NC STATE UNIVERSITY
JTATM
JOURNAL OF TEXTILE AND APPAREL, TECHNOLOGY AND MANAGEMENT

Volume 1, Issue 4, Summer 2001

THE CONFIGURATION OF TEXTILE FIBRES IN STAPLE YARNS

A. Primentas, C. Iype
School of Textile Industries, The University of Leeds

ABSTRACT

The observation of individual fibres in a mass of fibres becomes possible with the tracer fibre technique. For the microscopic examination of ring-spun yarns containing tracer fibres, the depth of focusing is used as a reference for the fibre location inside the body of the yarns. Three-dimensional configurations of the examined fibres in the yarns are generated by computer graphics. This method will assist researchers who are working in the field of yarn and fabric structural mechanics.

KEYWORDS: fibre migration, microscopy, tracer fibre technique

1. FIBRE MIGRATION

The need for theoretical description and interpretation of the various yarn properties has been met by both the microscopic and macroscopic examinations of yarns.

The observations of individual fibres in the twisted yarn structure became possible by the use of the tracer fibre technique. In applying this technique, a small proportion (that varies among 0.02 to 1.00 % by weight depending on the end product under examination) of black dyed tracer fibres is introduced in the carding stage, with the remaining undyed material. The resultant end-product (sliver, roving or yarn) is then immersed in a liquid medium having the same or substantially the same refractive index as that of the fibres concerned. When the yarn is then examined under a low-power microscope, the uncoloured fibres almost disappear from view leaving the path of each tracer coloured fibre to be clearly discerned (Figure 1). The tracer is seen against the faint background of the yarn body as a wavy line representing the projection in one plane of a helix. This method was devised by Morton and Yen [1] for the study of staple fibre yarns. Later, Riding [2,3] applied this technique for the study of continuous filament yarns. Description of this method can be found elsewhere [4].

Figure 1: Tracer Fibres in Short Staple Yarns

2. BEHAVIOUR OF THE FIBRE MIGRATION

The chief features of the migration behaviour are usually characterised by the following parameters [5, 6]:

a) ***Mean fibre position***. This represents the overall tendency of a fibre to be near the surface or near the centre of a yarn and can be calculated from the formula:

$$\overline{Y} = \frac{1}{z}\int_0^z Y dz = \frac{\sum Y}{n}$$

where $Y = \left(\frac{r}{R}\right)^2$ r = helix radius, R = yarn radius,
z = length along the yarn, n = number of observations.

b) ***Amplitude of Migration***. The magnitude of the deviations from the mean position and is represented by the *Root Mean Square Deviation (r.m.s.)*
r.m.s. deviation:

$$D = \left[\frac{1}{z}\int_0^z (Y-\overline{Y})^2 dz\right]^{1/2} = \left[\frac{\sum (Y-\overline{Y})^2}{n}\right]^{1/2}$$

(2)

c) ***Rate of Migration***. The rate of change of radial position. For this, the *Mean Migration Intensity* is used :

$$I = \left[\frac{1}{z}\int_0^z \left(\frac{dY}{dz}\right)^2 dz\right]^{1/2} = \left[\sum \left(\frac{dY}{dz}\right)^2 \Big/ n\right]^{1/2}$$

d) ***Migration Frequency***. It has been suggested [7] that the most interesting point in the migratory behaviour of a fibre is the frequency with which reversals in the direction of migration take place. The most satisfactory quantity to characterise the rate of reversal is considered to be the "*Mean Migration Period*".

3. METHODS FOR ASSESSING FIBRE MIGRATION

A typical configuration of a tracer fibre observed under microscope is shown in Figure 2.

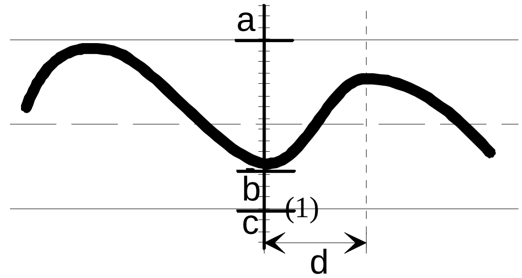


Figure 2. Measured Distances in a Yarn Containing Tracer Fibre

Morton and Yen [1] made measurements at successive peaks and troughs of the tracer image. Each peak and trough was in turn brought to register with the hair line of a micrometer eyepiece and scale readings were taken at *a*, *b*, and *c*.

The diameter of the yarn in scale units was then given by *c*-*a*, while the offset of the trough (or peak as the case might be) from the yarn axis was given by $b - \frac{a+c}{2}$. In addition, the distance between adjacent troughs and peaks, marked as *d*, as well as the overall extent of the tracer was obtained. With this method it was possible to track of the paths followed by the tracers in the horizontal plane.

In order to avoid effects due to change in the yarn diameter, Gupta [8] expressed the radial position of the fibres in terms of the ratio r/R:

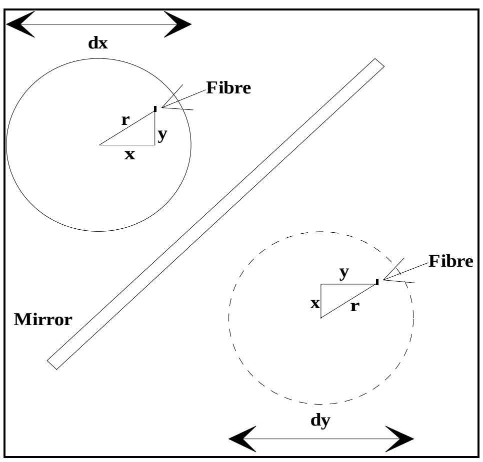
$$\frac{r}{R} = \frac{\left(\frac{a+c}{2}\right) - b}{\left(\frac{a-c}{2}\right)}$$

(3)

A plot of r/R against length along the yarn shows the cylindrical envelope of varying radius around which the fibre is following a helical path.

Since the path followed by a fibre in the yarn is actually in three dimensions, it can only be fully established if observations are made in more than one direction. Riding [3] achieved this by viewing the fibre from two directions at right angles by placing a plane mirror near the yarn in the liquid with the plane of the mirror at 45° to the direction of observation (Figure 3). By measuring the distances of the fibre from the yarn axis by the x and y co-ordinates, which are at right angles to each other for the two images as seen from the microscope, and the corresponding diameters dx and dy, he reached the following equation for fibre radial position:

$$\frac{r}{R} = 2\left[(x/dx)^2 + (y/dy)^2\right]^{1/2} \qquad (5)$$



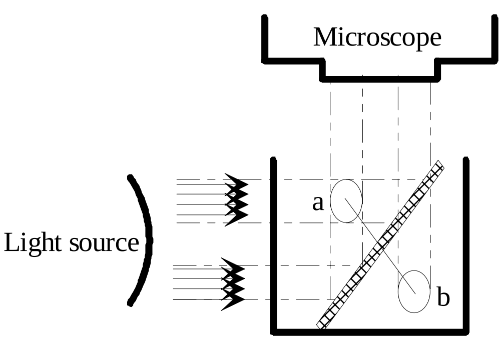


Figure 3: Modified Technique for Observing Two Orthogonal Projections of a Yarn [3] (a yarn, b image)

Prior to Riding, Goldberg [9] used a special apparatus to study the projection of the fibre path in 18 planes separated by angles of 20°.

Hearle and Gupta [6] moved a step further by taking into account the problem of asymmetry in the yarn cross section reaching the equation:

$$\frac{r}{R} = \frac{1}{2}\left(r_1/R_1 + r_2/R_2\right)$$

at $z = 1/2\,(z_1+z_2)$ (6)

where r_1, r_2 are the helix radii (crest, trough) and R_1, R_2 the yarn radii at positions z_1, z_2 along the yarn.

Hearle *et al* [10] suggested that the fibre migration in the yarns results from a combination of two mechanisms: one dependent on tension variation that results from the displacement of buckled fibres, and the other, termed "geometrical mechanism", that concerns the geometry of ribbon twisting. The former predominates to give a rapid migration while the latter, depending on the initial twist, gives rise to a slower migration. In ring spinning of staple fibres, because of the presence of roving twist, a fibre is likely to "be situated at an angle to the direction of motion before its emergence from the front roller to the twisting zone" [11]. As a consequence, part of the fibre may enter the high-tension zone, while the rest of it remains in the low-tension zone. This would allow the former part to migrate towards the core and the latter to the outer sheath resulting in the development of "long term migration" in the final yarn. It is probable that the geometric mechanism is not so important [12], although it might be caused to play a significant part as a means of controlling the yarn structure and properties.

4. CALCULATIONS

Difficulties can arise due to yarn irregularity along its length, deviations from a circular cross-section and the asymmetry of the axis of twisting found in real (spun) yarns. For the examination of the migration behaviour of such yarns, Hearle *et al* [5] derived suitable formulae to avoid these problems. The same formulae were also used for the present experimental work.

Tracer fibre measurements were expressed in terms of equation 4. For convenience, in each measurement, the "bottom line" of the yarn was brought to match with the horizontal hair line of the projector. In this way, ***c*** was always zero (0) and ***a*** was the actual measured horizontal diameter at this point of the yarn (see Figure 2). Expression 4 therefore became:

$$\frac{r}{R} = \frac{D/2 - f}{D/2} \quad (7)$$

where ***D*** the horizontal yarn diameter and ***f*** the indication of the position of the tracer fibre taken on the vertical hair line of the projection screen.

For the Mean Fibre Position expression 1 was used, whereas the amplitude of migration (Root Mean Square Deviation r.m.s.) was calculated from expression 2.

The mean Migration Intensity was calculated from a modified form of formula 3.

$$I = \left[\frac{\sum \left(\frac{Y_1 - Y_2}{l_1}\right)^2}{n} \right]^{1/2} \quad (8)$$

where l_1 was the distance between the adjacent indications Y1, Y2.

The expression $$\frac{I}{4D\sqrt{3}} \quad (9)$$

indicated the migration frequency.

5. THE NEW METHOD FOR THE OBSERVATION OF THE TRACER FIBRES

For the purpose of a research project [13] it was necessary to obtain a 3-dimensional graphic representation of the actual configuration of the fibres in the yarns. Thus a new method was developed based on the tracer fibre technique.

5.1 Principles of the New Method

Short staple rayon yarn specimens containing black tracer fibres were spun on a ring spinning frame. Each yarn specimen under test was led through a glass trough filled with ethyl salicilate having a refractive index of 1.550. The trough was mounted on the stage of a projection microscope "Projectina" (Figure 4). The yarn, as it was placed in the path of illumination, appeared bright due to its optical anisotropy with the dark tracer following a helical path. The image of a fibre could be brought in to view by the traverse movement of the stage. The "bottom line" of the yarn was always adjusted to coincide with a reference horizontal hair on the projection screen. A special device was designed in order to keep all the tested yarn samples under the same tension.

Figure 4: A Protractor Attached around Focusing Knob

It was clear that at high magnification ($\times$ 40) and consequently small yarn length sections viewed (maximum 1 mm), the focusing was highly dependent on the relative position of the fibre with respect to the body of the yarn (Figures 5,6,7). It was thought that the level of the focusing depth could be considered as a measure of the fibre position along the z axis with respect to the body of the yarn. With a suitable reference depth, it then became possible to plot the position of the tracer fibre with reference to the body in the x, y and z planes, by observing the position with regard to both the screen co-ordinates and the rotary position of the focusing knob. This rotary position was determined by noting the angle differences on a protractor fixed in relation to the focusing mechanism (Figure 4). Therefore, the obtained data such as the *length of the yarn* ***l*** between the chosen examined points, the *horizontal diameter* ***D*** of the yarn in each of these points, the *distance* ***f*** of the tracer fibre from one side of the yarn (viewed image), as well as the *distance* ***f′*** of the tracer fibre from one side of the yarn (along the viewing direction) obtained from angle readings of focusing depth, could provide sufficient information for plotting the possible 3-dimensional fibre configuration.

5.2 Calibration

The following method was adopted to convert the readings of angle degrees to the position of the fibre along the z axis (parallel to the path of illumination).

It was assumed [14] that, at each of the measured points along the tested yarn length, the horizontal and the vertical yarn diameters were equal. It was also assumed that the difference between the minimum and maximum values in depth represented the value of the vertical diameter, this being also equal to the horizontal diameter, it was at that point of the yarn where the highest value of depth was measured. For example, if 203° and 110° were the maximum and minimum values of depth recorded in the examination of a tracer fibre in a yarn sample, and 0.27 mm was the corresponding horizontal yarn diameter measured at the maximum reading of depth value, then

$$0.27 \text{ mm} = 203x - 110x \Rightarrow x = 0.0029$$

where x was a factor for converting the degrees (°) into millimetres (mm). After examining a number of 60 tracer fibres (measuring 20 points on each fibre), it was found that the most suitable value for the factor x should be 0.00248 with a C.V. 16.28%.

Figure 5: The Focused Part of the Tracer Black Fibre (an indication of 149°)

Figure 6: The Previously Unfocused Part (see Figure 5) of the Tracer Black Fibre, Focused in this Figure (an indication of 193°)

For each tracer fibre, the location of the individual fibre points and the distance from the outer yarn surface that was closer to the objective lens, were calculated at the end of the examination by multiplying the absolute difference between the overall minimum recorded value of depth and the value of that point, with the conversion constant 0.00248.

In a test (Figures 5,6), the horizontal yarn diameter was 0.23 mm measured in that part of the yarn where the maximum depth value (224°) was noted. The minimum value of depth was 109°. Therefore, for the Figure 5, the focused part of the tracer fibre with the indication of depth of 149° was located at:

$$|109° - 149°| \times 0.00248 = 0.10 \text{ mm}$$

from the front surface of the yarn (closer to the objective lens), whereas for the Figure 6, the focused part of the tracer fibre was located at:

$$|109°\text{-}193°| \times 0.00248 = 0.21 \text{ mm}$$

from the front surface of the yarn. It must be noted that the larger the indication in degrees of depth, the closer to the objective lens the yarn is being brought, focusing its back side.

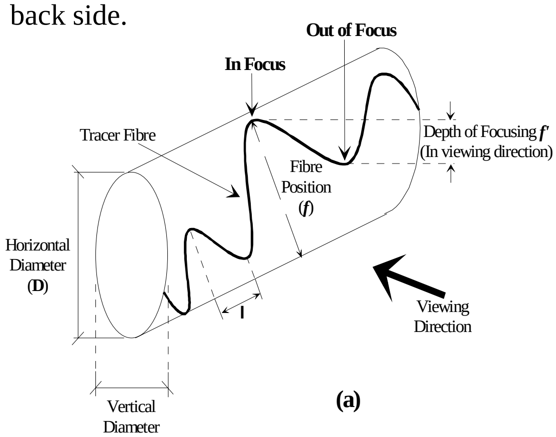


Figure 7: Graphic Presentation of Yarn

In some individual determinations of the tracer fibre vertical diameter, the calculated vertical diameter (depth) was found to be larger than the corresponding horizontal diameter. However, this was acceptable due to two facts: firstly the high variation in the chosen "constant" factor converting the degrees into millimetres, and secondly the hairy regions of those tested yarn parts that had not been taken into account when determination of the horizontal diameter was attempted. In such cases, a tracer fibre could protrude out of the main body of the yarn. Although it seemed that the chosen constant was erroneous for all these cases, the very small percentage (6%) of determinations for which this incident occurred, confirmed the good estimated value.

6. EXPERIMENTAL

In Table 1 the data obtained from measurements on a single tracer fibre are presented.

Table 1: Values (mm) Concerning the Fibre Position in the Yarn

Yarn Length	Horizontal Fibre Position	Vertical Fibre Position	Yarn Length	Horizontal Fibre Position	Vertical Fibre Position	Yarn Length	Horizontal Fibre Position	Vertical Fibre Position
l (x)	***f*** (y)	***f'*** (z)	***l*** (x)	***f*** (y)	***f'*** (z)	***l***(x)	***f*** (y)	***f'*** (z)
0.0	0.136	0.0000	1.7	0.184	0.2331	3.4	0.160	0.2926
0.1	0.160	0.0198	1.8	0.192	0.3026	3.5	0.184	0.3174
0.2	0.184	0.0471	1.9	0.200	0.3298	3.6	0.216	0.3472
0.3	0.192	0.0942	2.0	0.216	0.3522	3.7	0.176	0.3869
0.4	0.192	0.1190	2.1	0.208	0.4042	3.8	0.160	0.4216
0.5	0.184	0.1290	2.2	0.184	0.3993	3.9	0.136	0.4538
0.6	0.176	0.1513	2.3	0.160	0.3968	4.0	0.112	0.4538
0.7	0.144	0.1438	2.4	0.120	0.4042	4.1	0.088	0.4439
0.8	0.120	0.1389	2.5	0.096	0.3894	4.2	0.080	0.4166
0.9	0.072	0.1488	2.6	0.080	0.3621	4.3	0.056	0.3993
1.0	0.040	0.1910	2.7	0.056	0.3522	4.4	0.048	0.3745
1.1	0.024	0.1761	2.8	0.048	0.3224	4.5	0.040	0.3348
1.2	0.024	0.1463	2.9	0.040	0.3125	4.6	0.048	0.3050
1.3	0.048	0.1166	3.0	0.056	0.2877	4.7	0.072	0.2728
1.4	0.080	0.1066	3.1	0.072	0.2678	4.8	0.104	0.2753
1.5	0.120	0.1240	3.2	0.104	0.2654	4.9	0.144	0.2778
1.6	0.152	0.1587	3.3	0.128	0.2654	5.0	0.200	0.3298

In Figure 8, the observed path of the tracer fibre as it appeared on the projection screen is illustrated. Figure 9 represents a 3-dimensional configuration of the examined tracer fibre. This configuration is computer generated by processing data from the positions of the individual points of the tracer fibre along the yarn (***l***), across the yarn (***f***) and depth in the yarn (***f'***). Figure 10 gives the configuration of the tracer fibre as it can be observed looking at the cross-section of the yarn along the yarn length.

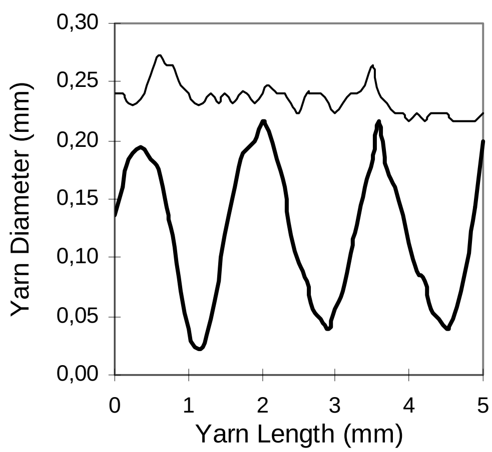


Figure 8: Observed 2-Dimensional Path of a Tracer Fibre in a Yarn. Note: The thin line indicates the correspondent yarn diameter fluctuation

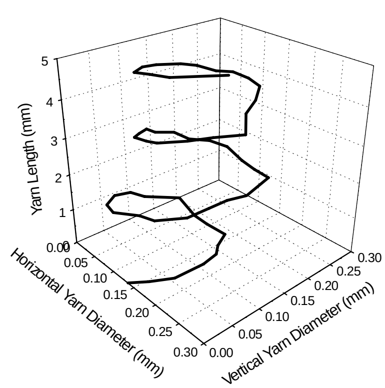


Figure 9: 3-Dimensional Configuration of a Tracer Fibre

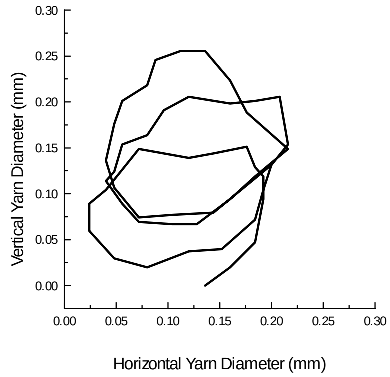


Figure 10: Tracer Fibre Configuration as Viewed from the Yarn Cross-section along the Yarn

7. CONCLUSIONS

The described method for the 3-dimensional observation of the configuration of the tracer fibres is in the embryonic stage of development. More work is needed for the evolution of this technique. The use of an on-line image analysis system for the direct location of every part of the tracer fibres might be very helpful for those who are dealing with the research in this sector of textiles.

REFERENCES

1. Morton, W.E. and Yen, K.C., "The arrangement of fibres in Fibro yarns", *Journal of the Textile Institute*, 1952, Vol. 43, No. 2, pp. T60-66

2. Riding, G., "An experimental study of the geometrical structure of single yarns", *Journal of the Textile Institute*, 1959, Vol. 50, No. 7, pp. T425-442

3. Riding, G., "Filament migration in single yarns", *Journal of the Textile Institute*, 1964, Vol. 55, No. 1, pp. T9-17

4. Morton, W.E., "The arrangement of fibres in single yarn", *Textile Research Journal*, 1956, Vol. 26, No. 5, pp. 325-331

5. Hearle, J.W.S., Gupta, B.S., Megchant, V.B., "Migration of Fibres in Yarns. Part I: Characterisation and Idealisation of Migration Behaviour", *Textile Research Journal*, 1965, Vol. 35, No. 4, pp. 329-334

6. Hearle, J.W.S. and Gupta, B.S., "Migration of fibres in yarns. Part III: A study of migration in staple fibre rayon yarn", *Textile Research Journal*, 1965, Vol. 35, No. 9, pp. 788-795

7. Rao, R.N., "Estimation of single yarn twist and the relation between the estimated and mechanical twists", *Textile Research Journal*, 1966, Vol. 36, No. 1, pp. 65-70

8. Gupta, B.S., *Ph.D. Thesis*, The University of Manchester, 1963

9. Goldberg, B.M., *M.Sc.Tech. Thesis*, The University of Manchester, 1953

10. Hearle, J.W.S., Gupta, B.S., Goswami, B.C., "The migration of fibres in yarns. Part V: The combination of mechanisms of migration", *Textile Research Journal*, 1965, Vol. 35, No. 11, pp. 972-977

11. Sur, D., Chakravarty, A.C., Bandyopadhyay, S.B., "Fibre migration in jute yarn. Part I: The effect of twist", *Journal of the Textile Institute*, 1975, Vol. 66, No. 5, pp. 180-185

12. Hearle, J.W.S. and Bose, O.N., "Migration of fibres in yarns. Part II: A geometrical explanation of migration", *Textile Research Journal*, 1965, Vol. 35, No. 8, pp. 693-699

13. Primentas, A., "Mechanical methods for the reduction of spirality in weft knitted fabrics" *Ph.D. thesis*, The University of Leeds, 1995

14. G.A.V. Leaf, Private Communication

AUTHORS

Dr. Anthony Primentas
Department of Textile Engineering
Technological Education Institute of Piraeus
250, Thivon & P. Ralli, 122 44 Athens, Greece
aprim@teipir.gr

Dr. Cherian Iype
School of Textile Industries
The University of Leeds
Leeds LS2 9JT, England
c.iype@leeds.ac.uk