak value, the packing density

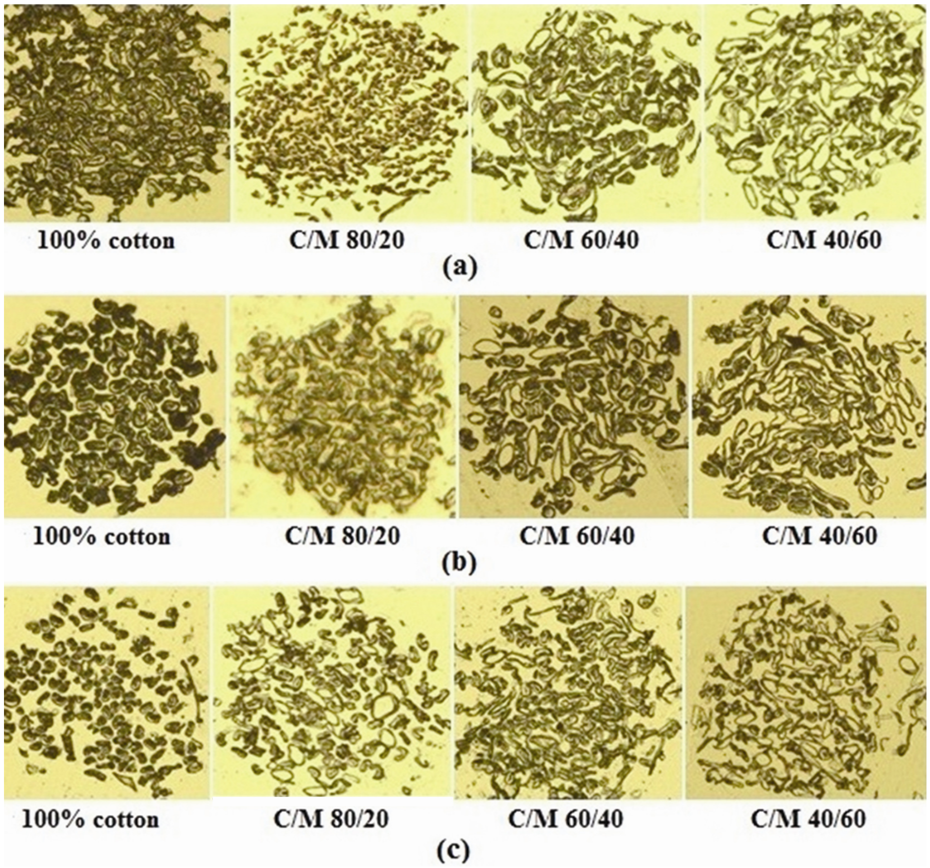


Fig. 2 —Yarn cross-sectional images of (a) ring, (b) compact, and (c) rotor yarns with various blend proportions

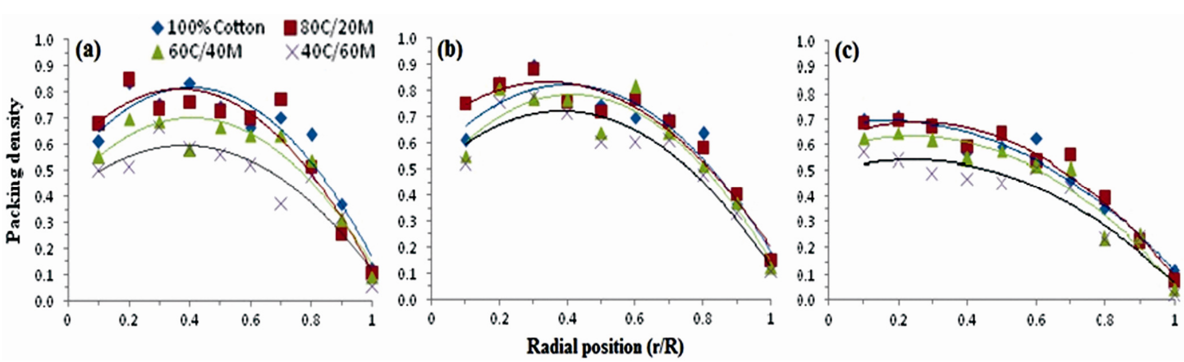


Fig.3 — Radial packing density curves of (a) ring, (b) compact, and (c) rotor yarns with various blend proportions

decreases towards the yarn surface in ring-, compact- as well as in rotor-spun blended yarns, where the fibre alignment is very poor. The compact-spun blended yarn possesses better packing density followed by ring- and rotor-spun yarns. This is mainly due to the reduced width of the fibre strand emerging from the front roller nip in the compact spinning process. Also the higher migration factor of compact yarns could have resulted in effective stitching of all the fibres in the yarn, leading to a better self-locked structure with higher packing density. As milkweed proportion increases, the packing density decreases due to the gradual decrease in migration factor. The outer fibres are unable to stitch the inner ones effectively, resulting in a lower packing density associated with an increase in yarn diameter.

## 4 Conclusion

**4.1** In general, structural differences in staple yarns lead to different yarn properties. The fibre migration in terms of migration factor has a positive correlation with yarn properties.

**4.2** The cotton fibre migration decreases and milkweed fibre migration increases with milkweed blend proportion. The lower migration of cotton with the increase in milkweed proportion leads to less stitching of fibre bundles which results in the lower tenacity of yarns.

**4.3** The packing density analysis shows that it is higher for compact yarns followed by ring and rotor yarns. Further, the packing density decreases with the increase in milkweed proportion due to the lower fibre migration and increase in yarn diameter. The longer and stronger cotton fibre shows inward migration for C/M 80/20 and 60/40 blended yarns. The finer milkweed fibres due to clustering of fibres show inward migration for C/M 40/60.

**4.4** From the yarn structural studies, it is observed that both fibre migration and packing density of yarn has a strong influence on yarn properties of C/M blended yarns.

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