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Investigation of the Physical and Mechanical Properties of Fine Polyester/Viscose-Elastic Composite Rotor-Spun Yarn

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Abstract
The aim of this paper was to investigate the physical and mechanical properties of fine Polyester/Viscose-Elastic Composite Rotor-Spun Yarn. Yarn samples with different values of the draw ratio and twist factor as well as similar normal yarns all with a linear density of 20 tex were produced on a modified rotor spinning system. The results showed that in composite yarns, the breaking tenacity and elongation increased with an increase in the spandex draw ratio and decreased with an increase in the twist factor. The maximum amount of the elastic recovery ratio was obtained at a draw ratio of 3.75, while it increased with an increase in the twist factor. These yarns have a greater amount of breaking tenacity, elongation and elastic recovery ratio than normal rotor-spun yarns. Longitudinal SEM photos and also cross sectional views of the elastic composite rotor-spun yarn structure revealed that the elastic component preferentially occupied the outer layers of the yarn structure.

Key words: *rotor yarn, elastic yarn, polyester, viscose, composite yarn, yarn properties, spandex, draw ratio, twist.*

Introduction

Elastic composite yarns have been widely used in textile industry to make different types of textile with high extensibility and good recovery, such as hosiery, swimwear, sportswear, and lace, as well as fashionable clothing in recent years [1, 2]. From a structural point of view, elastic composite yarns can be divided into three groups, namely "*elastic core spun yarns*", "*elastic twisted yarns*" and "*elastic wrapped spun yarns*".

In elastic core spun yarns, the elastic filament as a core is covered with staple fibres. Elastic twisted composite yarns are formed by twisting the two components together with a twister device. In elastic wrapped spun yarns, the staple fibre strand is wrapped around the elastic component or vice versa. These elastic composite yarns can be produced on the modified conventional ring spinning [2 - 10], modern spinning [11 - 15] and twisting [16] systems. In recent years, there have been some trends towards producing elastic composite yarns in new spinning systems [11 - 16].

Zhang *et al*. studied the influence of the draft ratio and linear density of spandex on the properties of coarse rotor composite yarns (58 tex) [11]. Test results showed that compared with composite yarns containing finer spandex, composite yarns containing coarser spandex exhibit higher breaking elongation, less irregularity (CV%) and a smaller number of imperfections [11]. In comparison with normal rotor spun yarn, elastic composite yarns have higher breaking strength, breaking elongation and elastic recovery, less irregularity CV% and a lower degree of hairiness [11]. They also verified the effect of the twist factor on the structure and properties of rotor-spun composite yarns with spandex. It was found that the yarn twisting parameter has a great influence on the properties of rotor-spun composite yarns with spandex. The twist deviation of composite yarn with spandex increases with machine twist. The properties of composite yarn containing coarser spandex are better and the twist deviation is less than that of composite yarn containing finer spandex. In comparison with normal rotor-spun yarn, composite yarns with spandex have higher breaking strength, elongation and elastic recovery, less irregularity (CV%), a lower degree of hairiness and less twist deviation [12]. In another study, Zhang *et al*. considered the effects of rotor speed (45,000, 49,300 and 53,700 r.p.m.), draft ratio (3.5, 4 and 4.5) and the twist factor (α_m) (142, 149, and 158) on the properties of coarse elastic rotor composite yarn (58 tex) [13]. It was found that all the parameters are effective, but the influence of the draw ratio is more significant. Comparing to normal yarns, the composite yarn surface is clearer and has better features [13].

Ortlek investigated the effects of nozzle pressure, delivery speed and elastane content on the mechanical properties of core-spun yarns produced on a modified MVS spinning frame [14]. The results obtained indicated that increasing the nozzle pressure and decreasing the delivery speed resulted in a significant deterioration of the mechanical properties of core-spun vortex yarns containing elastane [14]. In another research, Ortlek *et al*. examined the effects of spandex and core-spun yarn linear density parameters on the properties of elastic core-spun vortex yarns [15]. It was found that coarser yarns showed lower unevenness, imperfection and breaking elongation values than finer yarns. Coarser spandex led to a lower unevenness at a constant spandex drafting ratio [15].

It can be considered that current research works on the rotor spinning system are mostly concentrated on producing coarse elastic composite cotton spun yarns. However, there is no published work available on fine polyester/viscose elastic composite rotor spun yarns. Thus, the aim of this research was to investigate the effect of the spandex draw ratio and the yarn twist factor on the physical and mechanical properties of fine polyester/viscose elastic composite rotor spun yarns.

Materials and methods

Materials

We used a 4 ktex drawn carded polyester/viscose (65/35) sliver as well as an elastic filament (Lycra®) to produce yarn samples with a linear density of 20 tex. Both the polyester and viscose fibres were 38 mm in length and of 1.3 dtex (1.2 den) fineness. The linear density of spandex was 44.4 dtex.

Methods

In this work, the carded sliver was produced on a Litmax 0103 card machine equipped with a drawing frame before the coiling section. The carded sliver drawn was then fed to a modified rotor spinning machine (Saurer and Schlafhorst company, BD 340 Filea®) espe-

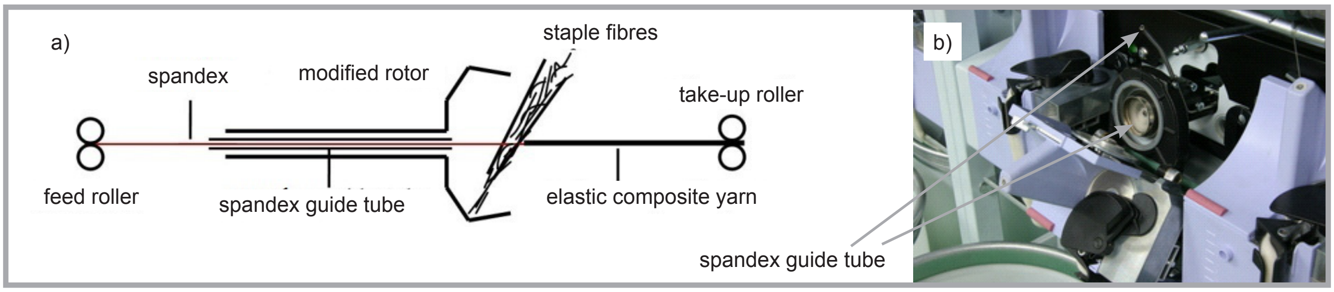

Figure 1. Typical pictures of the rotor spinning system; a) schematic diagram, b) rotor spinning section

cially designed to produce composite elastic rotor yarns. In this machine, the elastic component can be fed to an elastic guide tube by a positive drive system. A typical picture of this spinning system is shown in ***Figure 1***. The machine's constant parameters are as follows: OK61 opening roller with a rotational speed of 7,000 r.p.m., R6KS5 navel, rotor with an internal diameter of 54 mm and take-up speed of 70 m/min.

Spinning processing

To investigate the effect of the spandex draw ratio, 8 yarn samples with draw ratio values of 2.5, 3, 3.25, 3.5, 3.75, 4, 4.25 and 4.5 (D1 to D8) were produced by changing the positive linear speed of spandex feeding at a constant twist factor of (α_m) 118 and rotor speed of 60,000 r.p.m. In the second case, 4 yarn samples with different twist factors of 100, 109, 118 and 127 (T1 to T4) were prepared at a draw ratio of 3.5 by changing the rotational speed of the rotor. In order to compare the elastic composite rotor spun yarn properties with those of normal rotor-spun yarns, we also produced 5 normal rotor spun yarn samples (DN, TN1 to TN4). Thus 17 yarn samples were produced. Details of the yarn sample specifications are listed in ***Tables 1*** and ***2***.

Yarn tests

The physical and mechanical properties of the yarns produced, including tensile properties (breaking tenacity and elongation, elastic recovery ratio), irregularities and imperfections and hairiness were investigated. We used an Uster Dynamat II tensile tester to measure the breaking load and elongation. The specimen length was 50 and 60 cm for each yarn type. The percentage of yarn recovery was determined on an Instron tensile tester 5566 in which we used 5 loading cycles at a constant load of 147 cN, with a yarn gauge length of 0.25 m. The amount of yarn irregularity per 200 meters of the sample length was obtained on an Uster Tester 3 at a yarn speed of 200 m/min. 5 tests was done for each yarn sample. To measure yarn hairiness, a HTF Shirley hairiness tester was used at a speed of 60 m/min and yarn length of 50 meters. The machine was set to measure hairs with a length of more than 3 mm. All the tests were conducted under standard conditions (22 ± 2 °C and 65 ± 2% RH).

Yarn structure

To study the yarn structure, photos were taken in the longitudinal direction by using an SEM microscope (Philips, XL30) at a magnification of 30x. The Spandex position in the final yarn structure was also investigated by making cross sections of yarn for both samples of different draw ratio and twist factor values. The yarn cross-section was then observed with a reflective microscope at a magnification of 200×. For each type of yarn 20 images were analysed and then the spandex position categorised in four groups [5, 6]: Center type - in this case the spandex is positioned in the center of the yarn; Center-1/3R - the spandex is positioned between the center and 1/3 radius of the yarn; 1/3R-2/3R - the elastic filament is placed between the 1/3 radius and 2/3 radius of the yarn; and Radius type - the spandex is positioned beside the fringe of the yarn. In this case samples of maximum and minimum draw ratio and twist factor ratio (D1, D8 and T1, T4, respectively) were used.

***Table 1.** Yarn samples characteristics with different draw ratio and related normal rotor-spun yarn.*

Samples	Twist factor (α_m)	Linear speed of spandex feed, m/min	Draw ratio
D1	118	28.00	2.50
D2	118	23.33	3.00
D3	118	21.54	3.25
D4	118	20.00	3.50
D5	118	18.67	3.75
D6	118	17.50	4.00
D7	118	16.47	4.25
D8	118	15.56	4.50
DN	118	-	-

***Table 2.** Yarn samples characteristics with different twist factor and related normal rotor-spun yarn.*

Samples	Draw ratio	rotational speed of rotor, r.p.m.	Twist factor (α_m)
T1	3.5	51000	100
T2	3.5	56000	109
T3	3.5	60150	118
T4	3.5	65000	127
TN1	-	49500	100
TN2	-	54000	109
TN3	-	58400	118
TN4	-	62800	127

Results and discussion

Average results of the physical and mechanical properties of the yarn samples are summarised in ***Tables 3*** and ***4***. One way ANOVA and LSD tests were carried out using the statistical program SPSS15 to investigate whether there was any significant effect of different spandex draw ratios and yarn twist factors on the elastic polyester/viscose composite spun yarn properties.

*Table 3. Elastic composite yarn properties for different values of draw ratio and normal yarn properties; *S1: significant value without considering normal samples, **S2: significant value with considering normal samples, ***The figures in the brackets are S.D values.*

Samples	Tenacity, cN/tex	Elongation at break, %	Elastic recovery ratio, %	CV% per 200 m	Neps (+140%), km-1	Thin places (-30%), km-1	Thick places (+30%), km-1	Hairiness per 1 m
D1	17.64 (1.31)	11.04 (0.6)	49.20 (2.47)	12.55 (0.29)	40 (6.63)	237 (13.78)	21 (5.66)	0.06 (0.05)
D2	16.78 (1.61)	11.15 (0.83)	49.83 (2.14)	12.7 (0.20)	39.6 (7.16)	251 (12.90)	23.2 (6.1)	0.12 (0.04)
D3	18.84 (1.72)	11.59 (0.89)	52.22 (3.25)	12.72 (0.23)	34.2 (4.44)	227.6 (20.37)	21.8 (2.39)	0.12 (0.04)
D4	19.01 (1.55)	11.75 (0.81)	52.89 (1.09)	12.59 (0.25)	30.6 (7.73)	225 (10.49)	20.6 (3.36)	0.10 (0.00)
D5	19.08 (1.71)	11.81 (0.79)	56.98 (4.19)	12.42 ((0.26)	38.8 (5.45)	227 (14.35)	23.8 (4.02)	0.12 (0.04)
D6	19.32 (1.31)	11.86 (0.8)	54.79 (3.61)	12.65 (0.72)	35 (4.8)	225.2 (28.35)	22.4 (6.11)	0.06 (0.05)
D7	21.02 (1.48)	12.25 (0.87)	52.94 (1.20)	12.2 (0.09)	32.2 (6.87)	200 (15.12)	22.4 (2.97)	0.08 (0.04)
D8	20.43 (1.31)	12.48 (0.74)	52.30 (2.16)	12.22 (0.39)	32.8 (7.05)	192 (13.66)	21.6 (2.19)	0.08 (0.04)
DN	17.12 (1.4)	9.93 (0.82)	48.80 (2.64)	14.4 (0.19)	77 (10.22)	476.4 (12.19)	59.6 (8.79)	1.34 (0.26)
S1*	0.000	0.000	0.002	0.150	0.165	0.000	0.948	0.145
S2**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

*Table 4. Elastic composite and normal yarn properties for different values of twist factor; *S1: significant value without considering normal samples, **S2: significant value with considering normal samples, ***The figures in the brackets are S.D values.*

Samples	Tenacity, cN/tex	Elongation at break, %	Elastic recovery ratio, %	CV% per 200 m	Neps (+140%), km-1	Thin places (-30%), km-1	Thick places (+30%), km-1	Hairiness per 1 m
T1	19.65 (1.44)	13.2 (0.70)	48.41 (1.75)	12.08 (0.13)	21.80 (6.3)	206.2 (11.56)	19 (6.00)	0.24 (0.11)
T2	19.06 (1.52)	12.09 (0.73)	50.26 (1.44)	12.51 (0.37)	35.4 (5.08)	214.6 (13.2)	21 (3.67)	0.12 (0.08)
T3	18.64 (1.28)	11.62 (0.85)	54.14 (4.32)	12.45 (0.31)	29.6 (7.92)	213.8 (11.17)	21 (5.89)	0.10 (0.07)
T4	19.07 (1.09)	11.1 (0.80)	55.01 (1.62)	12.54 (0.22)	42.6 (3.05)	245 (9.92)	21 (3.67)	0.16 0.09)
TN1	17.74 (1.48)	10.86 (0.62)	39.47 (1.88)	13.67 (0.21)	51.2 (9.52)	370.8 (33.13)	34.6 (9.00)	1.52 (0.38)
TN2	17.59 (1.39)	10.54 (0.76)	42.80 (2.08)	13.81 (0.30)	63.4 (9.02)	409 (13.72)	45.6 (7.09)	1.22 (0.36)
TN3	17.38 (1.59)	10.1 (0.76)	46.83 (2.93)	14.04 (0.38)	70.2 (7.15)	433.6 (23.89)	55 (9.62)	1.32 (0.13)
TN4	17.81 (1.28)	9.72 (0.77)	53.33 (5.45)	14.48 (0.53)	85.6 (12.99)	508.2 (31.36)	69.4 (7.09)	1.40 (0.34)
S1	0.001	0.000	0.002	0.071	0.000	0.000	0.881	0.114
S2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

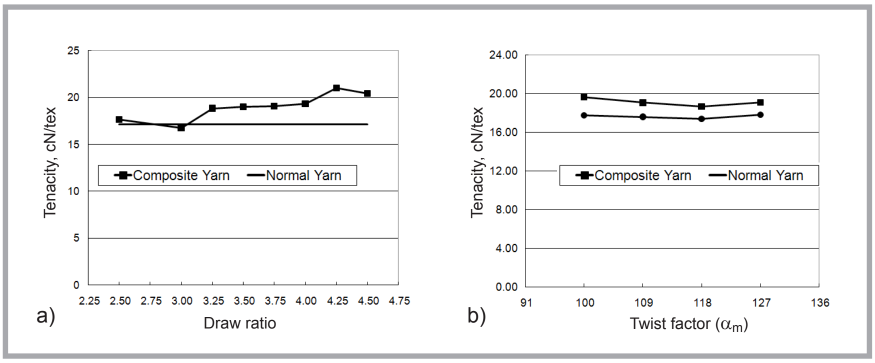

Figure 2. Effect of the draw ratio (a) and the twist factor (b) on the breaking tenacity of yarn samples.

Tensile properties

Tenacity

Figure 2a. and ***2.b*** show the effects of the draw ratio and twist factor on the tenacity of elastic composite yarns, respectively, comparing them with normal yarns. The composite yarn samples almost have a higher tenacity value than normal yarns, except at a draw ratio of 3, in which the value of tenacity is the same as the normal yarn value. In other cases an increasing trend is observed in the tenacity value with an increase in the spandex draw ratio. The tenacity of the composite yarn samples decreases from a draw ratio of 2.5 to 3 and then undergoes a rapid increase at a draw ratio of 3.25. It is also shown that a further increase in the draw ratio up to 4.0 has no significant influence on the yarn tensile strength. However, elastic composite rotor spun yarn has the highest tenacity at a draw ratio 4.25, which can be explained by considering that higher amounts of the spandex draw ratio leads to a decrease in the wrapping angle of elastic filament, presumably making it get closer to the central axis of the final yarn structure. As a result the elastic filament contributes much more to the composite yarn tenacity. This hypothesis is strongly in agreement with Kakvan *et al* [9].

The effect of the twist factor on yarn tenacity is shown in ***Figure 2.b***. For composite yarns, the tenacity has a greater value at a twist factor of 100, which slightly decreases at higher values of the twist factor. However, the differences between composite yarn tenacity values at twist factors of 109 to 127 are not significant.

In general, it is deduced that due to the twisting effect of spandex around the short-staple fibre strand with a relatively lower twist angle, the breaking tenacity of elastic composite rotor-spun yarns at different draw ratios and twist factor values is higher than that of normal yarns.

Elongation at break

The yarn elongation at break for different values of the draw ratio and twist factor are shown in ***Figures 3.a*** and ***3.b***. As shown in ***Figure 3.a***, we can see that increasing the amount of draw ratio, the breaking elongation of yarns increases gradually up to a value of 4 and then rises significantly with a greater slope. This is an acceptable result because higher values of the draw ratio lead to a greater amount of spandex retraction in the final yarn structure, thereby increasing the yarn elongation.

Increasing the twist factor has a reverse effect, as illustrated in ***Figure 3.b***, which leads to a significant decrease in the breaking elongation for both composite and normal yarns. Higher amounts of the twist ratio may intensify the wrapping effect of the elastic component around the staple fibre strand, which causes a greater amount of lateral pressure that prevents fibres from slipping over each other, resulting in lower breaking elongation.

Generally the breaking elongation of composite yarns is higher than that of normal yarns, which is apparently because of the application of spandex in the yarn structure.

Elastic recovery ratio

The typical elastic recovery of elastic composite yarn is shown in ***Figure 4***.

The effect of different values of the spandex draw ratio and twist factor on the amount of elastic recovery is also shown in ***Figure 5a*** and ***5.b***.

Increasing the draw ratio leads to a higher amount of the elastic recovery ratio up to a value of 3.75, which can be explained by considering that increasing the spandex draw ratio improves the stretch ability of the elastic filament in the yarn structure [5]. After this point, a further increase in the draw ratio deteriorates the elastic recovery behaviour of composite yarns, which can be attributed to the secondary creep phenomenon, expressed in previous studies [5, 7, 13, 15]. In most cases, composite yarns exhibit greater elastic recovery values compared with normal samples. The influence of the twist factor on elastic recovery is illustrated in ***Figure 5.b***. Increasing the twist factor results in an increase in the elastic recovery ratio for both normal and elastic composite yarn samples. It should be noted that spandex has a helical shape around the strand of staple fibres (***Figure 8***). At higher amounts of the twist factor, this form may be intensified, giving better elastic recovery properties to the final yarn structure.

Yarn irregularities

Yarn irregularity values (CV%) of the yarn samples are shown in ***Figure 6.a and 6.b***. The value of yarn CV% is significantly lower for composite yarns than for the normal yarn samples.

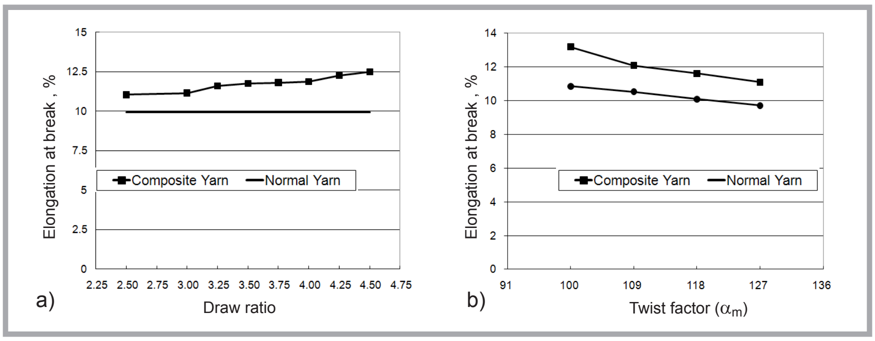

Figure 3. *Effect of the draw ratio (a) and the twist factor (b) on the breaking elongation of yarn samples.*

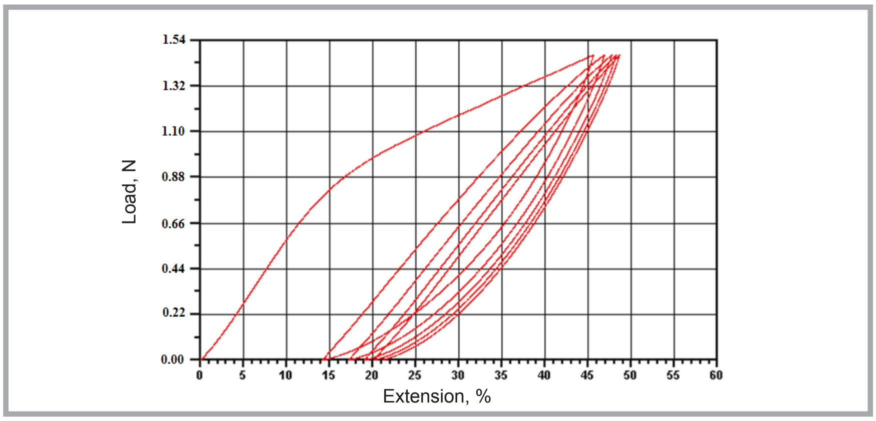

Figure 4. *Typical diagram of elastic recovery for sample D1.*

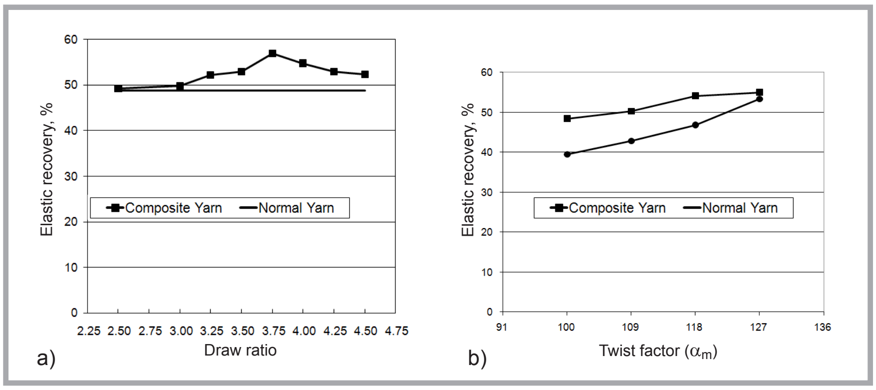

Figure 5. *Effect of the draw ratio (a) and the twist factor (b) on the elastic recovery ratio of yarn samples.*

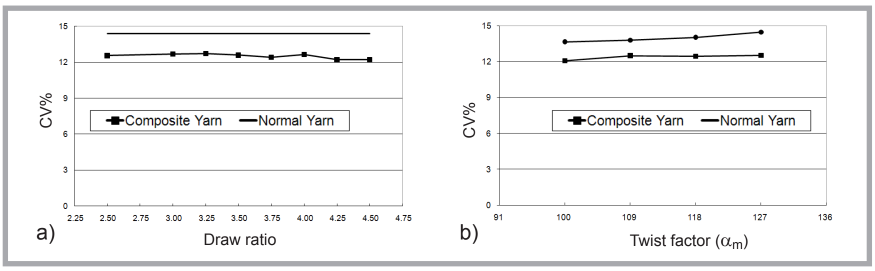

Figure 6. *Effect of the draw ratio (a) and the twist factor (b) on the CV% of yarn samples.*

Hairiness

The effects of the draw ratio and twist factor on the hairiness properties of elastic composite rotor-spun yarns is not significant. However, as shown in ***Figure 7***, the level of composite yarn hairiness is very low compared with normal yarns, which can be explained by considering the wrapping effect of the spandex that covers the surface of the staple fibre strand, which reduces the free ends of fibres coming out of the yarn body (***Figure 8***).

Yarn structure

Longitudinal view

Typical SEM photographs of longitudinal views for the composite yarn samples (D1, D8, T1 and T4) are shown in ***Figure 8***. It is clearly visible that the elastic component and short-staple fibre strand are twisted together, in which the elastic component can be distinguished from the staple fibre bundle. However, staple fibre strands are twisted around the elastic component since this component does not occupy the core section of the composite yarn.

Cross sectional view

Typical images of cross-sectional views of the elastic composite rotor spun yarn samples (D1, D8, T1 and T4) are shown in ***Figure 9***. It can be seen that the elastic component appears as a partially black or bright spot in the section. The elastic component is preferentially positioned in the outer surface of the composite yarn. As discussed before, the percentage of the elastic position in the composite yarn structure is classified according to Su *et al* [5, 6]. The percentage of the spandex position in each group is shown in ***Table 5***. The results of the spandex position against the relative radial position are also shown in ***Figure 10***. It is obvious that the elastic filament is mostly positioned in the outer layers of the yarn samples.

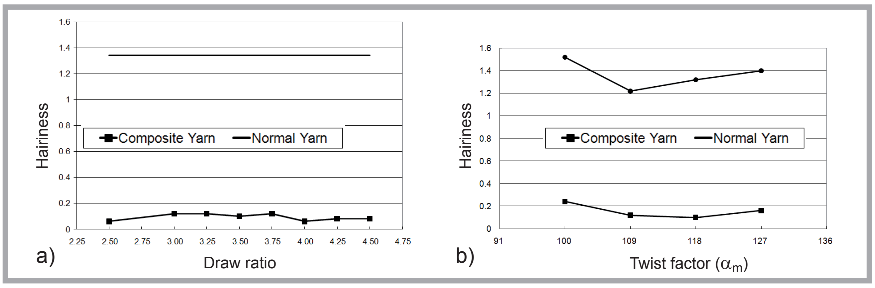

Figure 7. *Effect of the draw ratio (a) and the twist factor (b) on the hairiness of yarn samples.*

In elastic composite yarns with a lower amount of twist (T1), the elastic filament is more likely to be positioned in the central layers of the yarn, and its structure would be more similar to that of core spun yarn. However, for other yarn samples, the elastic component preferentially occupied the outer layers of the yarn section.

Conclusion

The test results show that the draw ratio and twist factor both have considerable effects on the tensile properties of the elastic composite yarn samples. The yarn breaking tenacity takes its lowest value at a draw ratio of 3 and reaches its maximum at a value of 4.25. Moreover the yarn tenacity decreases gradually with an increase in the twist factor, with the highest value of which occurring at a twist factor of 100. Increasing the draw ratio causes an increase in yarn breaking elongation, while increasing the twist factor reverses this trend. At first, with an increase in the draw ratio, the value of elastic recovery increases up to a value of 3.75 and then decreases. Increasing the yarn twist factor leads to an increase in yarn elastic recovery for all of the yarn samples. In most cases, the values of yarn breaking tenacity, elongation and elastic recovery of composite yarns are significantly higher than those of the normal spun yarn samples. The coefficient of variation (CV%) and other imperfections (neps, thin and thick places) of elastic composite yarns are significantly lower than those of normal yarns. The amount of yarn hairiness is also lower for elastic yarns compared with normal spun yarns. The pictures of yarn cross-sections show that the elastic filament is mostly positioned in the outer layer of the final yarn structure, but in samples with a lower amount of the twist factor, the spandex component occupies places closer to the central axis of the yarn.

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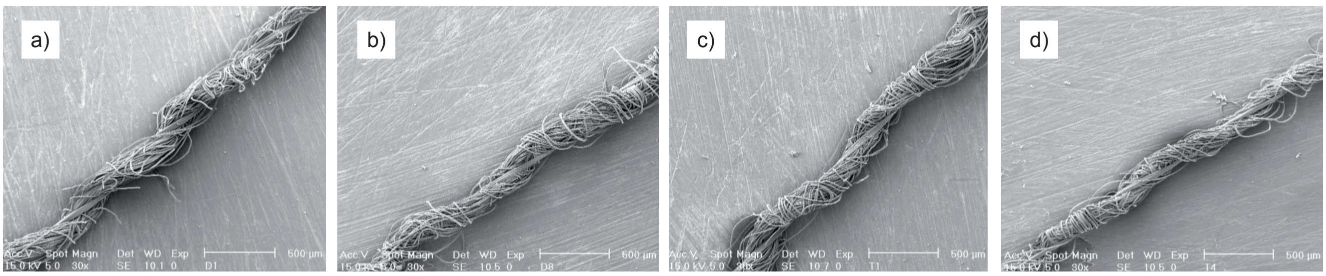

Figure 8. *Longitudinal view of yarn samples; a) sample D1 (draw ratio = 2.5, twist factor = 118, b) sample D8 (draw ratio = 4.5, twist factor = 118), c) sample T1 (draw ratio = 3.5, twist factor = 100), d) sample T4 (draw ratio = 3.5, twist factor = 127).*

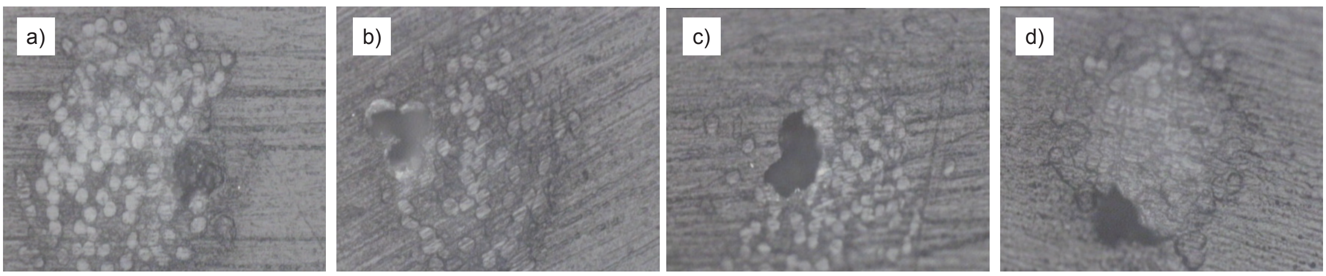

Figure 9. *Cross sectional view of yarn samples; a) sample D1 (draw ratio = 2.5, twist factor = 118, b) sample D8 (draw ratio = 4.5, twist factor = 118), c) sample T1 (draw ratio = 3.5, twist factor = 100), d) sample T4 (draw ratio = 3.5, twist factor = 127).*

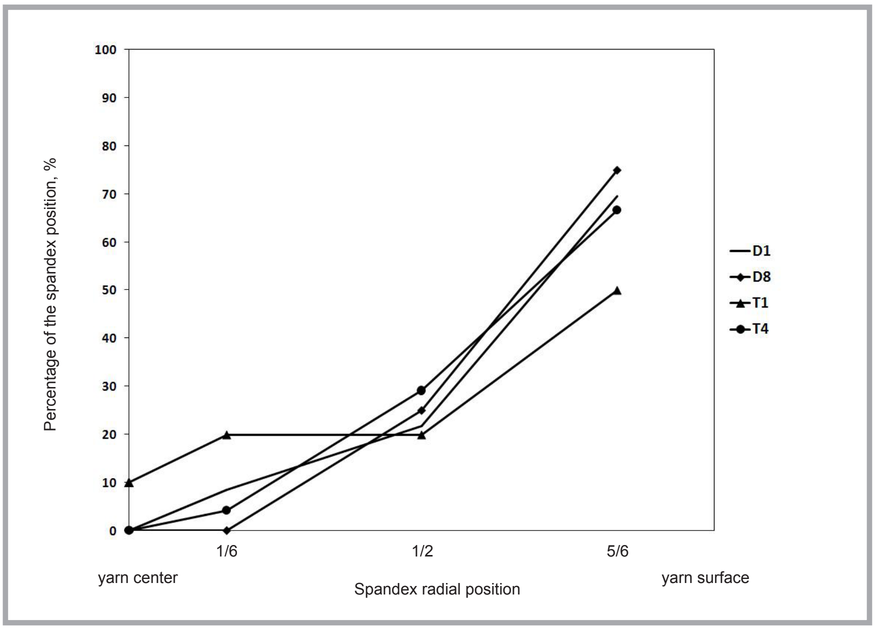

Figure 10. *Percentage of the spandex position against the radial position.*

Table 5. *Percentage of the spandex position in the final structure of the composite yarn.*

Samples	Spandex content, %			
	Cross-sectional type			
	Center	Center-1/3R	1/3R-2/3R	Radius
D1	0	8.6	21.7	69.6
D8	0	0.0	25.0	75.0
T1	10	20.0	20.0	50.0
T4	0	4.2	29.1	66.6

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