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Influence of polyester fibre shape and size on the hairiness and some mechanical properties of yarns

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Polyester fibres of different linear densities and cross-sectional shapes have been spun on ring frame at different twist levels. These yarn samples are subjected to the deformation both in tensile and bending mode to investigate the yarn behavior as a consequence of change in cross-sectional shape and fineness of polyester fibres. Young's modulus as well as bending rigidity of yarns increases with the increase in fibre linear density. These properties of yarns made of trilobal and tetrakelion fibres are higher in magnitude than those of their corresponding circular fibres, whereas the behaviour is opposite if scalloped oval fibre is dealt. As far as yarn hairiness is concerned, the higher the polyester fibre denier, the higher will be the hairiness count. Yarns made of scalloped oval fibres exhibit maximum numbers of hairs followed by tetrakelion and the circular fibres yarns respectively. Similarly the yarns of trilobal fibres are more hairy than their counterparts made of circular fibres.

Keywords: Flexural rigidity, Hairiness, Scalloped oval, Tetrakelion, Trilobal, Young's modulus

1 Introduction

Under most conditions of fibre processing, i.e. during spinning and post spinning operations, fibre strains of low magnitude both in longitudinal and transverse directions (i.e. tensile, bending and torsion) assume considerable importance. In fact, these fibre deformations eventually are responsible for ascertaining the yarn properties like young's modulus, bending stiffness and torsional rigidity which consequently have strong bearing on tactile evaluation of fabrics such as flexibility, drape, handle, crease retention and wrinkle recovery[1-3]. Hearle *et al.*[4] showed, by a theoretical analysis, a relationship between tensile moduli of multifilament yarn with fibre tensile modulus which was later modified to incorporate the discontinuities of the staple fibres. Similarly some theoretical contribution[5-8] regarding bending characteristics has been made exhibiting the translation of bending characteristics of the constituent fibres in to respective yarn characteristics. Some extensive experimentation[9,10] has also been carried out to establish the effect of other processing parameters like twist and setting conditions along with fibre parameters on the bending behavior of continuous and staple fibre yarns. Pillay[11,12] while working on cotton identified the torsional rigidity, flexural rigidity, fibre length and fibre weight in order of importance in the incidence of hairiness. In essence, the possibility of designing a textile product is realized depending on the way how the translation of fibre properties in to its product takes place and how they influence the yarn characteristics in general. Variation in fibre form or geometry does influence this translation efficiency through undergoing a change in its mechanical and surface characteristics which ultimately effectuate a change in product structure and properties.

As regards fibre mechanical behaviour, applying well established facts obtained from the study of the general mechanics of elastic, isotropic beam bending to the visco-elastic material i.e. fibre considering the relevant limitations, it can safely be stated that flexural and torsional rigidity of fibres is governed by denier (linear density) and cross-sectional shapes. As such, rigidity is the area-dependent, shape sensitive property of the fibre. Bend/torsional stiffness of a fibre is proportional to its denier squared (or diameter to the fourth power), whereas influence of profile is evaluated in terms of shape factor[13].

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As the shape factor becomes greater, the rigidity increases. Regarding surface characteristics, in fibres with non-smooth, non-circular cross-sectional shapes, however, a spiraling edge is generated (similar to that of a screw), thereby restricting the potential for inter-fibre contact and hence translation efficiency and other properties are accordingly realised[14].

Literature is abundant dealing with the contribution of fibre characteristics and process parameters to the structure and properties of yarn. But the information available[15-19] regarding the influence of fibre geometry, especially fibre denier and fibre profile on the yarn mechanical behaviour under different modes of deformations and its hairiness, influencing handle and touch feeling of its products is still limited and needs further investigations. In this study, an effort has been made to study the contribution of polyester fibre fineness and cross-sectional shape in influencing the tensile modulus, bending rigidity and hairiness of yarns. Determination of relative importance of these contributing variables along with level of yarn twist has also been attempted so that spinners can be guided in selecting the parameters that adequately meet end requirements.

2 Materials and Methods

2.1 Material Specifications and Sample Preparations

Details of the polyester fibres used in the study are given in Table 1. Rigidity values of these fibres were calculated using the fibre cross-sectional dimensions observed from their SEM micrographs and are presented in Table 2. Twenty seven yarn samples of 19.66 tex were spun from 100% polyester as shown in Table 3.

Mixing of each sample was laid down under industrial conditions after manual opening of the fibres. Each stock of mixing was manually fed to an MMC card followed by Lakshmi Rieter's draw frame DO/2S model to produce drawn sliver of 4.2 ktex. To get better homogeneity, three drawing passages were given to the carded sliver. The drawn slivers were later converted into rove of 0.42 ktex on Texmaco Howa simplex machine that was spun in the yarn of 19.66 tex on a Lakshmi Rieter's G5/1 ring frame at varying level of twist factor, viz. 27.26, 30.14 and 33.00. The other parameters were kept constant for all yarn samples.

2.2 Measurement of Fibre Elastic Modulus under Tensile Loading

Polyester fibres were tested for tensile modulus at 1% elongation on Lenzing Vibrodyne, using 20 mm gauge length and a 20 mm/min strain rate according to ASTM standard D-3822. Strain was extended up to the point of rupture to obtain the compliance ratio and energy to rupture.

2.3 Calculation of Fibre Flexural Rigidity

Fibre flexural rigidity could not be measured by ring loop method because of difficulties encountered in manipulating such fine fibres without causing permanent damage and because of poor shape of the ring loops that were produced. Classical theory of elasticity[20, 21] was adopted for the calculation of flexural rigidity values of various fibres using following equations:

$$M = E_f \times I_f \left(1/R\right) \qquad \ldots(1)$$

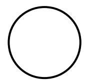
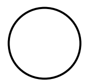
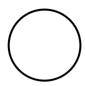
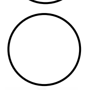
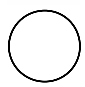
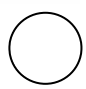
For a unit radius of curvature of bending, the Eq. (1) reduces to following equation:

Table 1—Details of polyester fibres

Fibre ref. no.	Fibre	Profile	Length mm	Linear density dtex	Tensile modulus cN/tex	Compliance ratio	Coeff. of friction (μ)	Work of rupture g.cm	Cohesion factor (μS*), m^2kg^{-1}
P_1	Polyester	Circular	44	1.33	390	-0.106	0.52	1.47	139.0
P_2	Polyester	Circular	44	1.55	388	-0.062	0.51	2.62	127.5
P_3	Polyester	Circular	44	1.66	369	-0.106	0.52	1.03	126.6
P_4	Polyester	Circular	44	2.22	288	-0.091	0.51	3.57	110.8
P_5	Polyester	Trilobal	44	2.22	290	-0.084	0.45	1.42	-
P_6	Polyester	Circular	38	1.66	375	-0.079	0.47	2.49	117.5
P_7	Polyester	Scalloped oval	38	1.66	271	0.366	0.51	1.06	-
P_8	Polyester	Tetrakelion	38	1.66	399	0.033	0.32	1.52	-
P_9	Polyester	Circular	38	0.99	362	-0.099	0.59	1.07	176.7

*S is the specific surface of fibre (m^2kg^{-1}).

Table 2—Calculated rigidity values of various fibres based on their geometric shape and size.

Fibre ref. no.	Profile		Tensile modulus cN/tex	Tensile force at 1% elongation, cN	Moment of inertia (I_f), μm^4	Flexural rigidity × 10^{-3} dyn-cm^2
P_1	Circular		390	52.02	718	3.87
P_2	Circular		388	60.50	938	5.04
P_3	Circular		369	61.64	1045	5.34
P_4	Circular		288	64.08	2041	8.12
P_5	Trilobal		290	64.52	2610	10.46
P_6	Circular		375	62.52	1160	6.01
P_7	Scalloped oval		271	45.27	782 (852)*	2.93 (3.19)*
P_8	Tetrakelion		399	66.51	1212	6.68
P_9	Circular		362	36.27	456	2.28

* Brackets indicate the values along the other perpendicular direction.

$$M = E_f \times I_f \qquad \ldots(2)$$

where E_f is the tensile modulus or modulus of elasticity of fibre (cN/tex); I_f, the moment of inertia of the cross-section about the neutral axis (μm^4); and R, the radius of bending curvature.

2.4 Measurement of Yarn Tensile Modulus

Instron tensile tester 4411 was used for the measurement of yarn tensile modulus (young's modulus). Modulus ratio was calculated to have an idea about the effect of inter fibre interaction working under low deformation conditions. Tensile test on yarns was done with a gauge length of 500 mm at a strain rate of 200 mm/min. Modulus ratio was calculated using the following relationship:

Modulus ratio = Yarn modulus (YM) / Fibre modulus (FM)

2.5 Measurement of Yarn Flexural Rigidity

All the yarns were tested for flexural rigidity on a Shirley weighted yarn stiffness tester by the ring loop method[22]. For each sample, fifty observations were made. The yarns were so twist lively that it was very difficult to make a loop without distortions and deformations. Therefore, steam setting treatment was given to all the yarns for 15 min. Rigidity ratio was also calculated to characterize the level of interactions among the fibres during the event of bending. It is defined as the ratio of observed yarn flexural rigidity (YR) to sum of rigidities of individual fibres in yarn cross-section ($N_f E_f I_f$), as shown below:

$$\text{Rigidity ratio} = YR/(N_f E_f I_f) \qquad \ldots(3)$$

where N_f is the number of fibres in yarn cross-section; E_f, the modulus of elasticity of fibre; I_f, the moment of inertia of the cross-section about the neutral axis.

2.6 Measurement of Number of Fibres in Yarn Cross-section and Yarn Hairiness

Cross-sections of yarns were cut and observed under the computerized microscope Leica Q500 MC and number of fibres in each section was counted.

Table 3—Effect of polyester fibre fineness and cross-sectional shapes on tensile modulus, bending rigidity and hairiness of the yarns made of 100% polyester

Yarn ref. no.	Fibre mix	Tex twist factor $tex^{1/2} \times$ turns/cm	Tensile modulus cN/tex	Modulus ratio	Average number of fibres in yarn X-section (N_f)	Minimum. yarn flexural rigidity (Min YFR, $N_f E_f I_f$) dyne-cm^2	Yarn Flexural rigidity (YFR) dyne-cm^2	Rigidity ratio	Hairs >3mm/200 m (S3)
S1	P_1	27.26	443.6	1.136			1.583	2.884	1031
S2	(100)	30.14	450.6	1.154	142	0.549	1.566	2.852	903
S3		33.00	457.7	1.172			1.506	2.743	866
S4	P_2	27.26	482.6	1.240			1.719	2.845	1184
S5	(100)	30.14	484.2	1.244	119	0.604	1.675	2.822	1093
S6		33.00	485.9	1.249			1.636	2.791	948
S7	P_3	27.26	485.5	1.312			1.753	2.827	1194
S8	(100)	30.14	490.9	1.327	116	0.620	1.740	2.806	1169
S9		33.00	504.2	1.363			1.720	2.774	1135
S10	P_4	27.26	500.8	1.736			1.948	2.815	1470
S11	(100)	30.14	520.7	1.805	85	0.692	1.930	2.789	1283
S12		33.00	546.6	1.895			1.921	2.776	1243
S13	P_5	27.26	507.0	1.746			2.096	2.434	2050
S14	(100)	30.14	526.1	1.811	82	0.861	1.987	2.307	1657
S15		33.00	560.8	1.931			1.969	2.286	1479
S16	P_6	27.26	488.4	1.301			1.720	2.481	1027
S17	(100)	30.14	492.3	1.312	115	0.693	1.700	2.453	998
S18		33.00	510.1	1.359			1.680	2.424	978
S19	P_7	27.26	369.6	1.360			1.333	4.039	1530
S20	(100)	30.14	404.0	1.487	112	0.330	1.305	3.954	1407
S21		33.00	501.3	1.845			1.244	3.769	1196
S22	P_8	27.26	492.5	1.233			1.861	2.436	1414
S23	(100)	30.14	535.6	1.341	114	0.764	1.814	2.374	1290
S24		33.00	549.3	1.376			1.724	2.257	1143
S25	P_9	27.26	444.1	1.224			1.411	3.273	708
S26	(100)	30.14	458.7	1.264	188	0.431	1.387	3.218	582
S27		33.00	473.8	1.305			1.335	3.097	543

Yarn hairiness was measured on Zweigle Hairiness Meter (Model G566) using a test length of 200 meters. Twenty observations were made for each yarn sample. S3 value was regarded as the index of hairiness level or hairiness count.

3 Results and Discussion

Observations made on all the yarn samples and relevant calculations are presented in Table 3. The influence of experimental variable, viz. fibre linear density, fibre cross-sectional shape, twist, has been assessed using linear regression analysis at 5% level of significance.

3.1 Yarn Tensile Modulus/ Modulus Ratio

It is a common knowledge and of practical experience that product properties are governed by respective properties of its constituent. In this way, at the first instance, the yarn tensile modulus is supposed to be dependent on its fibre's inherent elastic modulus which is modified by alteration in inter-fibre interactional forces as a result of changes in fibre's geometry (i.e. fibre denier and cross-sectional shapes) and yarn structural parameters (twist). But regression analysis of data excludes the fibre tensile modulus values from its regression equation due to its statistically non-significant contribution in explaining the yarn modulus behavior. This analysis gives us the indications that fibre geometry is dominating and decides significantly the concerned yarn parameter and fibre elastic modulus alone may not be showing here relationship of significance.

During the initial linear part of stress-strain curve of spun yarns, lateral forces among the various layers of fibres assume critical importance where the fibres begin to slip overcoming the initial inter-fibre friction as the helix begin to extend until it tightens on to the other fibres around which it is twisted, compressing these fibres together.

In an analytical treatment presented by Batra[8] it has been established that the lateral force intensity is a function of tension in the fibre, bending and torsional rigidities, bending curvature and torsion which can be represented by following Eq.(4). As per this treatment, the normal force/unit length (N) can be combination of two parts as shown in Eq. (4) under the assumption of yarn structure an idealized geometry consisting of helical disposition of fibres, as shown below:

$$N = \underbrace{T\frac{sin^2 q}{a}}_{\text{(I)}} + \underbrace{\left(EI - GI_p\right)\frac{sin^4 q \, cos^2 q}{a^3}}_{\text{(II)}} \qquad \ldots(4)$$

where E & G are the elastic and shear moduli of fibres; I & Ip; the area and polar moments of inertia of the fibre cross-section; T, the fibre tension subjected during tensile loading; q, the helix angle; and a, the radius of helix.

Part I of Eq.(4) is tension dependent which becomes dominant under tensile deformation (tension here means the product of modulus and linear density), while the other part II is dependent on moments of bending and twisting which assumes significance during the bending deformation when the application of tension is absent i.e. T=0.

From the above treatment, it can be understood that the yarn modulus is remarkably governed by inter-fibre interaction which is the trade-off between deteriorating effect (obliquity due to geometrical effect of twist) and reinforcing effect (cohesion, an outcome of fibre characteristics including fibre rigidities, pliability, coefficient of friction, contact area with neighboring fibres etc. and yarn structural features). High fibre tension at initial extension zone, which is the multiplicative product of fibre elastic modulus and fibre linear density, suggests more resistance being offered to the fibre movements/slippage, establishing the importance of fibre linear density.

Increase in yarn tensile modulus with increase in polyester fibre linear density, corresponding to three levels of twists is evident from Fig.1. Statistical analysis of observations demonstrates that yarn modulus predominantly depends on its fibre linear density which alone can explain 60% variations of data. Role of fibre fineness in ascertaining its tensile force (fibre tension) and rigidity (bending) is quite clear from Table 2. As such, in coarser fibres both the parts of lateral pressure in Eq.(4) are contributing to a higher extent which makes difficult the relative movement of the fibres (initial fibre slippage during helix extension) and compensates or even surpass the deteriorating effect of lower inter-fibre contact area owing to lesser specific surface. Under high load conditions, in later part of load-elongation curve, when initial fibre slippage is over, contacting surface area starts gaining importance for effective stress transfer. The rising level of response variable with increase in twist is obviously the outcome of increase in inter-fibre frictional resistance to fibre slippage caused by the enhanced radial pressure.

Figure 2 communicates the comparative response of different profile fibres in respect of yarn modulus. The yarns produced by tetrakelion fibres record highest modulus followed by circular and lastly

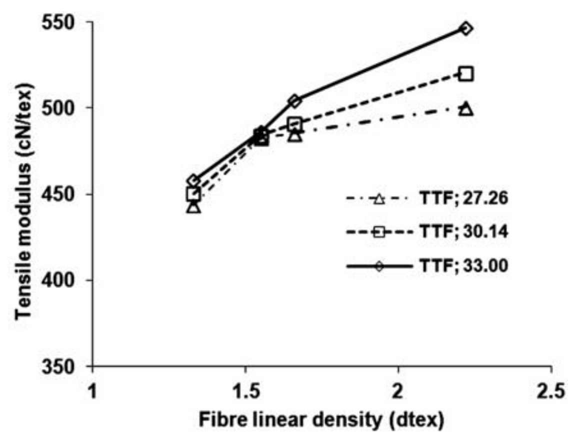


Fig.1—Influence of fibre linear density on tensile modulus of yarns with different levels of twist

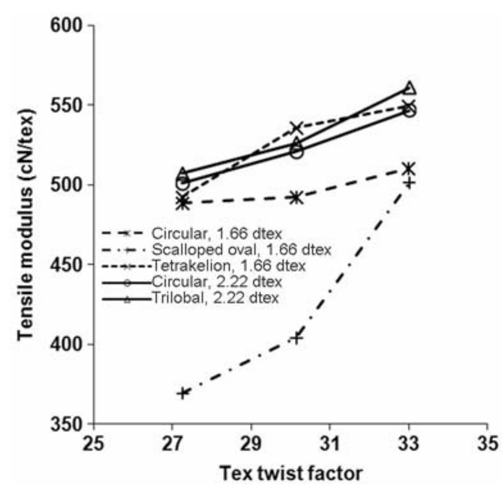


Fig.2—Effect of tex twist factor on tensile modulus of yarns corresponding to different ross-sections of polyester fibre

the scalloped oval. Similarly the trilobal pitches higher yarn modulus than its comparable circular one. This behavior is in compliance with the generalization that the yarn modulus is decided by tension generated in fibres modified by its inter-fibre frictional forces.

Also, tetrakelion fibres offer high lateral pressure because of their large bending stiffness as proposed by Batra[8] and the generation of higher fibre tension during tensile loading which makes the fibre movements difficult, although having low coefficient of friction. Therefore, its yarn shows high modulus followed by equivalent circular and the scalloped oval fibres respectively.

The response of trilobal cross-section is significantly different from its congruent circular one for which almost similar arguments can be propounded. Trilobal fibres are having some plane surfaces on its three faces. Sliding on flat surfaces is more difficult than gliding on curved surfaces. Relatively high bending stiffness in addition to its high tensile force elevates the young's modulus of its yarn as compared to its circular counterpart.

3.2 Yarn Flexural Rigidity

Statistical inferences drawn from data on yarn flexural rigidity clearly indicate that the fibre linear density is of highest significance explaining 92.7% variations in yarn rigidity. As shown in Fig.3, coarseness of fibres causes an increase in bending rigidity of the yarns. The rationale behind this relationship is that an increase in fibre linear density accompanies with an upturn in its bending rigidity which eventually gets translated into its yarn flexural rigidity. The calculations of flexural rigidities of fibres are given in Table 2.

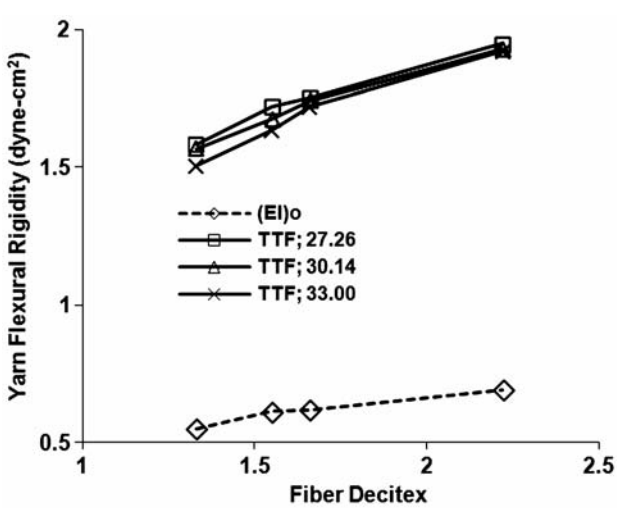


Fig.3—Variation of flexural rigidity of yarns with linear density of polyester fibre under three levels of twist

An attempt of determination of yarn bending rigidity based on bending rigidity values of single fibres in a yarn may be made to reemphasize the above stated fact. The first approximation of yarn bending rigidity is the sum of bending rigidities of individual constituent fibres contained in cross-section of yarn i.e. $(EI)_0$. Platt *et al.*[6] and Livesey *et al.*[7] designated it as the minimum yarn flexural rigidity if complete freedom of movement prevails among the fibres (i.e. zero inter-fibre friction). Data regarding theoretical minimum flexural rigidity of yarns $(EI)_0$ is exhibited in Table 3 and shown in Fig.3. $(EI)_0$ for the yarns comes out to be increasing with the increase in fibre linear density. This trend is conspicuously reflected in final yarn rigidity values.

In the light of strong relationship between the fibre and the yarn bending rigidity, explanation in regard to fibre profile effect can be suggested in a similar manner. Tetrakelion fibres owing to the maximum rigidity values produce a yarn with highest rigidity followed, in turn, by circular and scalloped oval fibres respectively. Exerting higher resistance to bending, trilobal fibre yarns outweigh its circular counterparts in regards to the flexural rigidity. A clear comparative assessment of rigidity of various profile fibres can be had from Table 2.

In this context, some idea about the influence of the concerned predictor variables i.e. fibre linear density or its cross-sectional shape on level of inter-fibre interactions during process of yan bending can be had in the form of rigidity ratios (Table 3). In fact during yarn bending, local strain caused in fibres at various yarn locations induce the relative motion within the yarn. Apart from inherent bending rigidity of constituent fibres, their relative motion also has a considerable influence on yarn rigidity. The extent of this relative motion between fibres is ascertained depending on the level of inter- fibre friction and the lateral forces which can be controlled by selecting these predictor variables. In this way, there are two opposing factors working in influencing the inter-fibre restraining forces specifically in reference to linear density of fibres; on one side, is the role of bending and torsional moments introduced during yarn twisting operation as recognized by Livesey *et al.*[7] and Batra[8] and on the other side, the cohesion forces. Coarser denier fibres owing to their higher torsional and bending rigidities develop high radial pressure among the fibre layers leading to increased inter-fibre friction, whereas reduction in cohesion forces and compactness occurs owing to less surface of contact. The difference in cohesion factor due to denier difference as displayed in Table 1 seems to be dominating over the former. Hence, the rigidity ratio has been observed to be decreasing with increase in fibre linear density.

Variation of yarn flexural rigidity with alteration in amount of twist inserted can be accessed from concerning data in the Table 3. Figure 3 presents graphically this effect in respect of different deniers and Fig.4 in respect of different profile fibres. The general effect of twist is that the yarn bending rigidity values consistently reduces with the rise of twist level, irrespective of fibre type, fibre fineness or fibre profile. This bahaviour may be the cumulative effect of well-known obliquity effect[5-7, 23] as well as lowering of fibre torsional stresses (residual stresses) owing to discontinuities at fibre ends in staple fibre yarns[9-10].

3.3 Yarn Hairiness

The information regarding hair count at measuring intervals of 1 mm, 2 mm and 3mm on Zweigle hairiness meter was obtained, but S3 value (hairs > 3mm), which is decisive to yarn processing behaviour, is specifically enlisted for hairiness evaluation (Hairiness Index) in Table 3. Figures 5-7 graphically represent the influence of fibre linear density and cross-sectional shapes on yarn S3 values corresponding to three twist levels. It is seen that the increase in fibre linear density and incorporation of non-circular fibres as against circular ones result in an increase in yarn hairiness.

Linear regression analysis demonstrates that fibre fineness and cross-sectional shape are having significant influence on generation of surface hairs and establishes the comparative importance of various independent factors in influencing the yarn hairiness.

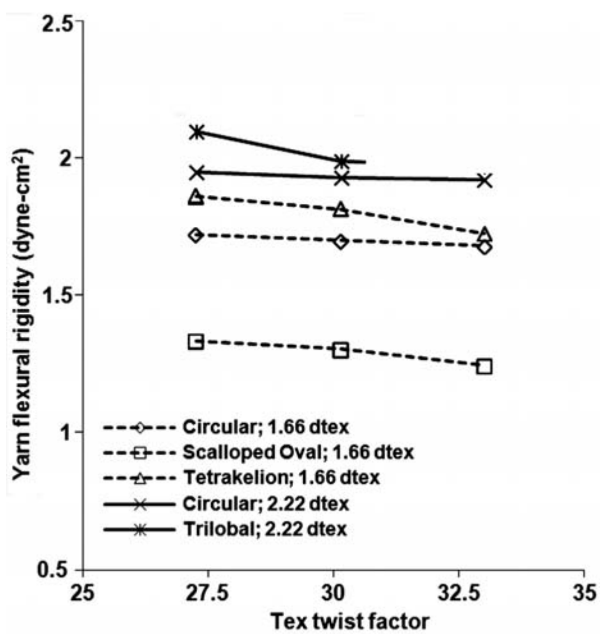


Fig.4—Variation of flexural rigidity of yarns with tex twist factor corresponding to different cross- sections of polyester fibre

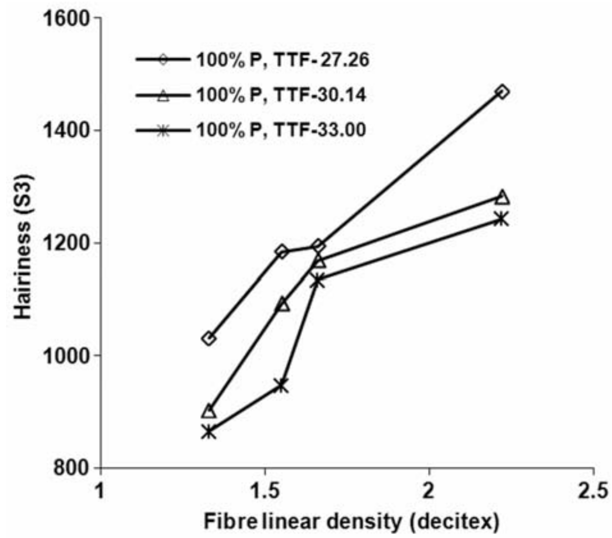


Fig.5—Influence of linear density of polyester fibre on hairiness of yarns (S3) corresponding to three levels of twist

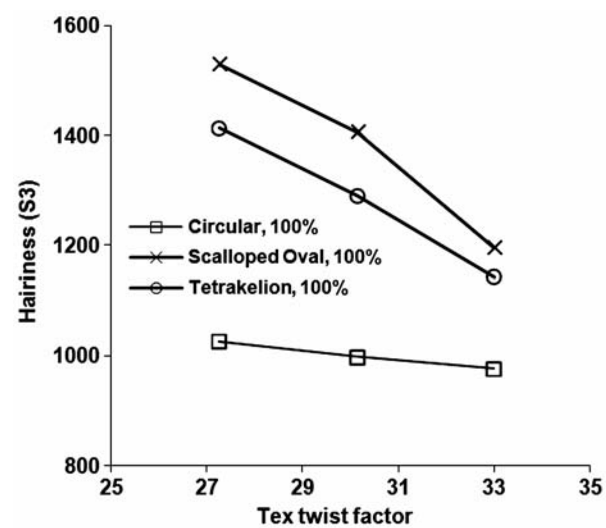


Fig.6—Influence of tex twist factor on hairiness of yarns (S3) corresponding to different cross-sectional shapes of polyester fibre

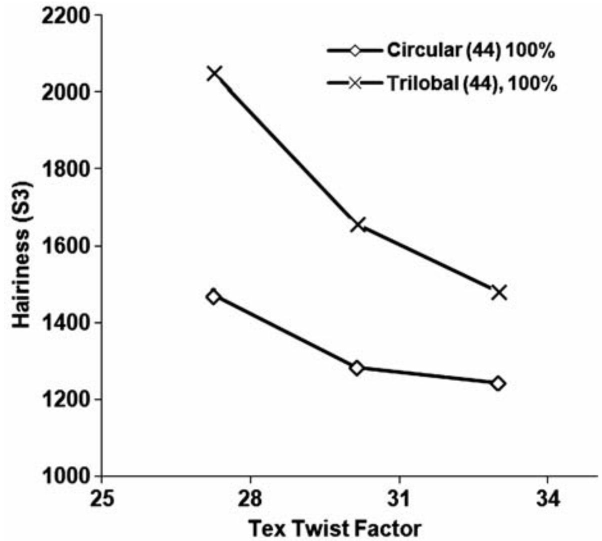


Fig.7—Influence of tex twist factor on hairiness of yarns (S3) corresponding to different cross-sectional shapes of polyester fibre

Higher β-value of fibre decitex clearly indicates its highest positive correlation with the yarn hairiness. This may be due to the fact that coarser fibres being more rigid have a greater resistance to the binding action imparted by the twist insertion and the fibre ends more in number as well as in length tend to project away from the yarn. During twisting process, higher centrifugal force acting on the heavier fibres may also be a contributory factor in enhancing the hairiness value. In connection with hairs generation mechanism, it can further be argued that as a first approximation, the yarn hairiness can readily be considered as directly proportional to the total number of fibres/fibre ends in the unit length of the yarns[11, 12]. How many fibre ends are converted in to protruded ends and consequently transform in to surface hairs are governed by fibre characteristics like linear density, cross-sectional shape etc.[24-26] and yarn structural parameters i.e. twist[11, 27-30].

Figure 7 compares the behaviour of trilobal fibres with their corresponding circular fibres. Circular fibres produce lesser hairs than trilobal fibres. Detaching forces caused by the rigidity of fibres seems to be more powerful in case of trilobal fibres. Therefore, even having less number of fibres in cross-section, their bending rigidity and shape won't allow these fibres to be packed tightly and hence generating highest hairiness in their yarns.

On the similar lines, less compact yarn structure due to non-circularity in cross-section of tetrakelion and scalloped oval fibres appear to be the main cause of their higher yarn hairiness as against the yarns of equivalent circular ones. Additionally, high torsional and flexural rigidity of tetrakelion polyester and likeliness of generation of more short fibres during mechanical processing of scalloped oval polyester (high fibre rupture is expected due to low energy to break) may further widen the gap between the yarn hairiness values of these fibres and that of their corresponding circular fibres. As an outcome of interplay of these and such like contributory factors, scalloped oval fibres generate highest yarn hairiness followed by tetrakelion and circular fibres respectively.

The general trend of decrease in hairiness index (S3) with increase in tex twist factor in all yarns can be viewed in Figs 5-7. This can be explained on the basis of yarn compactness[27-28] and migratory forces[29].

4 Conclusion

Young's modulus and bending stiffness of yarns increase with fibre linear density. But in respect of twist, these properties behave differently i.e. yarn bending rigidity reduces with increase in twist level but tensile modulus exhibits an increasing trend.

Yarns spun from Trilobal fibres have higher tensile modulus and flexural rigidity than that of their corresponding circular fibres. Scalloped oval fibre owing to its low flexural rigidity produce yarns of lower rigidity than its circular and tetrakelion counterparts. Further, tetrakelion outdo the circular both in flexural rigidity and young's modulus values.

Yarns made of higher denier polyester are more hairy. Scalloped oval fibre manifests highest hairiness index (S3) among all analogous profiles in their yarns which is followed by tetrakelion and circular fibres respectively. Hairiness of trilobal fibre yarns is more than equivalent circular fibre yarns. Hairiness tends to show a decreasing trend with increase in the level of twist.

References

1 Cassie A B D, *J Text Inst*, 37 (1946) 154.
2 Khayatt R M & Chamberlain N H, *J Text Inst*, 39 (5) (1948) T185.
3 Guthrie J C, Morton D H & Oliver P H, *J Text Inst*, 45 (1954) T912.
4 Hearle JWS, Grosberg P & Backer S, *Structural Mechanics of Fibres, Yarns and Fabrics* (Wiley-Interscience, New York), 1969, 148.
5 Backer S, *Text Res J*, 22 (9) (1952) 668.
6 Platt M M, Klein W G & Hamburger W J, *Text Res J*, Aug (1959) 611.

7 Livesey R G & Owen J D, *J Text Inst*, 55 (1964) T516.
8 Batra S K, *J Text Inst*, 64 (1973) 209.
9 Hunter I M, Slinger R I & Kruger P J, *Text Res J*, 41 (1971) 361.
10 Dhingra R C & Postle R, *J Text Inst*, 12 (1976) 426.
11 Pillay KPR, A study of the hairiness of cotton yarns, in *Proc. 4th Technological Conference of ATIRA, BTRA, SITRA* (ATIRA, Ahmedabad), 1962.
12 Pillay KPR, *Text Res J*, 34 (1964) 663.
13 Morton W E & Hearle JWS, *Physical Properties of Textile Fibres*, 3rd edn reprint (The Textile Institute Manchester), 1997.
14 Schick M J, *Surface Characteristics of Fibres and Textiles, Part-1* (Marcel Dekker Inc, New York and Basel), 1975.
15 Kaushik RCD, Tyagi G K & Chatterjee K N, *Indian J Fibre Text Res*, 15 (3) (1990) 120.
16 Kaushik RCD, Tyagi G K & Chatterjee K N, *Indian J Fibre Text Res*, 15 (4) (1990) 200.
17 Tyagi G K, Kaushik RCD & Salhotra K R, *Indian J Fibre Text Res*, 20 (4) (1995) 214.
18 Tyagi GK, Sharma KR, Goyal A & Singh M, *Indian J Fibre Text Res*, 29 (2) (2004) 184.
19 Tyagi G K & Madhusoodhanan P, *Indian J Fibre Text Res*, 31 (4) (2006) 496.
20 Pilky, Walter D & Pilky & Orrin H, *Mechanics of Solids* (Quantum Publishers Inc., New York), 1974.
21 Timoshenko S & Goodier JN, *Theory of Elasticity* (Mc-Graw Hill, New York), 1951, 267.
22 Oven J D & Riding G, *J Text Inst*, 55 (1964) T414.
23 Yoon H N & Buckley A, *Text Res J*, 5 (1984) 289.
24 Barella A, Torn J & Vigo J P, *Text Res J*, 41 (1971) 126.
25 Barella A, *Yarn Hairiness*, *Text Prog*, 24 (3) 1993.
26 Srivastava TVK, Onions W J & Townend P, *J Text Inst*, 68 (2) (1977) 86.
27 Barella A, *J Text Inst*, 79 (2) (1988) 189.
28 Barella A, *J Text Inst*, 79 (2) (1988) 335.
29 Vinzanekar G, *A study of hairiness of ring-spun viscose staple yarns with special reference to fibre arrangement*, paper presented at the Sixteenth Technological Conference of ATIRA, BTRA &, SITRA, ATIRA, Ahmedabad, 27-28 January 1975.
30 Boswell H R & Townend P, *J Text Inst*, 48 (5) (1957) T135.