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Manuscript received April 17, 1969.

Effect of Processing Factors and Fiber Properties on the Arrangement of Fibers in Blended Yarns

N. Balasubramanian

Bombay Textile Research Association, Bombay-Agra Road, Ghatkopar, Bombay-77, India

Abstract

A study was made of the influence of processing factors on the average disposition of fibers within a section and on the intimacy of mixing, when the blending constituents differ widely with respect of fiber dimensions.

A simplified measure was developed to characterize the preferential arrangement of fibers within a cross section, and the effects of spinning factors were evaluated. It was found that long and fine fibers have a definite tendency to occupy the core, while short and coarse fibers concentrate at the surface, and of the spinning factors, only strand width at the delivery nip has a significant effect on the arrangement. Further, no significant preferential segregation of the constituents was noticed across the width of the drafted strand, indicating that the biased arrangement develops during spinning. Spinning from multiple rovings showed promise of improving the preferential arrangement, but the average position of the constituent in the yarn section does not have any large effects on the strength or the extension of the yarn.

When blending is done prior to the card, intimate mixing of the components, close to ideal, is realized in the yarn even in blends composed of fibers that differ considerably in length and fineness. But with blending at the ring frame, the components are distributed almost independently of each other and, in such yarns, the variability in the blend proportion is of the same order as the variability in the total number of fibers. Evidence is presented to show that adjoining fibers tend to move together during drafting, and in order to minimize variation in the blend proportion longitudinally, adequate lateral intermingling of the components must be obtained.

Keywords

Degree of migration. Blending. Fiber count; fiber length; strands; slivers; roving; yarns; spindle speed; spinning tension; feed rate; twist; condensing; spinning; index of irregularity; index of blend irregularity; lateral mixing. Fiber migration; yarn strength; yarn strain. Ring frames; scutchers.

Introduction

It has been fairly well established [1, 2, 3] that in blended yarns composed of fibers differing in physical properties, a preferential arrangement of the fibers takes place and that, in general, short and coarse fibers tend to lie closer to the surface, while long and fine fibers lie at the core. However, the literature indicates very little work on the influence of spinning factors on the arrangement (of fibers) and its effect on yarn properties. The work by Townend and Dewhirst [4] was restricted to Bradford worsted drawing. Further, much of the earlier work dealing with the influence of processing variables on intimacy of mixing is confined to materials differing mainly in color, and mixing obtained on dimensionally different fibers has received only scanty attention.

This work, which was undertaken to fill this gap, covers broadly two aspects: arrangement of fibers within a section and intimacy of mixing. In the main, two blends have been considered, one differing in length and the other in fineness. A fairly simplified technique was adopted to characterize the degree of preferential distribution and using this measure, the influence of spinning factors such as spinning tension, geometry of the frame, drafting system, pressure between the aprons, and width of the drafted strand at the front nip have been investigated. The method of obtaining more biased distributions by spinning from rovings made of components was also considered and later extended to include the effect of fiber arrangement on yarn properties. The extent of mixing obtained with such blends has been examined in detail. The results have provided interesting information on the form of fiber movement during drafting and how it influences blend variability.

Experimental

Two blends were considered: in one the components differed in length and in the other, the components differed in denier. Viscose fibers were used to minimize the effect of variation in the properties under study. The fiber properties and blend composition were as follows:

Length-difference blend

1.25 in., 1.5 den, White Fibro 80%
1.75 in., 1.5 den, Black Fibro 20%

Denier-difference blend

1.5 in., 3 den, White Fibro 67% by weight
1.5 in., 1.5 den, Black Fibro 33% by weight

The fiber components were well opened by hand and spread uniformly on the lattice of the finisher scutcher in the required proportion and made into a lap after being opened by a Kirschner beater. A second passage was given through the scutcher before taking the material onto the card. Carding was on a flexible clothed card at a doffer speed of 6 rpm.

A study was made to determine whether preferential absorption of the fibers relating to fiber dimensions takes place in flat and cylinder wires. For this purpose, the average blend composition was estimated in the cylinder strips, flat strips, and card sliver. Pinches of fibers were chosen at random from the material and made into a hand sliver. From an aligned end of such a sliver, a thin tuft of fibers was removed, and the number of fibers of each type was counted under a low-power microscope. Such measurements were made on a number of tufts taken from two independently prepared slivers to give a total of 1000 fibers for each sample. The results are given in Table I.

TABLE I. Percent Blend Composition (By Number) in Card Sliver, Cylinder, and Flat Strips

Blend type		Card sliver	Cylinder strips	Flat strips
Length-difference blend	Percentage of 1¾ in. fibers	26.4	19.5	20.4
Denier-difference blend	Percentage of 1.5-den fibers	47.8	47.9	46.1

The results show that there is a preponderance of short fibers in the cylinder and flat strips, compared to card sliver, indicating that short fibers get preferentially absorbed in the wire surfaces. But no preferential selection of a similar type was noticed with respect to denier; this does not corroborate the findings of Mujumdar [5].

Card slivers were given three drawing passages and made into an intermediate roving on a two-zone, four-roller drafting frame. The spinnings were done on a spin tester fitted with an SKF top-arm drafting system. The roller settings at the draw frames and intermediate frames were set to suit the longer staple component.

Degree of Migration

A method similar to that of Townend and Dewhirst [4] was adopted for obtaining yarn cross sections and demarcating core and surface regions, but an improved measure was employed to describe the preferential migration. Lengths of yarn chosen at random from the sample were embedded in a 11% solution of Perspex in chloroform and, after the embedding medium had sufficiently dried, cross sections were taken on a hand microtome. The cross sections were examined under a microscope at a magnification of 200 × against a background of two concentric circles, the outer circle having been set to coincide with the yarn periphery. The inner circle defining the core of the yarn formed a quarter of the area under the outer circle. The camera lucida attachment was used to provide this background to the cross sections. The number of black and white fibers in the core and surface regions were counted for each section. Fifty cross sections were examined for each sample, and the mean proportion of black fibers in the core B_c and the surface regions B_s were obtained. If W_c and W_s denote the proportion of white fibers in the core and surface regions, respectively, then, obviously, $B_c = 1 - W_c$ and $B_s = 1 - W_s$. The difference $B_c - B_s$ itself gives an indication of the amount of preferential migration, but a better measure would be

$$M = \frac{B_c - B_s}{B_c W_s + B_s W_c}$$

M, defined as the degree of migration, will be zero when $B_c = B_s$, i.e., when black fibers occur with equal frequency at the core and the surface. *M* will have a value of +1, when either $B_c = 1$ or $B_s = 0$, indicating maximum inward migration of black fibers. Similarly, it will have a value of −1, when either $B_c = 0$ or $B_s = 1$, corresponding to the case of maximum outward migration. An index of this type has the advantage in that it is relatively less influenced by the blend proportion and the proportion of the cross section taken to represent the core in the work under consideration.

Standard Error

In order to appreciate the significane of the results, it is desirable to know the variability in the degree of migration within a sample. Accordingly, the standard error of *M* was estimated and was found to range from 0.03 to 0.05, so that a difference of 0.1 can be regarded as statistically significant.

The high variability in fiber disposition is generally attributed to the continuous migration of fibers from core to surface positions. A certain amount of variability is to be expected from statistical considerations alone, and it is useful to know whether the observed variability is much higher than the expected one. Accordingly, the variances of blend proportion in the different regions of the yarn were estimated and compared against the expected values. The expected variance is based on binomial distribution of the components. The results are presented in Table II from which it is seen that the observed

TABLE II. Variations in Blend Proportion in Different Regions of the Yarn

	Observed variance	Expected variance	Observed / expected
Core	0.01296	0.01004	1.29
Surface	0.00558	0.00537	1.04
Whole yarn section	0.00451	0.00353	1.28

variances are close to the expected values in the core and surface regions. Further, the blend proportion at the core does not bear any association with that at the surface, as will be seen from Figure 1.

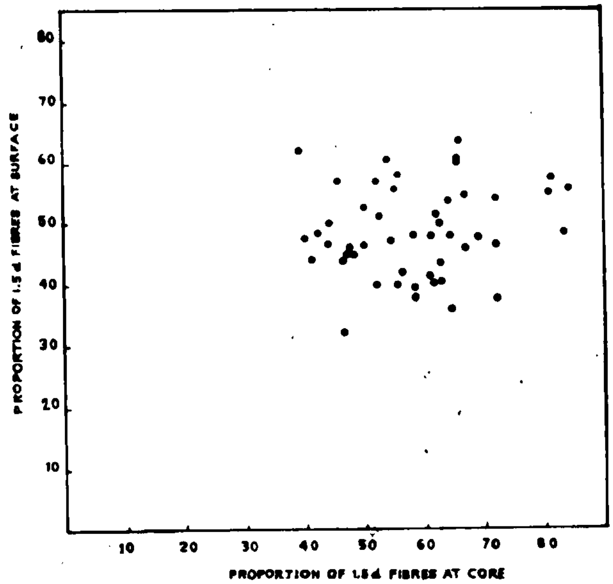

Fig. 1. Relation between blend composition at the core and that at the surface.

Effect of Processing Variables on Migration

Spindle Speed

Since the variations in tension in the component fibers is regarded as a primary factor causing migration, spinning tension may be expected to exercise some influence on the fiber arrangement. The spinning tension was varied by means of spindle speed and the effect on migration intensity was studied on both length-difference and denier-difference blends.

The results show that the long fibers in the length-difference blend and the fine fibers in the denier-difference blend exhibit a significant preference for the core region, a finding which conforms with the results of earlier workers. Varying the spindle speed, however, does not appear to influence the amount of preferential migration, although a slight tendency towards a more biased arrangement, which, however, is not statistically significant, is noticed at the higher speed with the length-difference blend.

Width of Drafted Strand at Front Nip

This effect was investigated by spinning identical counts from rovings of widely different hank members through suitable adjustment of draft at the ring frame. With a coarse roving the drafted strand will have an enhanced width at the delivery point. With length-difference blend, 50s Ne yarns were prepared from 1- and 3.3-hank intermediate rovings, while with the denier difference blend 30s Ne yarn were spun from 0.84- and 2-hank rovings. The results of migration intensity are presented in Table IV.

With the length-difference blend the preferential migration becomes more pronounced as the width of strand is increased, but with the denier-difference blend there is no significant effect associated with strand width. It is apparent that the differences in migration could not be due to differences in fiber arrangement in the input roving, when the results of blend 5 are compared with those of 1 and 2 (Table III). Although the latter blends have been obtained from the same back material as the former, they have a much lower value of migration intensity.

With a ribbon of larger width, the fibers are in a less compact form, with the result there is less hindrance to fiber migration, and the twisting triangle is also more obtuse. The results of this work should be taken to indicate that these factors significantly modify fiber arrangement when the components differ in length.

Single- and Double-End Feed

Comparisons of single- and double-end feed with regard to fiber arrangement were confined to the length-difference blend. Yarn of 50s Ne was spun from 3.3 Ne intermediate roving as a double roving,

TABLE III. Effect of Spindle Speed on Fiber Arrangement

Blend No.	Blend type	Count, Ne	Twist, turns/in.	Spindle speed, rpm	B_o-B_s	Degree of migration
1.	Length-difference	20s	15.5	3,500	0.0270	0.071
2.	Length-difference	20s	15.5	12,000	0.0542	0.146
3.	Denier-difference	30s	19.0	3,500	0.0982	0.195
4.	Denier-difference	30s	19.0	8,600	0.0965	0.192

TABLE IV. Effect of Width of Drafted Strand at Front Nip on Arrangement

Blend No.	Blend type	Count, Ne	Twist, turns/in.	Input roving hank, Ne	Ring frame draft	B_o-B_s	Degree of migration
5	Length-difference	50s	24.7	1	52	0.1208	0.315
6	Length-difference	50s	24.7	3.3	16.2	0.0435	0.118
7	Denier-difference	30s	19.0	0.82	37.5	0.0744	0.148
8	Denier-difference	30s	19.0	1.9	17.1	0.0894	0.178

TABLE V. Effect of Method of Feed and Frame Used of Fiber Arrangement

Blend No.	Blend type	Ring frame	Type of feed	Count, Ne	Twist, turns/in.	B_o-B_s	Degree of migration
6	Length-difference	Spin tester	Single	50s	24.7	0.0435	0.118
9	Length-difference	Spin tester	Double	50s	24.7	0.0430	0.132
10	Length-difference	Shirley Miniature (sliver to yarn)	—	50s	24.7	0.0396	0.115
11	Length-difference	OM (sliver to yarn)	—	36s	21.4	0.0402	0.118

and the degree of migration was compared with that obtained from single-end feed (blend No. 6). The results are shown in Table V.

Nearly the same amount of migration is noticed with the two feeds, which suggests that the reasons for preferential arrangement do not lie in the fiber disposition in the roving. It must be noted that in double-end spinning the two strands tend to stay as separate entities which twist around each other as in a doubled yarn, and the mechanism of twisting is not the same as that in spinnings where a roving double the width is fed at the back.

Type of Spinning Frame

In this work, the form of back material and the type of frame used for spinning were studied. Spinnings were made for this purpose on the Shirley miniature ring frame and OM spinning frame, using the third head drawing sliver as back material. Unfortunately, 50s could not be spun satisfactorily from this material on the OM frame at the required speed, and, hence, a coarser count (36s) was spun on this frame. The results are shown in Table V. The degree of migration appears to be hardly influenced by the frame used for spinning or by form (sliver or roving) of the back material. Although the frames differed considerably in the geometrical arrangement of the spinning zone and roller stand angle, no detectable difference was noticed in migration, indicating that these factors do not exercise a significant control on the migration.

Pressure Between Aprons

The effect of this factor was investigated for the denier-difference blend. For this purpose, 30s Ne yarns were spun with two widely different spacings between the aprons.

The results in Table VI indicate a slight increase in the intensity of migration as the space between the aprons is reduced, but the difference is not statistically significant. With close setting, the ribbon is flattened and the fibers are subjected to greater tension. These factors do not seem to have any pronounced effects on migration.

Fiber Arrangement in the Ribbon

The various blends studied so far indicate a consistent tendency on the part of long and fine fibers to occupy preferentially the core region. To find out whether this preference is due to any biased distribution across the face of the drafted ribbon, we examined the fiber arrangement in the drafted ribbon at the front roller nip. As the ribbon could not be collected without disturbance to arrangement during running, the frame was stopped and the ribbon was transfered onto a slide, and counts of black and white fibers in three equally divided zones of the drafted strand were made, using a low-power microscope. About 40 slides were examined from which the mean blend proportion in the center and outside regions was estimated. The tests were made on blends 5 and 7 where the drafted strand had an enhanced width; the results are given in Table VII.

The differences in the blend proportion in the different regions of the strand are within the limits of sampling variation and do not indicate any clear tendency on the part of the components to concentrate at the center or at the sides. This is at variance with the results of Townend and Dewhirst [4] who observed that long and fine fibers are in greater proportion in the central portion of the strand in Bradford Drawing. Thus, there is no segregation of the

TABLE VI. Effect of Opening Between Aprons on Fiber Arrangement

Blend No.	Blend type	Space between aprons	Count, Ne	Twist, turns/in.	B_o–B_w	Degree of migration
8	Denier-difference	Close	30s	19.0	0.0894	0.178
12	Denier-difference	Wide	30s	19.0	0.0639	0.127

TABLE VII. Blend Proportion in Different Regions of the Drafted Strand

Blend No.	Blend type	Count, Ne	Position in the drafted ribbon			Degree of lateral mixing
			Left	Center	Right	
5	Length-difference	50s	0.803	0.786	0.808	1.002
7	Denier-difference	50s	0.523	0.480	0.486	1.046

components in the strand, and the biased distribution evidently develops during spinning.

As a fiber is gripped and drafted by the front rollers, the portion extending behind into the drafting zone is under tension, as it has to overcome interfiber friction forces and is likely to get elastically extended to some extent. The extension is released the moment the portion passes beyond the front roller nip. With long and fine fibers, the restraining forces are likely to be greater in view of their larger surface area, and the extension is expected to be more. If this were to happen, long and fine fibers would be delivered at a slower rate, compared to short and coarse fibers and would, therefore, preferably go to the core.

Spinning From Multiple Rovings

The concentration of the long and fine fibers at the core regions in the foregoing blends, though significant and consistent, is not considered to be sufficiently large to result in substantial modification of the yarn properties. With fibers arranged almost at random in the drafted strand, there is evidently not much scope for fibers of one type to come together and migrate to the core, displacing in this process the remaining fibers to the surface. It was thought that if the spinnings were done from multiple rovings made from the components, the constituent fibers would be kept together, facilitating greater migration. In this connection, it is of interest to note that Boswell and Townend [6] have observed that, while spinning from triple roving of fibers of the same type, the central roving occupies a position closer to the core, while the ones at the sides show up more prominently at the surface. Morton [7] has also reported evidence which indicates that fibers in the left roving stay at the surface and contribute more to wild fibers.

Rovings of 3.8-Ne hank were prepared separately from 1.5-den and 3-den viscose fibers under identical conditions of processing. Spinning was made from triple rovings, made of two of 3-den and one of 1.5-den, to obtain a yarn of 20s Ne with a twist factor of 2.5. The rovings were kept separate and fed side by side, and two spinnings were made, one with 1.5-den component at the center and other with 1.5-den component at the left.

Examination of the yarn under the microscope showed a tendency on the part of the strand made of 1.5-den to migrate from time to time from the surface to core position. The migration is clearly apparent when 1.5-den component is dyed and the yarn viewed after immersion in an agent like methylsalycilate which has the effect of optically dissolving the white 3-den component. The migration was noticed with both methods of feed of the black component, i.e., at the center as well as at the left. In order to get more quantitative information on fiber arrangement, yarn cross sections were taken and the proportion of fibers of different types were estimated in the core and surface regions from which the degree of migration was evaluated. The results are presented in Table VIII.

A marked tendency on the part of the fine fibers to occupy the core is evident from the results of Table VIII. A comparison with the earlier results where the components have been more intimately mixed indicates that the biased distribution has been considerably increased when like fibers are kept together as in triple-roving spinning. The degree of migration is slightly higher when the fine fibers are fed at the center than at the left, but the difference is small and, moreover, not statistically significant.

A similar effect was also found when the components differing in length were made separately into rovings and spun as triple rovings from two shorter components and one longer component. The long-fiber strand was found to frequent the core from time to time, and this was noticed both when the strand is fed at the center and at the left.

Condensing the Rovings

The effect of various ring-frame parameters was investigated in an effort to improve the preferential arrangement, and it was ultimately found that when the three rovings were condensed together before they enter the main drafting zone, with the long-fiber component at the center, the latter exhibited a more marked tendency to stay at the core. Under these conditions, the place of feed was found to exercise considerable influence over arrangement, the centrally fed strand decidely showing a preference for the axial position.

The effect of condensation was investigated in greater detail for a cotton/viscose blend. Two rovings of 3.4 Ne from a combed CO_2[1] cotton (1⅛-in. staple) were blended with one of viscose (black, 1¾-in., 1.5-den) of identical hank to spin a yarn of

[1] A popular variety of Indian cotton.

20s Ne. The rovings were condensed together with the viscose strand at the center by means of a condenser of 2-mm width fitted in the break-draft zone close to the nip of the middle rollers. Clear differences in regard to shade were noticed upon condensation, the yarn obtained with the condensation having a distinctly whiter shade. To obtain a precise estimate of the effect on fiber disposition, the proportions of viscose fibers in the core and surface regions were estimated from which the degree of migration was calculated. The degree of migration increases almost four-fold upon application of condenser, confirming the visual assessment.

The pronounced migration of the viscose component to the core is the combined effect of the difference in physical properties of the fibers and the place of feed. To get more quantitative information as to their relative importance, another spinning was made where two rovings of viscose were combined with one of cotton. The rovings were condensed, but with the cotton roving at center, and yarn of 20s Ne was prepared under identical conditions. The yarn cross sections were analyzed, and the mean degree of migration was computed. The results (Table IX) show that the order of migration is now reversed, with the cotton component showing a preference for the core, but the degree of migration is much lower than that obtained when the long-fiber component (viscose) was maintained at the center.

Effect of Fiber Disposition on Physical Properties

It was noticed earlier that the average fiber position in the cross section could be controlled to some extent by condensation, and it was of interest to examine whether this brings about significant changes in yarn properties. This matter was first investigated with the cotton/viscose blend studied earlier. Different fiber arrangements were obtained by spinning with and without the application of a condenser. Spinnings were made at two twist factors, 3 and 4.5, and the yarns were tested for single-thread strength and elongation. The results of strength and elongation which are the mean of 100 tests from each sample are given in Table X.

The results suggest that variation of the fiber arrangement within the range indicated in Table IX does not have significant effect on either the strength or extension of the yarn.

The effect of fiber arrangement on yarn strength and extension was investigated for two more blends obtained by spinning from triple rovings composed of (1) one of 1.75-in., 1.5-den Fibro (black) and two of 1.25-in., 1.5-den Fibro and (2) one of 1.5-in., 1.5-den Terylene (black) two of 1.5-in., 1.5-den Fibro. The fiber arrangement was varied both by the use of a condenser and by altering the place of feed. The results (Table X) once again show negligible differences in strength and extension, although clear differences in regard to the shade were appar-

TABLE VIII. Effect of Place of Feed on Fiber Arrangement

Blend No.	Blend type	Place of feed of 1.5-den component	Count, Ne	Twist, turns/in.	B_o–B_s	Degree of migration
13	Denier-difference (spun from triple rovings, two of 3 den and one of 1.5 den	Center	20s	11.2	0.367	0.648
14		Left	20s	11.2	0.320	0.607

TABLE IX. Effect of Condensing the Rovings on Fiber Arrangement

Blend No.	Blend type		Count, Ne	Twist, turns/in.	$B_s - B_c$	Degree of migration
15	From triple roving, two of cotton and one of viscose (viscose at center)	With condenser	20s	13.5	0.194	0.428
16		Without condenser	20s	13.5	0.044	0.104
17	From triple roving, two of viscose and one of cotton (cotton at center)	With condenser	20s	13.5	−0.043	−0.091

TABLE X. Effect of Fiber Arrangement on Yarn Properties

Blend No.	Blend type	With or without condenser	Place of feed of black component	Count, Ne	Twist, turns/in.	Single-thread tenacity, tex	Single-thread extension, %
15	Spun from triple roving two of cotton (1⅛ in. staple) and one of Fibro (1⅜ in. black)	With	Center	20s	13.5	10.4	7.0
16		Without	Center	20s	13.5	10.7	7.0
18		With	Center	20s	20.1	12.4	7.5
19		Without	Center	20s	20.1	12.4	7.3
20	Spun from triple roving two of Fibro (1.25-in. 1.5-den) and one of Fibro (1.75-in., 1.5-den black)	With	Center	30s	13.7	8.8	5.6
21		Without	Center	30s	13.7	9.3	5.7
22		With	Left	30s	13.7	9.2	5.7
23		Without	Left	30s	13.7	8.9	5.6
24	Spun from triple roving two of Fibro (1.5-in., 1.5-den) and one of Terylene (1.5-in. 1.5-den, black)	With	Center	20s	11.2	13.3	8.2
25		Without	Center	20s	11.2	13.9	8.2
26		With	Center	20s	20.1	11.6	7.9
27		Without	Center	20s	20.1	11.3	7.9

ent. The results can be summarized to indicate that, within the range encountered in the present studies, the average position of the component in the yarn cross section does not have much influence on the tensile properties of the blend.

The influence of condensation on the geometrical arrangement can be explained from the manner in which the strands get twisted together in triple-roving spinning. Two extreme forms of twisting are found to occur: one in which all the three strands are folded together without a core and the other in which one of the strands forms a core around which the others get wrapped. Intermediate situations with one of the strands receiving a preferential cover are also encountered. When the rovings are kept apart, any of them is free to take the core position, and the place of feed does not have much influence on the fiber disposition. But when the strands are fed condensed, it will become clear that only the central strand will have scope for taking the core position, since those at the sides would have to penetrate between the remaining strands in order to reach the core. The central strand, therefore, receives a better cover because, under these conditions, the outer strands are effectively prevented from going to the core, which is feasible when the strands are kept apart.

To obtain further confirmation of this hypothesis, spinnings were made from triple rovings, of the same material but of different colors, arranged in the order of blue, white, and red, at the front nip. Two spinnings were made, in one instance, condensing the three strands together and in the other condensing the white and red alone while keeping the blue apart. The spun yarns were found to be distinctly different in shade, the red color showing more prominently on the surface, compared to white in the first spinning, while both white and red are noticed with equal intensity on the surface in the latter.

Intimacy of Mixing

Mixing at the Scutcher

Earlier studies on intimacy of mixing have been chiefly confined to blends composed of fibers of the same type but differing in color. In this study, blends have been prepared from components differing in physical properties, and it would be of interest to know whether adequate mixing is obtained under such conditions.

The intimacy of mixing was assessed by calculating the index of blend irregularity, a measure developed by Coplan and Klein [8] to test the measured variation in blend proportion against the theoretically expected value for ideal mixing. The values of the index for the various blends are given in Table XI from which it will be seen that, with blending at scutcher, the index is close to unity, and the departure from randomness is generally not significant.

There is no evidence of preferential clustering of fibers of one type and the blend behaves as though composed of a single constituent. On the other hand,

TABLE XI. Index of Irregularity and Index of Blend Irregularity for the Various Blends

Blend type	Blend No.[a]	II,[b] K_1	IBI,[c] K_2
Scutcher blends			
Length difference	1	1.79	1.11
Length difference	2	1.58	0.97
Length difference	5	1.52	1.17
Length difference	6	1.56	1.11
Length difference	9	1.42	1.25
Length difference	10	1.68	1.16
Length difference	11	1.62	1.24
Denier difference	3	1.56	1.09
Denier difference	4	1.39	1.21
Denier difference	7	1.11	0.96
Denier difference	8	1.54	0.84
Denier difference	12	1.42	1.19
Blending at ring frame (from triple roving)			
Length difference	15	1.39	1.68
Denier difference	13	1.24	1.42

[a] The blend numbers refer to the blends prepared in connection with the earlier studies on degree of migration and details of yarn particulars and spinning conditions may be obtained by referring to the earlier Tables against the corresponding blend numbers.
[b] II = Index of Irregularity.
[c] IBI = Index of Blend Irregularity.

the index of irregularity of the yarn which compares the variability of total number of fibers against the theoretically expected value, is generally much higher than unity indicating the presence of extra irregularities in the material. Thus, while the thickness variability is significantly higher than the ideal, the blend variability is close to it.

Further evidence of this feature is provided by a significant positive correlation observed between the number of fibers of one component with that of another in these blends. In Figure 2 the number of 1.5-den fibers is plotted against the corresponding number of 3-den fibers at any section for a denier-difference blend (No. 3). A close association is found between the two, with a highly significant correlation coefficient. A similar association is also observed between the number of short and long fibers in length-difference blends (Fig. 3). The correlation between the components is a characteristic feature of the blends made at the scutcher and is due to the fact that the factors which influence the variability of the blend as a whole exercise an equal influence on the constituents. These factors include uncontrolled movement of fibers in the drafting zone and mechanical faults. Although the short fibers are out of control of the rollers over a greater length in a length-difference blend, they do not seem to move independently of the long fibers and no preferential grouping of these fibers was observed.

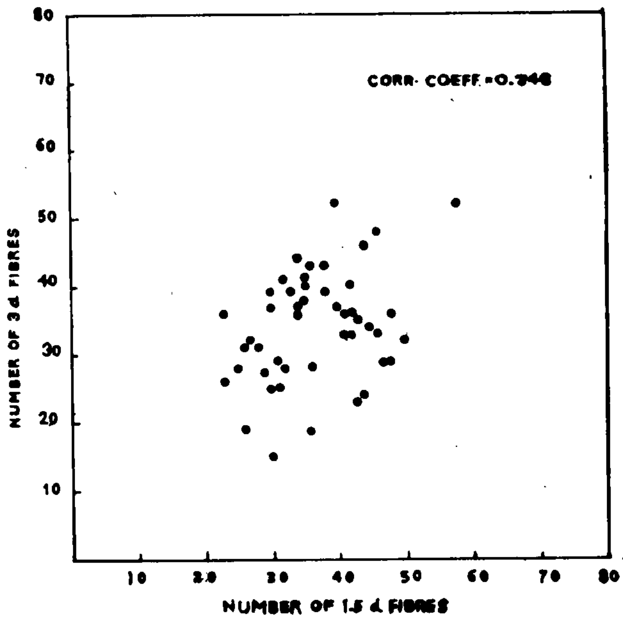

Fig. 2. Relation between number of 1.5-den and 3-den fibers, denier-difference blend (No. 3).

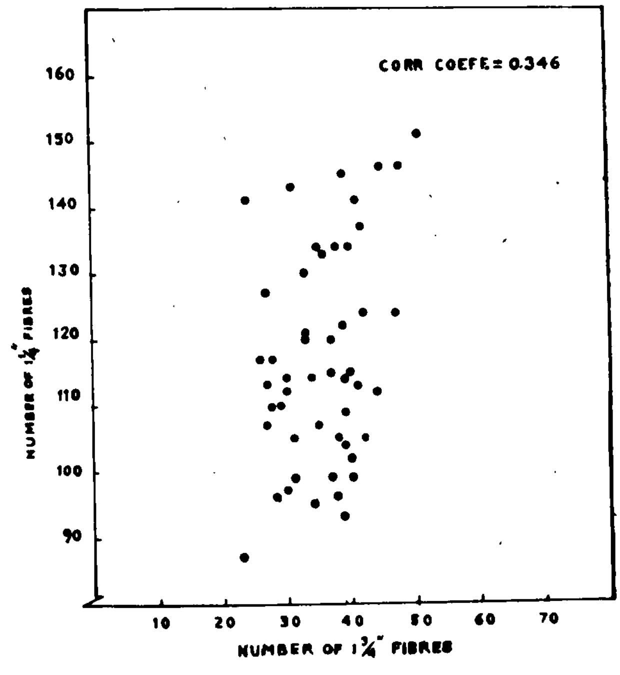

Fig. 3. Relation between the number of $1\frac{3}{4}$-in. fibers and $1\frac{1}{8}$-in. fibers, length-difference blend (No. 2).

The correlation between the total number of fibers in a section and the blend proportion in that section was also calculated to find out whether thicker regions contain more than their share of any of the components. The correlation was generally found to be nonsignificant and close to zero in both types of blends.

Lateral Mixing

De Barr and Walker [9] have shown that the number of groups composed of fibers of like type could be used to characterize the intimacy of lateral mixing in a blend. When the blends Nos. 5 and 7 were examined for blend composition at the different regions of the drafted strand, the number of groups of like fibers was also noted, and from this the degree of mixing was estimated. The results are included in the last column of Table VII. The degree of mixing is denoted by the ratio of the actual number of groups to the theoretically expected number and will have a value close to unity when the mixing is random. The results of Table VII indicate that the mixing is close to random in both length-difference and denier-difference blends. The figures for degree of mixing given in the table are the mean of measurements made on 40 sections for each sample. In Figure 4, the actual number of groups in a section is shown vs the expected value for that section [i.e., $np(1-p)$ where $n =$ total number of fibers and p the blend composition in the section] for the 40 sections on which measurements have been made. The association between the two quantities is observed to be close in both blends, reaffirming once again that the mixing is close to random and there is no preferential grouping of fibers of the like type.

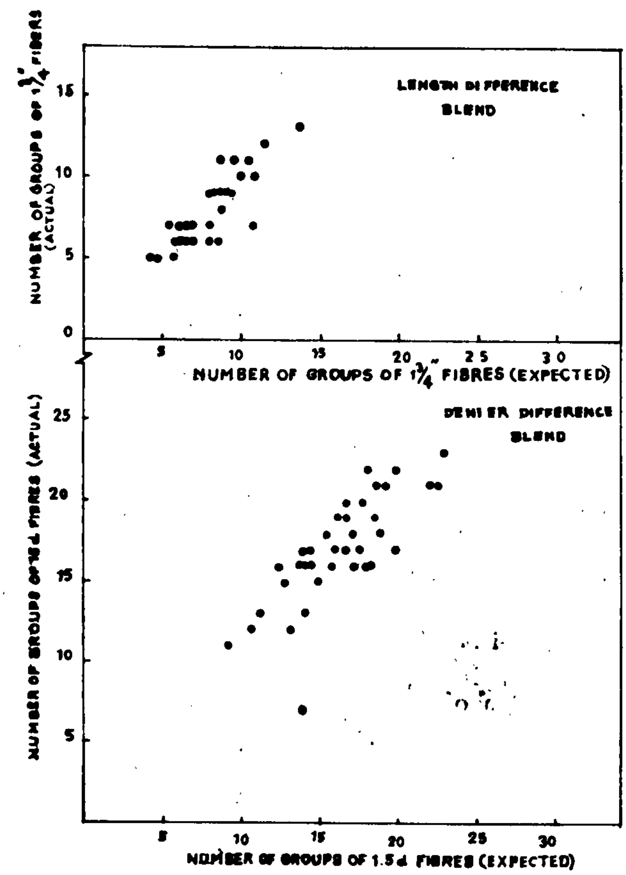

Fig. 4. Relation between actual and expected number of groups of constituent fibers in blends.

Blending at Ring Frame

On the other hand, when blending is done at the ring frame by doubling rovings made from the constituents, the component fibers are almost independently distributed, and the IBI is close to the II. In Figure 5, the number of 1.5-den fibers is shown vs the number of 3-den fibers for blend 13 and Figure 6 shows a similar plot between number of cotton (1⅛-in. staples) and viscose fibers (1⅛-in.). In both cases, the association is observed to be poor and the correlation is nonsignificant.

Correlation Between the Components

The indices of irregularity, blend irregularity, and the correlation between the components are interrelated quantities and the association between them can be easily deduced as follows.

Let

K_1 = index of irregularity
K_2 = index of blend irregularity
r = correlation coefficient between the number of white and black fibers
V_w^2 = variance of white component
V_B^2 = variance of black component
V_T^2 = variance of the blend as a whole

and

V_p^2 = variance of blend proportion

The number of white fibers at any section, w, is related to the total number of fibers at that section, T, by

$$w = pT,$$

where p = blend proportion of white fibers.
The variance of white fibers is then given by

$$V_w^2 \simeq p^2 V_T^2 + T^2 V_p^2 + 2pT \operatorname{Cov}[p,T]$$

$$\therefore V_B^2 \simeq (1-p)^2 V_T^2 + T^2 V^2_{1-p} + 2(1-p)T \operatorname{Cov}[(1-p),T]$$

$$V_w^2 + V_B^2 \simeq [p^2 + (1-p)^2] V^2_T + 2T^2 V_p^2 + 2T(2p-1) \operatorname{Cov}[p, T] \quad (1)$$

as

$$\mathrm{Cov}\,[p, T] = -\,\mathrm{Cov}\,[(1-p), T]$$
$$V^2_T = V^2_w + V^2_B + 2V_wV_Br \qquad (2)$$

Substituting Equation 2 in 1 and noting that

$$V_T^2 = K_1^2T \quad \text{and} \quad V_p^2 = \frac{K_2^2p(1-p)}{T}$$

$$2V_wV_Br \simeq [(1-p^2) - (1-p)^2]K_1^2T - 2K_2^2Tp(1-p) - 2T(2p-1)\,\mathrm{Cov}\,[p, T]$$

For the typical case, $p = 0.5$

$$r \simeq \frac{K_1^2 - K_2^2}{K_1^2 + K_2^2} \qquad (3)$$

When $K_2 = 1$ (i.e., blending is ideal),

$$r \simeq \frac{K_1^2 - 1}{K_1^2 + 1}$$

A similar relationship has been given by Cox [10], though derived from different considerations.

When mechanical faults are kept to a minimum, the extra irregularities in the yarn arise chiefly from irregular movement of fibers at the later stages of processing. It appears that the irregularities arise from the movement of adjoining fibers in groups during drafting and because of this, there is a close correlation between the movement of neighboring fibers, while there is practically little correlation between those well separated. Drafting irregularities can, therefore, be expected to have an equal influence on both constituents only when there is intimate mixing of the components across the width, i.e., when the chances of a white fiber making contact with a black fiber equals the proportion of black fibers in the blend. When the constituents are kept separate, as in triple-roving spinning, the correlation r would be almost zero and K_2 would be close to K_1. Where mixing has been done at the scutcher, we have already seen that the lateral mixing is close to random and, hence, there is a significant positive correlation between the components, and K_2 is much lower than K_1 and approaches the ideal value of unity.[1] Thus lateral intermingling of the components is a prerequisite for minimizing the longitudinal variations in blend proportions.

[1] Just when this work was completed, S. Yamashita *et al.* [11] reported work on blend irregularity arising in drafting of rayon/polyester blends. The authors have observed, among other things, that correlation between the components increases when the mixing within a section is improved, which is in conformity with the results of this work.

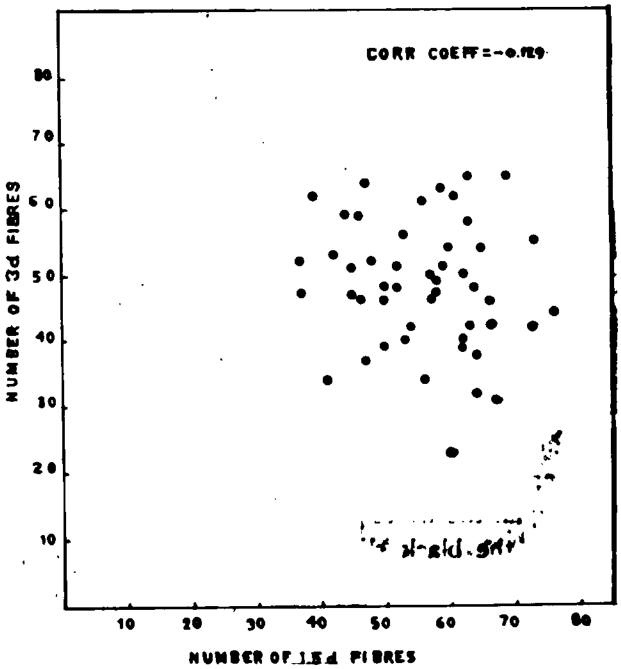

Fig. 5. Relation between number of 1.5-den and 3-den fibers, denier-difference blend, blending at ring frame (No. 13).

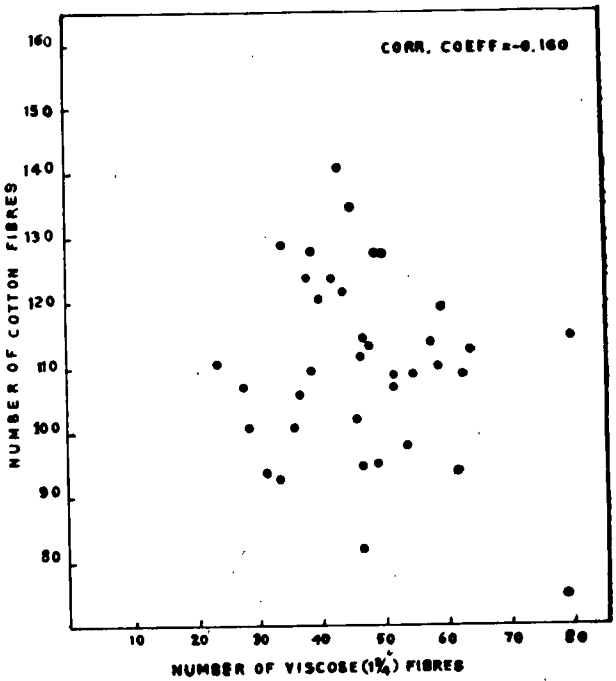

Fig. 6. Relation between number of viscose and cotton fibers, viscose-CO$_2$ blend, blending at ring frame (No. 15).

Lateral Mixing and Blend Variation

The following experiment was made to demonstrate the influence of lateral mixing on longitudinal blend variation. Second-head drawing slivers were prepared from 1½-in., 3-den white Fibro and 1½-in.

3-den black Fibro and two blends were made from them in the following manner.

Slivers A

Five white and five black slivers were arranged alternately and doubled with a draft of 10 to obtain a third-passage drawing sliver. Ten such slivers were once again doubled and drafted to obtain a fourth-passage drawing sliver.

Slivers B

The white and black slivers were each separately given a passage of drawing with a doubling of 10 and a draft of 10. Five white and five black slivers thus prepared were blended at the fourth passage, keeping all the white slivers together at one side and likewise the black slivers on the other side. Evidently, a more intimate mixing of the components within a section is obtained by the first method than by the second, although the total number of doublings is the same in both blends. The slivers A and B were then spun on a OM spinning frame to 30s Ne (ave. number of fibers per section = 56), and the drafted strands emerging from the front rollers were transferred onto a glass slide, and counts were made of white and black fibers in a section. In addition, the number of groups of white fibers in the section was also noted and from this the degree of lateral mixing was estimated. From 80 such observations made on randomly chosen portions of the strand, the II, IBI, and the correlation between the components were calculated; the results are presented in Table XII. The plots showing the association between the number of white and colored fibers is given in Figure 7.

TABLE XII. Effect of Lateral Mixing on Blend Variability

Blend type	No. of groups of white fibers	Degree of mixing	II, K_1	IBI, K_2	r
A	14.12	0.97	1.50	1.14	0.273
B	7.04	0.52	1.60	1.63	−0.023

It will be noticed from Table XII and Figure 7 that a significant correlation is observed between the components only when there is intimate lateral mixing. The variation of the blend proportion is also much lower with this blend and the IBI is lower than the II and is close to unity. But in blend B, where the lateral mixing is poor, there is no correlation between the components, and the IBI is close to the II. The results support the hypothesis that the material drafts like a number of lengthwise strips, the movement of fibers within a strip being correlated while those between are unassociated.

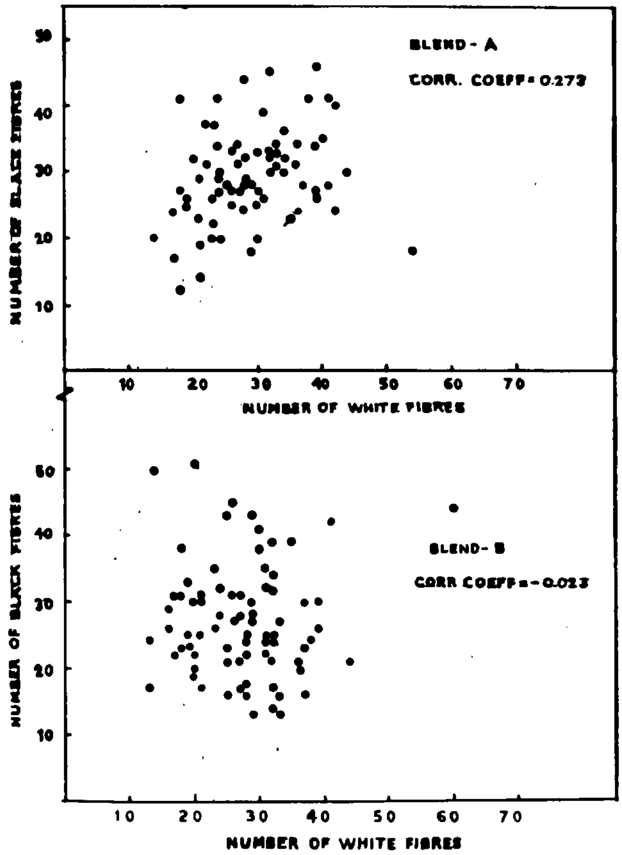

Fig. 7. Relation between the constituents in blends differing in intimacy of lateral mixing.

Summary

The influence of processing factors on the arrangement of fibers within the yarn cross section and on the intimacy of mixing, in blends composed of fibers differing in physical properties, have been investigated in this paper. Two blends composed of fibers differing in length and in denier were prepared from Fibro fibers, the mixing being done at the scutcher. A simplified index was employed to characterize the tendency, if any, on the part of the components to occupy preferred positions in the cross section and, using this, the influence of spinning factors on fiber arrangement was investigated. It was observed that the long fibers in the length-difference blend and the fine fibers in the denier-difference blend had a consistent tendency to stay closer to the core, while the short and coarse fibers

in the respective blends concentrated near the surface and, of the spinning factors, only strand width at the delivery nip had a significant effect on the arrangement. With an enhanced width of the drafted ribbon, the long-fiber component exhibited a greater preference for the core position. But, no significant preferential grouping of the components could be discerned across the width of the strand, indicating that the biased arrangement develops during spinning.

When the constituent fibers were kept separate by spinning from triple rovings, the strand composed of the long and fine fibers showed a tendency to migrate from time to time to the core. The place of feed of the constituent did not seem to have much effect on the amount of migration, provided the rovings were kept apart. It is shown that the biased arrangement could be considerably enhanced, if the rovings were condensed together prior to drafting, with the longer component at the center. The average position of the constituent in the yarn section could be controlled to some extent in this manner, but it has no effect either on the strength or the extension of the yarn.

Results on the intimacy of mixing obtained in these blends show that where blending was done at the scutcher, intimate mixing of the components close to the ideal both in the longitudinal and lateral directions was realized in the yarn in spite of the fact that the components differed in length and fineness. The blend behaves as though composed of fibers of a single constituent, and drafting irregularities have an equal influence on both components, which is exemplified by a positive correlation between the number of fibers of one component with that of another along the length of the yarn. On the other hand, where blending was done at the ring frame, the components were distributed almost independently of each other and, in such material, the variability in the blend proportion was of the same order as the variability in the total number of fibers. Evidence is presented to show that the irregularities in drafting arise from the movement of adjoining fibers in groups, and to minimize the variations in blend proportion longitudinally, adequate lateral intermingling of the components must be obtained.

Acknowledgments

The author's thanks are due to Mr. G. S. Nijsure and Mr. G. K. Trivedi for assistance in fiber counting in the yarn cross sections and drafted ribbons and to Dr. C. Nanjundayya, Director, BTRA, for encouragement and permission to publish the paper.

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Manuscript received April 14, 1969.