Indian Journal of Fibre & Textile Research
Vol. 33, June 2008, pp. 203-212

# Influence of material and process parameters on the inter- fibre cohesion in ring-spun yarns

N Gokarneshan[a]
Department of Textile Technology, Kumaraguru College of Technology, Coimbatore 641 004, India
V Subramaniam
Department of Textile Technology, Jaya Engineering College, Tiruninravur 602 024, India
and
N Anbumani
Department of Textile Technology, PSG College of Technology, Coimbatore 641 004, India

*Received 2 August 2007; revised received and accepted 4 February 2008*

The inter-fibre cohesion phenomenon is an important aspect to be considered, as it directly affects the yarn strength/tenacity and indirectly affects the productivity in ring spinning. Also, inter-fibre cohesive forces influence the individual fibre mobility in yarn structure and the yarn mobility in fabric structure. This paper critically reviews the past and recent research works on the inter-fibre cohesion and provides scope for further research in this area.

**Keywords :** Cotton, Fibre, Inter-fibre cohesion, Ring-spun yarn, Yarn, Yarn twist

**IPC Code:** Int. Cl.[8] D02G3/00

## 1 Introduction

The inter-fibre cohesion phenomenon is an important aspect to be considered, since it is directly related to the twist and indirectly affects the productivity in ring spinning. It is measured in terms of the minimum twist of cohesion (MTC), which is the minimum number of untwisting turns required to break a yarn (single yarn). Earlier research work was concerned with cotton slivers, rovings, and yarns.[1] The possible utility of the concept of the MTC in spinning prompted further studies. Recently, more elaborate studies have been made in cotton, synthetic, and blended yarns. The influence of various raw material and process variables on the inter-fibre cohesion in yarns has been investigated. Various chemical treatments, which considerably affect the cohesion behaviour in yarns, have also been given to the yarns. Though this area of work has remained limited for long, recent studies have provided vast scope for further research in this area. The present paper critically reviews the past and recent research work on the inter-fibre cohesion.

[a]To whom all the correspondence should be addressed.
E-mail: advaitcbe@rediffmail.com

## 2 Studies on Worsted Yarns

Some critical factors, such as pre-tension, yarn sample length, and some chemical treatment, that influence the cohesion in worsted yarns have been investigated.[2] In the pre-tension zone ranging between 1.5 g/tex and 3 g/tex, the coefficient of minimum twist of cohesion is found to be practically independent of the applied tension and remained almost constant. However, change has been observed beyond 3g/tex. This could be attributed to the fact that the pre-tension value comes closer to the fibre tenacity, which suggests that the fibre breakage could possibly take place during testing.

The cohesion has been found to vary almost linearly with specimen length. It has been found to be more closely related to fibre fineness than to fibre length. Since fibre surface properties have been found to influence the fibre cohesion, chemical treatments that modify fibre surface have been studied. Treatments include alkaline, acid, carbonizing, chlorination, oxidation, reduction, oiling, sizing and dyeing. Within each of these groups there are the treatments for which the increase or decrease in residual twist is related to the intensity of treatment and other treatments where the influence is neither dependent nor proportional to the intensity with which they have been applied to the fibre. The treatments, such as oiling, chlorination and oxidation, are found to increase the coefficient of residual twist. Treatments, such as alkaline, cyton and sizing, are found to decrease the coefficient of residual twist. All these treatments modify the frictional coefficient of wool fibres and hence considerably affect the cohesion behaviour of the yarns.[3] While treatments, such as oiling, chlorination, and hydrogen peroxide treatment, increase fibre slippage and hence reduce the cohesion, other treatments such as Lyofix, alkaline, and reducing agent increase the fibre friction, thereby improving fibre cohesion in the yarns.

## 3 Fibre Cohesion in Cotton Rovings and Yarns

The technique of measuring the inter- fibre cohesion in terms of the 'minimum twist of cohesion' had been developed.[4,5] This parameter could practically be related to the twist inserted in rovings at the roving frame and it decides the upper limit of twist insertion during the stage. The relationships between MTC and some concepts and fundamental theories concerning roving and yarn structures have been sought and an excellent correlation between these has been found.[6,7]

### 3.1 Influence of Testing Conditions and Fibre Characteristics

The influence of testing conditions and fibre characteristics on fibre cohesion has been investigated.[8] As regards the test conditions, the specimen length and tension have been considered. The coefficient of MTC varies little for the tensions ranging from 1.5g/tex to 2.5g/tex, while variation is more above 4g/tex tension. Specimen length has little effect in the range of 25-50 cm. However, the MTC coefficient increases with higher length. The significance of variation has been found to be more for length than for tension. Cotton rovings have been investigated for the influence of staple length, micronaire, twist and count. The studies show that the minimum twist of cohesion, expressed in turns per meter, is inversely proportional to the square root of the number of fibres in the cross-section of the roving. The MTC decreases with the increase in micronaire index. The increase in staple length is found to reduce the coefficient of residual twist. The fibre length appears to have a less important influence than the micronaire index on the coefficient of minimum twist of cohesion. It could be summarized that the MTC, for a given roving weight, increases as the micronaire index increases and decreases as the fibre length increases. Also the MTC, in terms of tpm, is a complex function of the number of fibres in cross-section.

### 3.2 Influence of Twist

The role of original yarn twist on the cohesion phenomenon, particularly its influence on the coefficient of MTC, has been investigated.[9] This provides a practical measure of cohesion. The twist given to yarns ranges from the weakest to that approaching the maximum strength. The results reveal that there is a positive and highly significant correlation between the original yarn twist and the eliminated twist in the cohesion test, as well as between their respective coefficients. The MTC does not depend on the original and removed twists, as well as their respective coefficients. As the yarn becomes finer and twist increases, there seems to be an inter-dependence between original and residual twists. However, the trend is so slight that the hypothesis of independence can be considered valid. Also, the coefficient of MTC is practically independent of yarn number. These findings relating to the independence of coefficient of twist, with respect to count and original twist of yarns, can only be considered as approximately valid if Koechlin's coefficient[9,10] is applied. Significant trends have been reported at 5% confidence level for the twist levels and 1% level for count. The significance of count is greater than that of the twist and hence the hypothesis of independence can only be applied to yarns of a similar count.

Estimation of the cohesive interactions between individual cotton fibres in a yarn structure prompted the formulation of a suitable parameter. In attempting to establish a parameter for such forces, the influence of yarn twist on the yarn breaking force has been considered. The rupture of a spun yarn is a rather complex phenomenon involving the breaking of individual fibres as well as the mobility of the fibres within the structure, which affect the ability of the fibres to assume optimum stress supporting positions. A decrease in yarn twist opens the yarn structure and results in a gradual decrease in yarn strength with increasing twist removal. It is assumed that when the yarn has been untwisted up to a certain point, the strength of the yarn is mainly dependent on the cohesive interactions between fibres. At this point, the yarn breakage process involves only fibre slippage and not fibre breakage. This possibly occurs at a point where all the twist has been removed from the yarn. On untwisting the yarn further, a reverse twist is imposed on the yarn and the yarn strength increases again. The breaking twist/untwisting relationship apparently goes through a minimum, and it is this minimum force which is taken as the new parameter to characterize cohesive interactions within a yarn.

### 3.3 Effect of Fibre Parameters on Cohesion of Non Twisted Slivers

Studies have been carried out on American upland cottons based on their lengths and fineness maturity complex such that the influence of both parameters on MTC could be considered.[11] Other types of cotton have been included subsequently. The impact of the extent of parallelisation of fibres on the cohesion of slivers has also been studied. The findings have been compared with derived mathematical/empirical relationships[12-14], and they practically imply an agreement with the results of the influence of length, micronaire index, and the sliver hank on the twist. Furthermore, comprehensive studies of the arrangement of the fibres in the sliver[15-20] enable interpretation of the influence of degree of parallelism of fibres on the cohesion of slivers.

The MTC has been found to directly depend on the micronaire index and the hank of the sliver, and inversely dependent on the length, which has been found to confirm previous studies. The arrangement of the fibres in the slivers, their apparent length, and the existence of a greater or smaller percentage of fibres with hooks seem to be of major importance. An index for the degree of parallelism of fibres has been established by dividing the apparent length of the fibre in the sliver by the actual length. This degree of parallelism is found to reach a value of 0.85 for the third passage of the draw frame. However, the degree of parallelism in a sliver coming from a flyer may be slightly greater. Another important aspect is the existence of hooks in fibres.[19] Unhooked fibres are found to be about 70% in the sliver from the third passage of draw frame. In the flyer, the extent of straightened fibres is found to be in the range 74-82%. Other studies[21] have also shown that the number of straight fibres present in the sliver increases essentially with the draft used without any influence of settings, draft distribution, number of doublings, or sliver hank. The structure of the sliver is determined by the extent of parallel arrangement of the fibres and their straightness, which, in turn, influence the MTC. The more straightened and parallel the fibres, the greater is the cohesion among them, and the lower is the value of MTC. The MTC could thus be used as an indirect measurement of the degree of parallelism of the fibres.

### 3.4 Influence of Cohesion of Twisted Rovings on Yarn Properties

The effect of roving twist on the yarn properties, particularly those affecting yarn quality as well as its commercial value, has been investigated[22] so as to find whether the development of MTC in the rovings improves yarn properties. An overall assessment of yarn properties has been considered rather than individual yarn properties. Accordingly, following two indices[23,24] have been used to carry out the estimate:

$$\text{Yarn quality factor} = \frac{\begin{matrix}\text{Count lea} \\ \text{strength (kg)}\end{matrix} \times \begin{matrix}\text{single yarn} \\ \text{tenacity (g/tex)}\end{matrix}}{\text{Irregularity (U\%)}}$$

$$\text{Quality index} = \frac{R \times a \times N_m}{\left(1+\frac{CV_R}{100}\right)\left(1+\frac{CV_A}{100}\right)}$$

where $R$ is the breaking strength (kg); $a$, the elongation-at-break; $N_m$, the metric count; $CV_R$, the coefficient of variation of breaking strength; and $CV_A$, the coefficient of variation of elongation-at-break.

The yarn quality factor covers the mass irregularity and is a function of this parameter and of yarn strength as well, the latter appearing twice in the numerator, so that it is an index evaluating strength above the other factors. The quality index mentioned above does away, to a certain extent, with the mass irregularity and takes into account only the strength and elongation, corrected by their respective coefficients of variation.

The lea strength or single yarn strength has been found to show an increasing trend with the twist of the roving fed. In general, it could be postulated that under normal conditions, yarn tenacity increases with the increase in roving twist and decreases with increase in roving weight. The dependence of roving properties (count and twist) on yarn strength has led to contradictory conclusions. Other investigators found a slight loss in yarn strength with increasing roving twist, which was in accordance with the studies reported by some earlier researches where twist is not related to yarn strength but to end breakages at the spinning frame. The roving twist is the most important factor for fibre control during drafting, which can explain the fact that the higher the roving twist the greater is the yarn strength. Other investigations have shown that the yarn tenacity increases as roving twist goes up.

The MTC for twisted slivers is less than that normally employed in practical spinning. In principle, it does not seem to be advantageous to utilize MTC at the roving frame in connection with the characteristics of the yarns spun under conditions that do not seem to be the optimum for yarn strength and its quality index. Despite this fact, the utility of MTC as the ancillary technique in the studies of the measurement of both roving tenacity and cohesion is maintained. It is of greatest interest in determining yarn cohesion as well as in all studies of the cohesion of cottons after chemical treatments in any of the stages of industrial manufacture, or modifying yarn properties.

### 3.5 Effect of Durable Press Treatments of Cotton

The influence of conventional pad–dry-cure durable press (DP) treatments on the properties of cotton twill fabric as well as on the corresponding yarns and single fibres has been studied.[25] It has been assumed that the cross-linking between cellulose chains occurs during the treatment. The extent of cross-linking depends on the level of resin add-on, resulting from the treatment. Severe losses in strength and abrasion result from such treatments even though improving the wrinkle recovery angle of the fabric. Hence, efforts to reduce such losses in properties have become critical and have paved the way towards improved methods of durable press treatments of all cotton fabrics. The improved DP treatments attempt to introduce cross-links under the conditions different from those of conventional treatment. The effects of such improved treatments on the properties of cotton fibres, yarns and fabrics have been investigated and compared to the effects of conventional DP treatments.[26] Besides, the influence of such treatments on the inherent mechanical properties of the fibres, and their effect on fibre-fibre interactions involving the effect of fibre mobility on the yarn structure needs to be considered. This mobility is profoundly influenced by cohesive interactions between the fibres, which also plays a vital role in yarn mobility within the fabric structure.

Cross-links are formed inside the structure of cotton fibre during the curing stage of the conventional DP treatment. At this point, the cellulose structure is assumed to be in a collapsed state since most of the water and swelling agents have been removed. The extent of cross-linking occurred is difficult to estimate. The most noteworthy and significant effects of cross-linking are related to the viscoelastic behaviour of fibres during deformation in the post yield region.[26] The distribution of stress in the deformed structure changes at the yield point. This implies that the mobility of the chain segments increases drastically and is attributed to the breaking of some critical bonds. The introduction of cross-links decreases and eventually prevents this mode of stress distribution, thereby making the structure more rigid. This, in turn, leads to accumulation of stress, ultimately leading to premature failure. This rigidification of the structure leads to an increase in elastic component of the viscoelastic response to deformation. The increase in elasticity and rigidity of fibre results in increased resilience and decreased strength. These changes in fibre properties are, in turn, translated to yarns and fabrics, thereby contributing to the wrinkle recovery phenomenon, and also to the observed detrimental effects on abrasion resistance and other energy absorbing aspects of fabrics.

In the case of wet fixation treatment as against conventional DP treatment, the polymers are built in the fibre structure in the swollen state and then cross-linked with the polymeric material having swollen structure or with residual monomeric elements. The cellulose structure is prevented from collapsing during curing, and probably the cross- links are introduced into positions different from those in case of conventional treatment. One significant and noticeable difference is that the wrinkle recovery angles are at specific levels of wet fixation and show much higher value than those in the conventional DP treatments. The higher wrinkle recovery of fabrics by wet fixation treatment could possibly be attributed to properties other than the inherent mechanical properties of the fibres. The assumption that these properties are related to the fibre-fibre interactions, which, in turn, are influenced by surface modifications and changing the mobility of fibres within the yarn structure, appears to be more logical. Attempts have thus been directed to evolve a parameter that quantitatively describes cohesive interactions between fibres in a yarn structure.

The relationships between cohesive interactions and wrinkle recovery angles have been established (Table 1).[26] The cohesive interactions have been indicated in terms of minimum breaking force value, which affects the wrinkle recovery angle. Negative values of cohesion parameter indicate lower cohesion than the untreated sample, while positive values reflect higher cohesion.

Table 1 – Relationship between cohesion parameter and wrinkle recovery angle for treated cotton twill fabrics

| Type of treatment | Minimum Breaking force, g | Cohesion parameter g | Wrinkle recovery angle (W+F), deg | |
|---|---|---|---|---|
| | | | Dry | Wet |
| Untreated | | | | |
| No softener | 59 | 0 193 | 200 | |
| Polyethylene softener | 28 | -0.525 | 19 | 221 |
| Urethane latex softener | 112 | +0.899 | 229 | 246 |
| PF 183 | | | | |
| No softener | 62 | +0.051 | 215 | 234 |
| Urethane latex softener | 102 | +0.729 | 256 | 283 |

## 4 Studies on Ring and Compact Yarns

Extensive studies have been done on ring yarns recently.[27] The MTC between nose, middle and base regions of ring cop has been compared and it is observed that the MTC at base region of cop is least, indicating that the cohesion is maximum. This could possibly be attributed to the higher spinning tension due to the greater balloon height at the nose region, which results in better fibre migration and packing of the fibres in this region of the yarn. Better migration of the fibres results in greater interlocking of fibres in the yarn structure. This results in improved cohesion in the base region. On the other hand, the least cohesion is found to be in the nose region, which is due to the spinning tension in this region.

Carded, semi-combed and combed yarns have been compared. The combed yarn gives the best cohesion, followed by semi-combed and then carded. Combed yarn gives the best cohesion due to more removal of short fibres. Hence, the remaining longer fibres have better frictional contact and increases the cohesion. Semi-combed yarn gives better cohesion than carded yarn since 10% of short fibres is removed in the carded yarn.

In another interesting study, ring and compact yarns were compared for cohesion. The results have shown that the compact yarn exhibits better cohesion than ring yarns. This is because compact yarns have greater packing density of fibres as compared to the ring yarns and hence the number of contact points between fibres in case of compact yarns are more. Also, the hairiness or protruding fibres are less in case of compact yarns. This enables a greater proportion of the fibre length to contribute to cohesion.

The effect of spinning to various counts has been investigated.[28] The cohesion of fibres is found to increase with coarser counts for a given fibre type. This may be due to the fact that the increased number of fibres in the yarn cross-section enhances more number of contact points in the yarn structure, which leads to better cohesion. On the contrary, spinning to finer counts with the same fibre type gives lower cohesion.

The type of cotton mixing has also been found to influence the cohesion behaviour. Superior variety of cotton gives better cohesion for a given yarn count due to longer fibre length and lesser micronaire value. Longer fibres will have more contact points and this results in better length exploitation. On the other hand, finer fibres have more surface area, leading to better packing of the fibres in the yarn.

Another important aspect is the noil percentage extracted at comber. It has been found that between 8% and 11% noil extraction, there is no significant change in the MTC value. However, between 11% and 19% noil extraction, there is a marked increase in the cohesion and after that the cohesion value remains unchanged. The reason for better cohesion above 11% noil extraction is more removal of short fibres. Above 19% noil extraction level, there is no improvement in the fibre cohesion (Fig.1).[28] This may be due to the fact that the proportion of short fibres is less that it does not significantly affect the cohesion.

Alteration in drafting pressure at ring frame affects the cohesion behaviour. The cohesion improves up to drafting pressure of 2.1 kg/cm$^2$. Higher pressure in the drafting zone increases tension of the fibres emerging from the front roller nip. The fibres thus emerging from the front roller nip are twisted in taut condition, which results in better packing of fibres in the yarn, leading to better cohesion. Also, higher friction field is generated between fibres and fibre movement in drafting zone is more controlled. Hence, there is less drafting irregularity. There is no change in the cohesion beyond drafting pressure of 2.1 kg/cm$^2$.

Cohesion also improves with the increase in number of draw frame passages. The increase in the number of draw frame passages results in more removal of fibre hooks and also straightening of the hooks. This leads to better mean fibre extent in the yarn, which, in turn, results in better cohesion.

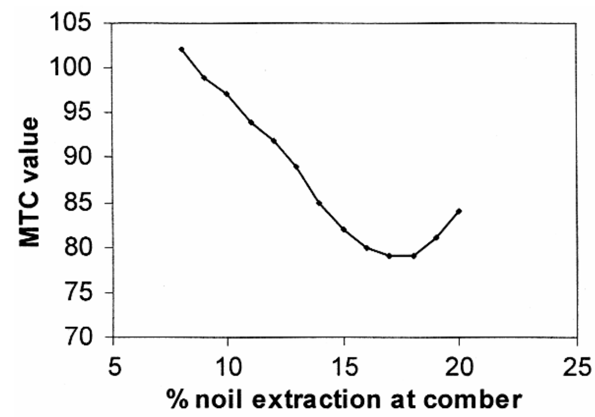


Fig. 1 — Effect of noil extraction on minimum twist of cohesion

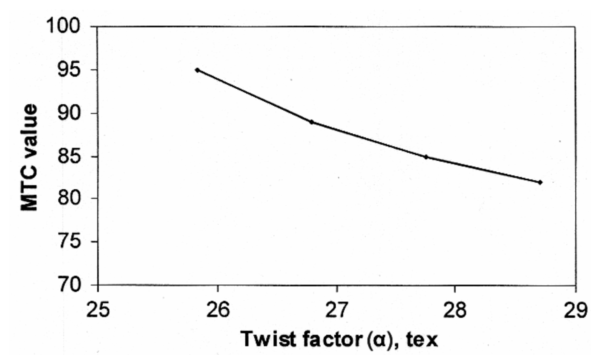


Fig. 2 — Influence of varying twist factor on minimum twist of cohesion of polyester yarn

## 5 Man-made and Blended Yarns

Investigations of MTC have been carried out for man-made and blended yarns.[29] Studies have been focused on spun polyester yarns, viscose yarns and their blends with varying blend proportion. The influence of varying twist multiplier (TM) on the MTC of polyester yarn shows that with the increase in level of TM, there has been drop in the MTC (Fig.2).[29] This could be ascribed to the better gripping of fibres at higher TM. The increase in twist tends to bring the fibres closer together and thus increases the packing density of the fibres in the yarn. The trend is found to be similar in the case of 100% viscose yarn. However, the lower value of MTC in the viscose yarn reflects better cohesion as compared to polyester yarn. This is because of the multi-lobal or serrated cross-section of the viscose fibre which generates higher frictional forces between the fibres and thus enhances the inter-fibre cohesion.

The influence of fibre denier and length on the MTC of 100% polyester spun yarn shows that both the parameters affect the inter-fibre cohesion significantly. Similar trend has also been observed in viscose yarns.

Trilobal and circular cross-sectional polyester fibres have been compared for the cohesion and it has been found that the fibres having trilobal cross-section have better cohesion as compared to those having circular cross-section. The influence of the type of blend on the MTC of yarn has been investigated. Polyester-viscose blend gives better cohesion as compared to polyester-cotton blend. Though polyester-cotton and polyester-viscose blended yarns show almost the same trend for different blend proportions, polyester-viscose yarn shows better results. This may be explained to the same reason ascribed previously.

The influence of type of the fibre on the MTC of yarn has shown that the MTC value is maximum in the case of cotton, which suggests that the yarns made from cotton fibres have the least cohesion. This may be due to the effect of average fibre length on cohesion. Cotton fibre having lesser average fibre length results in lower value of cohesion. The inter-fibre cohesion in the case of viscose fibre is the best, even better than that observed in the polyester fibre. This is due to the multi-lobal cross-section of the fibre, which increases the frictional resistance between the fibres in the yarn.

The influence of spin finish on the MTC of polyester yarn reveals that with the increase in the percentage of spin finish added to the fibres, the MTC value increases, indicating poorer cohesion. This may be due to the fact that spin finish oil tends to reduce the frictional resistance between the fibres, thereby reducing the inter-fibre cohesion.

## 6 Effect of Critical Ring Frame Parameters

In one of the recent studies[30], the important ring frame parameters that could possibly influence the inter-fibre cohesion in yarns have been considered. The factors considered here are twist multiplier, spindle speed and traveler size. The study on influence of these factors on the fibre cohesion shows that all these factors are found to influence the cohesion.

It has been observed that there is a clear cut minima for MTC at higher levels of spindle speed, traveler mass, and twist multiplier. In other words, the value of MTC diminishes and hence the fibre cohesion in the yarn improves with the increase in spindle speed, traveler mass, and twist multiplier. The results can be explained on the basis of the following reasons.

An increment in the spindle speed and traveler mass increases the yarn withdrawal force in the spinning region and results in high spinning tension. A higher value of spinning tension causes superior fibre migration in the spinning triangle, which, in turn, enhances a better interlocking of fibres in the yarn. In addition, an increase in spinning tension also leads to higher yarn packing density. These factors are accountable for better fibre cohesion in the yarn at higher spindle speed as well as traveler mass.

The increment of fibre cohesion in the yarn with the twist multiplier can be ascribed to the increase in transverse pressure. A higher value of yarn twist results in more lateral pressure to the fibres, thereby improving fibre cohesion. Also, an increase in yarn packing density with the twist is responsible for an enrichment of fibre cohesion.

Furthermore, from the regression coefficients corresponding to the different factors in the above regression, it is certain that the spindle speed has the highest influence on MTC followed by twist multiplier and the traveler mass. This could probably be due to the experimental set-up used in the investigation.

## 7 Studies on Siro yarns

Siro yarns, also known as double rove yarns, have recently developed an interest. The yarns produced by doubling two rovings have good strength and are equivalent to doubled yarns. Although extensive work has been carried out on the characteristics of double rove/siro yarns as a function of the strand spacing which have, in some cases, demonstrated that the maximum tenacity has occurred at 8 mm strand spacing, no satisfactory explanation on what decides or causes this increase in tenacities of double rove yarns is provided. The answer lies on the question of the dependence of the MTC on yarn tenacity. The dependence of the tenacities of spun yarns is well established by many research workers. In view of the excellent relationship between MTC and tenacity, it can be unequivocally stated that the MTC is capable of explaining the strength of the yarn. The study of yarn MTC has been directed to yarns spun by siro technique.[31] The influence of different strand spacings in the siro spinning method has been investigated. Cotton, and polyester-cotton & polyester-viscose blends were used in the study.

In the case of cotton siro yarns, the cohesion is found to be maximum at 2mm strand spacing, and the inter-fibre cohesion reduces with higher spacing. This is attributed to the fact that with higher strand spacings, particularly beyond 8 mm, the cohesion is reduced due to the lack of control of fibres in the apron zone.

The trend observed in the case of 50/50 polyester-cotton yarn is the same as in the previous case. However, the MTC values are higher as compared to 100% cotton yarn. This is due to the lesser contribution of the polyester component to the cohesion. In other words, the polyester fibres have a finer and uniform surface, and offer less frictional resistance and thus contribute less to cohesion. Here, inter-fibre cohesion decreases more drastically at strand spacing beyond 8 mm. The reason is the same as explained previously.

In the case of polyester yarn, the decrease in cohesion is less up to 8 mm spacing in comparison with the earlier cases. However, the fall in cohesion is more drastic beyond 8 mm spacing as in the earlier cases for the same reason as explained above. Since

100% polyester fibres are used in the yarn, the MTC values are higher than the earlier cases due to the lesser frictional resistance of the polyester fibres.

## 8 Relationship among Fibre Openness, Drafting Force and Cohesion

Recent studies[32] have shown the influence of some relatively unconventional and neglected but important parameters on spinning performance and quality of product. Openness of fibre, drafting force of sliver or roving and fibre friction are some of the unconventional parameters which affect the spinning performance and quality of sliver, roving and yarn significantly.[33,34] The influence of openness at blow-room and carding, drafting force of roving and fibre-fibre friction on properties of processed materials and yarn quality has been studied.[35] Openness of fibres has a direct influence on the quality of yarn. The effect of some material variables such as fibre-fibre friction, (which is directly related to fibre cohesion), roving hank and roving twist are known to influence the drafting force. It has been observed that the drafting force increases sharply with the increase in the fibre friction and roving twist multiplier as the mutual coherence among the fibres increases rapidly. A thorough analysis on the influence of fibre-to-fibre friction along with the carding parameters on the openness of fibre has revealed that the fibre-to-fibre friction has significant influence on the fibre openness also.

Despite the great importance of fibre openness, drafting force of roving or sliver and fibre-to-fibre friction during staple fibre spinning and yarn quality, no sincere effort has been made in understanding these parameters in totality. No information is available as to how these factors, in combination, affect the spinnability or quality of yarn.

At lower fibre-to-fibre friction (cohesion) the degree of opening is also low, which means that the fibre openness increases with the reduction in fibre friction. This could possibly be attributed to the fact that the fibre with lower coefficient of friction is having lower inter-fibre cohesion which results in easy separation between the fibres at the time of opening and cleaning. With the decrease in openness of fibre the drafting force increases. This may be due to the fact that the decrease in openness of fibre causes increase in contacts between the fibres and thus more cohesion among the fibres, which results in increase in roving drafting force. The drafting force increases when the roving hank is either coarser or finer. At constant roving twist multiplier, the increase in fibre friction causes increase in drafting force due to increase in inter-fibre cohesive force. With the increase in fibre friction the drafting force increases and the fibre openness decreases.

## 9 Relationship between Wax Content in Cotton and Cohesion

The effect of wax content in cotton on the yarn properties including fibre cohesion has been studied recently.[36] An important role of cotton wax in textile processing is as a lubricant. It reduces friction forces among fibres as well as between fibres and machine parts. As a result, processing problems such as static and fibre breakage are reduced.

Fibre friction per section is difficult to measure[37]. Fibre cohesion is the interaction between two or more fibres due to the combined effects of surface characteristics, length, crimp, finish, and linear density of fibres. Although wax removal increases the cohesion force almost three times, wax content shows a very low correlation coefficient of 0.01 with cohesion

The wax of cotton fibres is chemically complex, containing acids and alcohols of high molecular weight.[38] Nevertheless, wax appears to be very effective in assuring sufficient cohesion for web formation at the card and draw frame, while allowing fibres to slide over themselves during drafting processes. Lack of wax causes problems in textile processing, as evident when bleached cotton is used without adding a lubricant .[39]

## 10 Recent Studies on Mechanical and Chemical Treatments

Recent studies[40] are concerned with some treatments such as strain hardening, mercerization in slack and taut conditions, colloidal silica, acetylation, benzyolation, and enzymatic treatments. Also, studies have been carried out on the effect of mechanical and chemical treatments on the properties of cotton, viscose and polyester yarns[41-45]. Treatments such as heat annealing affects the sorptional and mechanical properties of viscose based nonwovens. Mercerization affects the frictional and mechanical properties of ring- and rotor-spun yarns. The add-on finish is found to affect the recovery properties of jet-spun polyester yarns.

Cotton yarns have been subjected to different levels of stretch ranging from 0.5% to 4% in the dry state.[40] Strain hardening of the yarn in the dry state improves the fibre cohesion. Considerable improvement has been observed up to 2% stretch level, beyond which there has been no significant improvement in the yarn cohesion. Stretching a twisted yarn up to a limit (2% in this case) tends to bind the fibres closer together, and thus improves the packing of fibres in the yarn. When the stretch exceeds this optimum limit, the fibres overcome the frictional resistance and begin to slip. At higher levels of stretch, the fibre slippage and breakage occur, which has a negative effect on the cohesion of the fibres in the yarn. On the other hand, yarns have been subjected to stretch conditions in the wet state ranging from 1% to 4%. The trend is found to be similar to the previous case. However, there was a slight improvement compared to the previous dry-state method. In this case, the contribution to cohesion is found to be less beyond 2% stretch, for the same reason as mentioned above.

Mercerization has shown a good effect on the cohesion of fibres in the yarn. It is well-known that the mercerization causes swelling and change in cross-section of the fibres. The cotton fibre, which has a bean-shaped cross-section, changes to a circular cross-section due to multi-directional swelling. The swollen fibre has a greater surface area of contact, which improves the cohesion. Beyond 16% concentration of caustic soda, no improvement in the cohesion is observed, as there is no further swelling beyond this level. The influence of the level of stretch during mercerization on the inter-fibre cohesion of the yarn is found to be significant only up to 3.5% stretch. There is no significant change in the cohesion beyond this. However, from a stretch level of 5% the cohesion decreases. This could suggest that the initial level of stretch would compact the fibres increasing cohesion, and the fibre slippage would begin later, thus contributing to the decrease in cohesion.

Addition of colloidal silica (cytan) improves the fibre cohesion.[40] The improvement can be seen only up to 1.4% cytan concentration. Beyond this level of concentration, the cohesion remains unchanged. Colloidal silica tends to modify the surface of the fibre, thereby increasing the frictional resistance of the fibres, and thus contributing to better inter-fibre cohesion. However, the concentration beyond 1.4% does not tend to change the surface characteristics further, and thus the cohesion is not affected beyond this level of concentration.

Investigations have shown that the enzymatic treatment reduces the cohesion, which can be ascribed to the fact that the enzyme has a smoothening effect on the fibre surface. The convolutions in the cotton fibre are removed and the fibre becomes cylindrical in shape. The smoother fibre surface reduces the frictional resistance between the fibres in the yarn, and thus it reduces the cohesion.

## 11 Conclusions

The influence of material and process parameters have a considerable effect on the inter-fibre cohesion in ring yarn. However, further research is suggested in the following areas:

- More detailed investigations on fibre cohesion need to be carried out in the case of compact yarns. This could be done by comparing the compact yarns spun by different systems such as mechanical and pneumatic at different twist levels.
- Since different chemical treatments have been found to influence the cohesion behaviour in yarns, as indicated by earlier and recent studies, the effect of newer types of textile finishes needs to be investigated.
- As processing is found to affect fibre cohesion in yarns, the effect of post spinning operations such as winding, warping, weaving and knitting needs to be investigated.

## References

1 Barella A, *J Text Inst,* 43(1952) 734.
2 Barella A, Miro P & Crespo R, *Text Res J* , 30(1960) 633.
3 Lipson M, *Nature*, 156 (1945) 268.
4 Barella A, *Texture* , 1(1953) 28.
5 Barella A, *Proceedings*, *Conferencia Internacional de la Tecnica Textil* ( Barcelona), 1954, 349.
6 Hannah M, *J Text Inst*, 41(1950) 57.
7 Barella A, *Bull Inst, Text France*, 89(1960) 79.
8 Barella A & Sust A, *Text Res J*, 32(1962) 217.
9 Barella A & Sust A, *Text Res J*, 33(1963) 75.
10 Wagner E, *Handbuch fur Textilingenieure and Textilpraktiker* (Wuppertal), 1953.
11 Barella A & Sust A, *Text Res J*, 34(1964) 283.
12 Corley J R, Simpson J, Fiori L A & Brown J J, *Text Res J*, 23(1953) 750.
13 Hannah M, *J Text Inst*, 41(1950) 57.

14 Merchant V B, *J Text Inst,* 54(1963) 58.
15 Bhaduri S N, *Text Res J*, 33(1963) 75.
16 Garde A R, Wakankar V A, & Bhaduri S N, *Text Res J*, 31(1961) 1026.
17 Morton W E & Summers R J, *J Text Inst*, 40(1949) 106.
18 Nutter W, *Text Res J*, 32(1962) 430.
19 Raes G, *Assoc Ind Portuense*, 6 (1961) 159.
20 Terjusnov A, *Textiln Pfomysl*, 2(1963) 34.
21 Ghosh G C & Bhaduri S N, *Text Res J*, 32(1962) 864.
22 Barella A & Sust A, *Text Res J*, 35(1965) 491.
23 Beevers R B, *J Colloid Sci*, 19(1964) 40.
24 Flory P J & Garrett R R, *J Am Chem Soc*, 80(1958) 4836.
25 Weighmann H D, Scott M G & Rebenfeld L, *Text Res J*, 39(1969) 460.
26 Weighmann H D & Scott M G, *Text Res J*, 41 (1971) 475.
27 Gokarneshan N, Anbumani N & Subramaniam V, *Indian J Fibre Text Res*, 30(2005) 340.
28 Gokarneshan N, Anindhya Ghosh, Anbumani N & Subramaniam V, *Fibres Polym*, 6(2005) 336.
29 Gokarneshan N, Anindhya Ghosh, Anbumani N & Subramaniam V, *Fibres Polym*, 7(2006) 70.
30 Gokarneshan N, Anindhya Ghosh, Anbumani N & Subramaniam V, *Indian J Fibre Text Res ,* 31(2006) 342.
31 Gokarneshan N, Anbumani N & Subramaniam V, *J Text Inst,* 98(2007) 289.
32 Ishtiaque S M & Das A, Spinning solutions – A critical approach, *Asian Text J*, 3(2004) 71.
33 Ishtiaque S M, Das A & Sharma Vikas, *Proceedings*, *43rd Technological Conference of ATIRA, BTRA, SITRA and NITRA* (IIT, Delhi), 2002.
34 Ishtiaque S M, Das A, Yadav P, Sharma Vikas & Kumar Rajesh, *Proceedings*, *44th Joint Technological Conference of ATIRA, BTRA, SITRA and NITRA* (SITRA, Coimbatore), 2001, 114.
35 Ishtiaque S M, Nishkam A & Tripathi V, *Proceedings*, *40th Joint Technological Conference of ATIRA, BTRA, SITRA and NITRA* (SITRA, Coimbatore), 1999, 25.
36 Xiaoliang Leon Cui, John Price B, Timothy C A, James Hemstreet M & William Meredith, *Text Res J*, 72(5) (2002) 399.
37 Clifford P H & Probert M E, *J Text Inst,* 15(1924) 401.
38 Xiaoliang Leon Cui, John Price.B, Timothy C A, James Hemstreet M & William Meredith, *Text Res J*, 72(7) (2002) 631.
39 Zurek W, *The structure of yarn* (Foreign Scientific Publications Department of the National Center for Scientific, Technical and Economic Information, Warsaw, Poland), 1975, 244.
40 Gokarneshan N, Anbumani N & Subramaniam V, *Autex Res J*, 7(2007) 48-52.
41 Tyagi G K, Ashvani Goyal, Gou D P & Mahajan DK, *Indian J Fibre Text Res*, 32(2007) 279.
42 Dhanuja S & Manpreet Manshahia, *Indian J Fibre Text Res*, 32(2007) 295.
43 Tyagi G K, Amarjit Singh & Goyal A, *Indian J Fibre Text Res*, 29(2004) 44.
44 Tyagi GK, Ashvani Goyal & Dhanda K, *Indian J Fibre Text Res*, 29(2004) 357.
45 Slavenka Lukic, Kovilika Asanovic & Aleksandra Milutinovic Nikolic, *Indian J Fibre Text Res*, 30(2005) 55.