Exploratory Work of Spinning Condition on Structure of Staple-core Twin-spun Yarns

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ABSTRACT

In order to design and develop novel-spun yarns with good functionality, we investigated how to construct a core-sheath structure adapted from a multilayered structure of triplet-spun yarn and/or made from a twin-spun yarn with core-staple fibers using an experimental ring spinning frame. The results were follows: (1) staple-core twin spun yarn, a new yarn, could be made by applying the production method of triplet-spun yarn and/or combining the production methods of core-spun yarn and twin-spun yarn into one twisting process; (2) by adopting three rovings made from fibers of differing length and fineness, the resulting triplet-spun yarn had the core-sheath structure within an adequate spinning condition; (3) for the construction of core-sheath structure, it is important that there be a difference between spinning tensions at the center and the two sides of the drafted fiber strands or drafted strand lengths from the front roller nip to the point of yarn formation by controlling the distance of supply rovings and the yarn's twist factor.
***Key words*:** staple-core twin-spun yarn, differing fiber length, differing fiber fineness, triplet-spun yarn

Introduction

To differentiate textile products from each other, many yarns are made from chemical fibers with various functional properties. However, in recent years, issues such as "comfort", "safety", "user-friendliness" and "greenness" have become key concepts, not only the production of regenerated fibers, but also the utilization of natural fibers, which has been on the rise. In addition, for diversifying and improving the properties of spun yarns, it is necessary to develop new techniques and methods for combining different types of fibers in a multilayered yarn structure. Hybrid and composite yarns are produced using not only the ring-spinning frame, but also the open-end, the jet, the friction spinning machines, among others [1-13].

In our previous papers [14], we have reported on the development and characteristics of triplet-spun yarns made by combining staple fibers of three different finenesses with the same fiber length into one twisting process. In this paper, we describe the design and development of novel staple-core twin-spun yarns (SCTY) and/or triplet-spun yarns with the core-sheath structure made from regenerated staple fibers of differing fineness and length (DFDL) using an experimental ring-spinning frame. As it is not easy to control short-staple fibers in the roller drafting system, in particular, one of the most important techniques is to produce a difference between the spinning tensions of the drafted-staple fibers, which simultaneously emerge from the front roller of the spinning frame. So, to produce the SCTY, we investigate the effects of spinning condition without an adequate tension device for the staple-core fibers.

Experiment

Figure 1 shows schematic illustrations for various yarn productions using an experimental ring-spinning frame. In general, single yarn is made from one staple fiber roving. Twin-spun yarn is produced by twisting together two of the same strands that have been separated in the drafting zone, resulting in a yarn with the characteristics of a two-fold structure within a conventional single yarn. As in the spinning method for twin-spun yarn, triplet-spun yarn with a three-ply structure can be produced using three staple fiber rovings. On the other hand, core-spun yarn is generally made by combining staple fibers for the sheath layer and a filament yarn for the core layer using a spinning frame in which the core-filament yarn is controlled at an adequate tension by a device. Geometrically speaking, the core-sheath structure can be constructed by utilizing the difference between spinning tensions and/or path lengths in the inner and outer layers in the yarn. In the spinning system, although it is easy to control the tension of a core-filament yarn, it is very difficult to control the tension of staple fibers as core yarn. However, it is well known that finer and longer fibers have a tendency to locate at the center of a yarn, whereas the coarser and shorter fibers can be found near the yarn surface [15-17]. Therefore, by applying the spinning method for triplet-spun yarn or combining the spinning methods of core-spun yarn and twin-spun yarn into one twisting process, we investigate how to produce SCTYs or triplet-spun yarns whose core-sheath structure is made from fibers of DFDL. It has to be understood that the method used lacks of a proper tension device for the staple-core fibers.

In the spinning method for triplet-spun yarn shown in Figure 1, a drafted fiber strand of length (*L*1) from the front roller nip to the point of yarn formation at the center position of "B" is shorter than that of length (*L*2) at each side position of "A" or "C". When these strand lengths vary with the type of roving, the distance of the supply rovings, the twist factor of the yarn, and so on, the structures of triplet-spun yarns differ from each other and these factors constitute the spinning parameter of each yarn. Regarding the arrangement of the three supply rovings in the spinning, when two rovings at the each side position are made from the same fibers and fibers drafted from the other center roving are located at the center in the yarn produced, this yarn is called SCTY. Furthermore, in combinations in which these two types in three rovings are made from staple fibers of differing length and the same fineness, the resultant yarn is called "same fiber fineness and different fiber length of staple-core twin-spun yarn" (SFDLSCTY). In combinations in which the two types of supply rovings are made from staple fibers of differing fineness and the same fiber length, this yarn is called "different fiber fineness and same fiber length of staple-core twin-spun yarn" (DFSLSCTY). When the supply rovings are made from staple fibers of DFDL, this yarn is called "different fiber fineness and different fiber length of staple-core twin-spun yarn" (DFDLSCTY).

To investigate the geometric position of each fiber in the SCTYs, we used four kinds of rovings made from viscose rayon staple fibers of differing fineness (0.9 and 1.4 (dtex)) and cut length (38 and 51 (mm)) as listed in Table 1. Table 2 lists the arrangement of the three supply rovings in the triplet-spun yarn spinning method. The linear density of the yarn produced was about 29.5 tex (20 Ne). In the spinning condition for triplet-spun yarn, the drafted strand length (*L*1) at the center position (B) of the three rovings arrangement was measured by a scale in which each measurement was repeated 10 times per yarn. The other strand length (*L*2) at each side position (A or C) was calculated from the mean value of the center length using the basic trigonometry. Moreover, by manual operation, yarn with a tension of 5 gf was wound with a space in between the adjoining coils on a thick cover glass. Under a microscope, we observed longitudinal and cross-sectional views of the yarn, in which each testing was repeated 10 times with different samples. Furthermore, the breaking strengths of the rovings were observed using an Instron constant rate of an elongation tensile tester with different test lengths, an extension rate of 300 mm/min, and 10 tests per roving.

Results and Discussion

Figure 2 shows longitudinal views of various yarns produced under different spinning conditions of the roving distance (*S*) and the twist factor (*K*). In the spinning method for triplet-spun yarn, the drafted strand lengths of *L*1 and *L*2 increase with increase of the roving distance and/or decrease of the twist factor [10]. Then, the twist level per unit length of the produced yarn increases with increase of the roving distance and/or the drafted strand length. In the roving arrangement of same fineness and different length (SFDL) with a different fiber cut length of A38 / B51 / C38 mm and the same fiber fineness of 0.9 dtex, when the spinning condition is controlled at a roving distance of 9 mm and a twist factor of 4.5 turns per 2.54cm/Ne$^{1/2}$, the produced yarn has a core-sheath structure in which the longer staple fibers in the center roving are covered with the shorter staple fibers in each side roving as shown in Figure 2(c). In general, the core-sheath structure or the core-spun yarn is constructed by tensioning of the core yarn or the filament yarn. Accordingly, it can be expected that the spinning tension of the staple fibers in the center strand is greater than that of each side strand. However, it was observed that, when the twist factor is lower than about 4 turns per 2.54cm/Ne$^{1/2}$ with a roving distance of 9 mm, the spinning does not continue the yarn formation with increase of the fiber strand length of *L*2.

Table 3 lists the relationship between the drafted strand length and the difference from 1/2 of fiber cut length under different spinning conditions. It is assumed that when the length of a drafted fiber strand becomes shorter than 1/2 of the fiber cut length, the strand has a greater spinning tension. As most of the obtained strand lengths of *L*1 and *L*2 are shorter than 1/2 of each fiber cut length, these drafted strands have a greater tension. However, when the spinning condition is controlled at a roving distance of 9 mm and a twist factor of 4.5 turns per 2.54cm/$Ne^{1/2}$, not only is the strand length of $L1$ shorter than 1/2 of the fiber cut length, but also the strand length of $L2$ is greater than 1/2 of the fiber cut length. Thus, this spinning condition is controlled at a greater tension for $L1$ and a lower tension for $L2$. Namely, the core-sheath structure in the yarn produced can be made by the difference between the spinning tensions of $L1$ and $L2$.

Furthermore, SCTY with the various roving arrangements of SFDL, differing fineness and the same cut length (DFSL), and DFDL were produced under the spinning condition controlled at a roving distance of 9 mm and a twist factor of 4.5 turns per 2.54cm/$Ne^{1/2}$. In this paper, an arrangement of three rovings made from fibers of differing fineness and cut length at the positions of A, B, and C are denoted as A0.9 / B1.4 / C0.9 dtex, A38 / B51 / C38 mm, and so on. Figure 3-5 show the longitudinal views of various yarns produced using the differing roving arrangements.

In SFDL as shown in Figure 3, in a comparison with a roving arrangement of A51 / B38 / C51 mm and the same fiber fineness of 0.9 dtex in Figure 3(a) or an arrangement of A38 / B51 / C38 mm and the same fiber fineness of 1.4 dtex in Figure 3(c), the good coverage structure in the yarn produced was made from an arrangement of A38 / B51 / C38 mm and the same fineness of 0.9 dtex in Figure 3(a). It is also found that the longer and finer fibers were easily located at the center in the yarn cross section, and the shorter and coarser fibers at the yarn surface.

In DFSL as shown in Figure 4, in comparison of the yarn structure covered with staple fibers of the two side rovings, the yarn appearance in Figure 4(a) is nearly equal to that of Figure 4(b)-(d). So, it can be understood that the difference between fiber fineness appears to have a small effect on production of the core-sheath structure.

In DFDL as shown in Figure 5, in a comparison with a roving arrangement of A1.4 / B0.9 / C1.4 dtex and A51 / B38 / C51 mm in Figure 5(b) or an arrangement of A0.9 / B1.4 / C0.9 dtex and A51 / B38 / C51 mm in Figure 5(d), the good coverage structure of the yarn produced was made from an arrangement of A0.9 / B1.4 / C0.9 dtex and A38 / B51 / C38 mm in Figure 5(a) or an arrangement of A1.4 / B0.9 / C1.4 dtex and A38 / B51 / C38 mm in Figure 5(c). Furthermore, the longitudinal view of yarn in Figure 5(a) is nearly equal to that of Figure 5(c). Thus, for constructing the core-sheath structure in the yarn produced and tensioning the core staple fibers, the effect of the fiber length is greater than that of the fiber fineness.

Accordingly, in the production of SCTY, the core-sheath structure can be made from the roving arrangements of SFDL and DFDL excepting of DFSL. Table 4 lists the relationship between the covered structure in the yarn produced and the drafted-staple fiber strands of $L1$ and $L2$. It is also clear that the good coverage structure resulted from the difference between the spinning tensions, which were controlled at a greater tension for the center strand and at a lower tension for each side strand without a tension device. Thus, if the same spinning tension was set up in other arrangements of three supply rovings made from various fibers, the core-sheath structure in the yarn can surely be produced. Namely, it is necessary to set up the spinning condition by controlling the distance of the supply rovings and/or the twist factor of yarn.

Moreover, Figure 6 shows the typical cross-sectional views of SCTY. In a roving arrangement of SFDL with A38 / B51 / C38 mm and 0.9 dtex in Figure 6(a) or an arrangement of DFDL with A38 / B51 / C38 mm and A0.9 / B1.4 / C0.9 dtex in Figure 6(c), the yarn cross section shows the core-sheath structure as illustrated in Figure 1(c). On the other hand, when the strand length of $L1$ is longer than 1/2 of the fiber cut length, the fibers must migrate outwards and do not get well anchored in the yarn. So, the yarn cross section does not show the core-sheath structure as illustrated in Figure 6(b). However, if three fibers strands of $L1$ and $L2$ are nearly equal to the same spinning tension, the produced yarn has a side-by-side structure in which the central angle of fiber assembly is equal to 120° (see [14]).

Finally, to check the relationship between the spinning tension and the drafted strand lengths of $L1$ and $L2$, the breaking loads of the four rovings were assessed. Table 5 lists the relationship between the breaking load of the rovings and the sample length that were tested. In all four types of rovings made from staple fibers of DFDL, the breaking load decreases with increase of the sample length. However, it was observed that, when it comes to the breaking load of roving, the effect of the fiber cut length is greater than that of the fiber fineness. When the sample length becomes shorter than about 1/2 of the fiber cut length, each roving has a greater load of about 40 N. In addition, when the sample length is longer than the fiber cut length, the fiber slippage dictates the failure and fibers are just non-load bearing elements, resulting into low tensile strength.

Conclusions

To design and develop novel-spun yarn with good functionality, SCTYs and/or triplet-spun yarns with the core-sheath structure made from staple fibers of differing fineness and cut length using an experimental ring-spinning frame without a tension device for the staple-core fibers were investigated. The results were as follows: (1) SCTY could be produced by the arrangement of three rovings made from staple fibers of SFDL or those of DFDL; (2) in the production of SCTYs, it was very important to create a difference between a greater spinning tension of the staple fibers in the core layer and a lower spinning tension of the staple fibers in the sheath layer by controlling the distance of the supply rovings and the twist factor; (3) in the construction of the core-sheath structure of the resultant yarn, the effect of fiber length was greater than that of fiber fineness; (4) it was very useful to control the spinning tension of the short-staple fibers using the same production method as for triplet-spun yarn.

Further study is needed to refine the spinning method of SCTY and to investigate the characteristics of novel-spun yarn and fabrics.

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Literature Cited

1. Gore, C., The Siro Spun Process, *Textile Ind*., **146**, 64-65 (1982).
2. Happey, F., "Contemporary Textile Engineering", Academic Press, London 1982, p.87.
3. Salhotra, K., Quality Improvement of Sirospun Yarns Through Use of Finer Rovings, *Textile Res. J*., **60**, 687-689 (1990).
4. Wu, W., Lee, J., Effects of Spread Width on the Structure, Properties, and Production of a Composite Yarn, *Textile Res. J*., **65**, 225-229 (1995).
5. Fatma, G., Demet, Y., Özer, G., A Comparison of Compact Yarn Properties Produced on Different Systems, *Textile Res. J*., **76**, 226-234 (2006).
6. Soe, A., Takahashi, M., Nakajima, M., Matsuo, T., Matsumoto, T., Structure and Properties of MVS Yarns in Comparison with Ring Yarns and Open-End Rotor Spun Yarns, *Textile Res. J*., **74**, 819-826 (2004).
7. Cheng K. B. and Murray R., Effects of Spinning Condition on Structure and Properties of Open-End Cover-Spun Yarns, *Textile Res. J.*, **70**, 690-695 (2000).
8. Matsumoto Y., Toriumi K., Tsuchiya I., and Harakawa K., Properties of Double-Core Twin Spun Silk Yarns and Fabrics, *Textile Res. J.*, **62**, 710-714 (1992).
9. Matsumoto Y., and Tsuchiya I., Apparatus and Method for producing Composite Yarn", Japan Patent, No.2635172 (1997).
10. Matsumoto, Y., Saito, H., Toriumi, K., Morooka, H., Harakawa, K., Twist Level of Triplet Spun Silk Yarn, *J. Seric. Sci., Jpn.*, **66**, 323-329 (1997).
11. Matsumoto Y. "Open-End Rotor Spun Hybrid Yarns and their Production Methods", TOKUGAN 2000-137864, Japan.
12. Matsumoto Y., Fushimi S., Saito H., Sakaguchi A., Toriumi K., Nishimatsu T., Shimizu Y., Shirai H., Morooka H., and Gong H., Twisting Mechanisms of Open-End Rotor Spun Hybrid Yarns, *Textile Res. J.*, **72**, 735-740 (2002).
13. Matsumoto Y., Saito H., Sakaguchi A., Toriumi K., Nishimatsu T., Shimizu Y., Shirai H., Morooka H., and Gong H., Combination Effects of Open-End Rotor-Spun Hybrid Yarns, *Textile Res. J.*, **74**, 671-676 (2004).
14. Matsumoto Y., Kimura H., Yamamoto T., Matsuoka T., and Fukusima K., Characteristics of Novel Triplet Spun Yarns Made from Fibers of Differing Fineness, *Textile Res. J.*, **79**, 947-952 (2009) .
15. Boswell, H. R. and Townend, P. P., Some Observations on the Structure of a Multicolored Yarn, *J. Textile Inst.*, **46**, T778-T779 (1955).
16. Morton, W. E., The Structure of Multi-colored Yarns, *J. Textile Inst.*, **47**, T239-T240 (1956).
17. Balasubramanian, N., Effect of Processing Factors and Fiber Properties on the Arrangement of Fibers in Blended Yarns, *Textile Res. J.*, **40**, 129-141 (1970).

Table 1 Sample rovings

Fiber			Roving count
Fineness (dtex)	Cut length (mm)	Color	($\times 10^2$ tex)
0.9	38	Brown	5.9
0.9	51	Green	5.9
1.4	38	Black	5.9
1.4	51	Blue	5.9

Table 2 Arrangement of supply rovings

Sample No.	Roving arrangement	Fiber: Fineness (dtex)	Fiber: Cut length (mm)
1	SFDL	0.9	38 / 51 / 38
2		0.9	51 / 38 / 51
3		1.4	38 / 51 / 38
4		1.4	51 / 38 / 51
5	DFSL	0.9 / 1.4 / 0.9	38
6		1.4 / 0.9 / 1.4	38
7		0.9 / 1.4 / 0.9	51
8		1.4 / 0.9 / 1.4	51
9	DFDL	0.9 / 1.4 / 0.9	38 / 51 / 38
10		1.4 / 0.9 / 1.4	51 / 38 / 51
11		0.9 / 1.4 / 0.9	51 / 38 / 51
12		1.4 / 0.9 / 1.4	38 / 51 / 38

All denoted by the roving position of A / B / C

Table 3 Strand lengths and difference from 1/2 cut length

	Fiber cut length (mm)			
	51		38	
	Drafted strand length			
Spinning condition	*L*1 (mm)	Difference	*L*2 (mm)	Difference
Twist factor (*K*) = 4.5 (turns per 2.54cm/$Ne^{1/2}$)				
Distance of roving (*S*) = 4.5 (mm)	12.0	< 51/2	12.8	< 38/2
6.0	13.0	<	14.3	<
7.5	19.0	<	20.4	=
9.0	23.0	<	24.7	>
Twist factor (*K*) = 6.0 (turns per 2.54cm/$Ne^{1/2}$)				
Distance of roving (*S*) = 4.5 (mm)	6.0	<	7.5	<
6.0	8.0	<	10.0	<
7.5	12.0	<	14.2	<
9.0	15.0	<	17.5	<

Table 4 Relationship between covered structure and strand condition

			Yarn structure			
Roving			Good coverage		Poor coverage	
Position	Cut length (mm)	Strand	Mean length (mm)	Expected tension	Mean length (mm)	Expected tension
SFDL and DFDL						
B	51	L1 =	22.9 (<51/2)	Greater	25.6 (=51/2)	Lower
A&C	38	L2 =	24.6 (>38/2)	Lower	27.1 (>38/2)	Lower
DFSL						
B	38	L1 =	—		23.4 (>38/2)	Lower
A&C	51	L2 =	—		25.1 (=51/2)	Lower

Table 5 Breaking load of rovings

Fiber			Maximum load (N)	
Fineness (dtex)	Cut length (mm)	Sample length (mm)	Mean	CV%
0.9	38	10	68.7	7.23
		20	43.9	14.8
		30	10.1	14.0
		40	0.85	65.4
		50	0.76	57.5
1.4	38	10	63.5	6.27
		20	39.2	6.67
		30	9.4	19.0
		40	0.77	55.2
		50	0.64	51.1
0.9	51	10	77.1	1.88
		20	56.1	3.41
		30	27.9	10.5
		40	12.6	7.67
		50	1.57	46.1
1.4	51	10	78.8	0.535
		20	56.6	8.70
		30	28.1	11.3
		40	11.4	9.71
		50	1.26	32.7

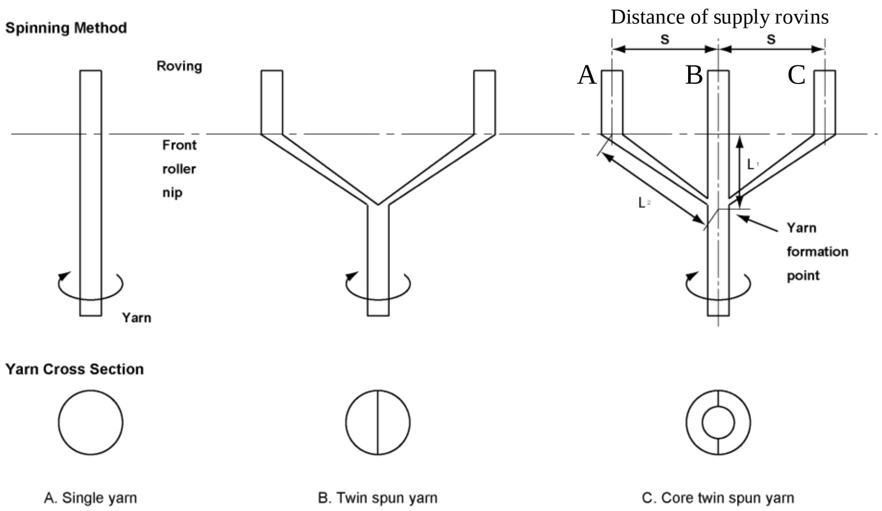
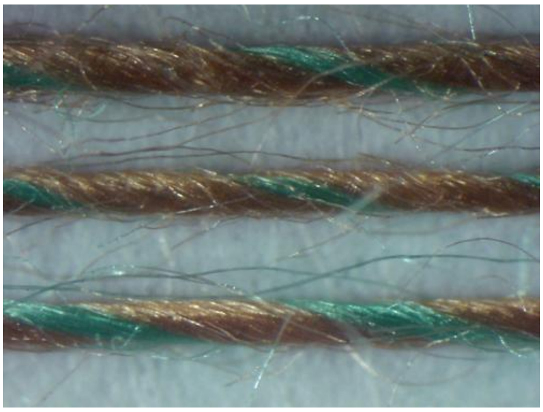
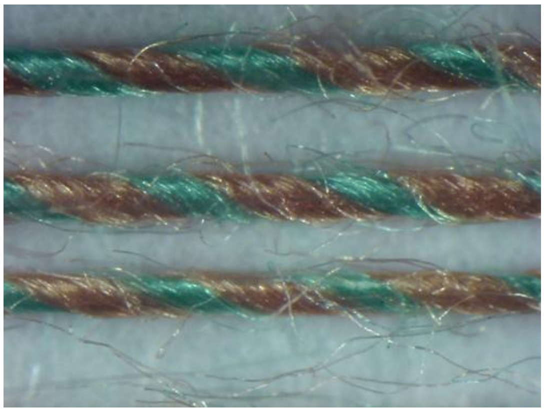


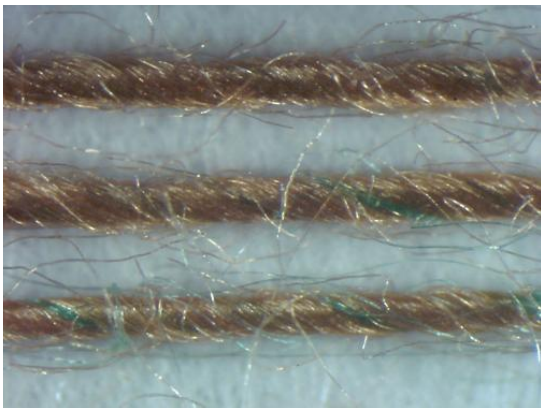
Figure 1 Schematic illustrations of various spinning methods.



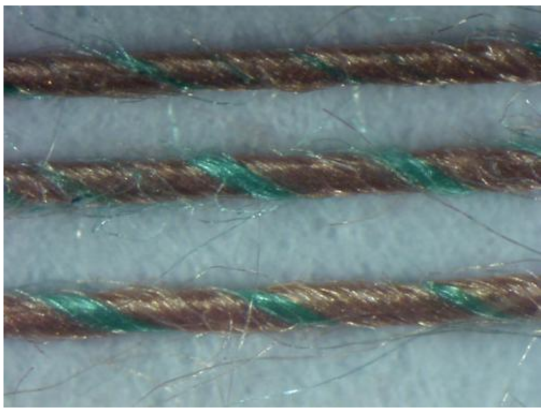
(a) S=4.5mm, K=3.5turns per 2.54cm/Ne$^{1/2}$



(b) S=4.5mm, K=6.0turns per 2.54cm/Ne$^{1/2}$

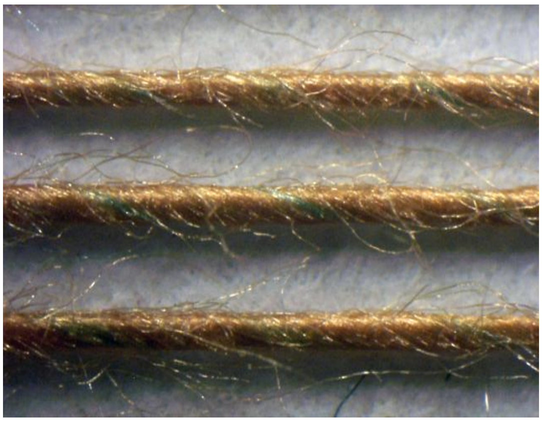


(c) S=9.0mm, K=4.5turns per 2.54cm/Ne$^{1/2}$



(d) S=9.0mm, K=6.0turns per 2.54cm/Ne$^{1/2}$

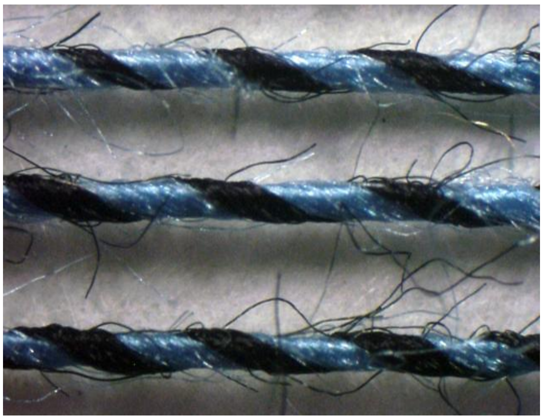
Figure 2 Longitudinal views of yarns (SFDL: 0.9 dtex - 38/51/38 mm).



(a) 0.9 dtex - 38/51/38 mm
*L*1 = 22.6 mm, Greater tension
*L*2 = 23.4 mm, Lower tension

(b) 0.9 dtex - 51/38/51 mm
*L*1 = 20.8 mm, Lower tension
*L*2 = 22.7 mm, Greater tension

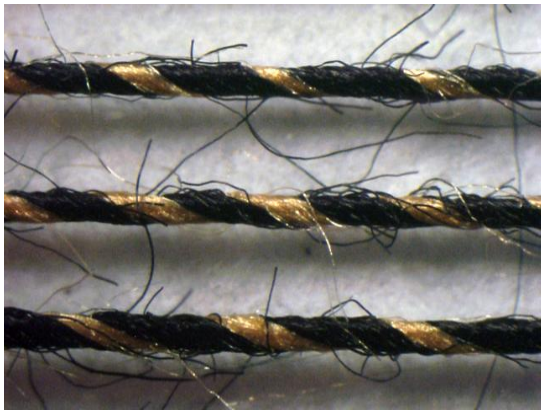
(c) 1.4 dtex - 38/51/38 mm
*L*1 = 24.4 mm, Greater tension
*L*2 = 26.0 mm, Lower tension



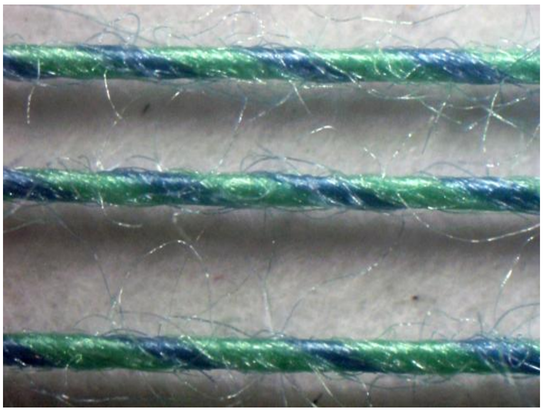
(d) 1.4 dtex - 51/38/51 mm
*L*1 = 25.7 mm, Lower tension
*L*2 = 27.2 mm, Lower tension

Figure 3 Appearances of yarns from fibers of SFDL.

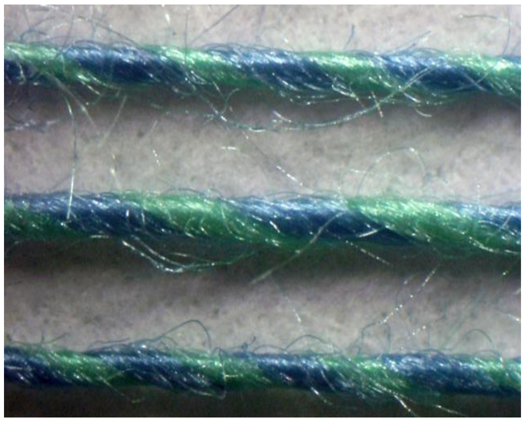
(a) 38 mm – 0.9/1.4/0.9 dtex
*L*1 = 23.1 mm, Lower tension
*L*2 = 24.8 mm, Lower tension



(b) 38 mm – 1.4/0.9/1.4 dtex
*L*1 = 23.0 mm, Lower tension
*L*2 = 24.7 mm, Lower tension

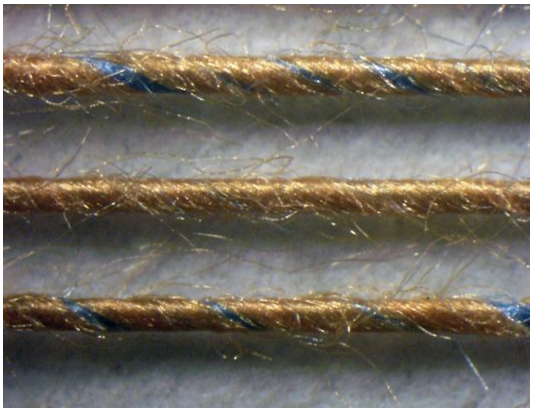


(c) 51 mm – 0.9/1.4/0.9 dtex
*L*1 = 26.8 mm, Lower tension
*L*2 = 28.3 mm, Lower tension



(d) 51 mm – 1.4/0.9/1.4 dtex
*L*1 = 25.6 mm, Greater tension
*L*2 = 27.1 mm, Lower tension

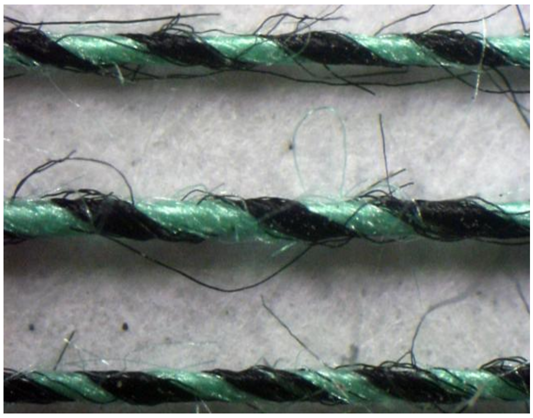
Figure 4 Appearances of yarns from fibers of DFSL.



(a) 38/51/38 mm – 0.9/1.4/0.9 dtex
*L*1 = 23.6 mm, Greater tension
*L*2 = 25.2 mm, Lower tension

(b) 51/38/51 mm – 1.4/0.9/1.4 dtex
*L*1 = 22.2 mm, Lower tension
*L*2 = 24.0 mm, Greater tension

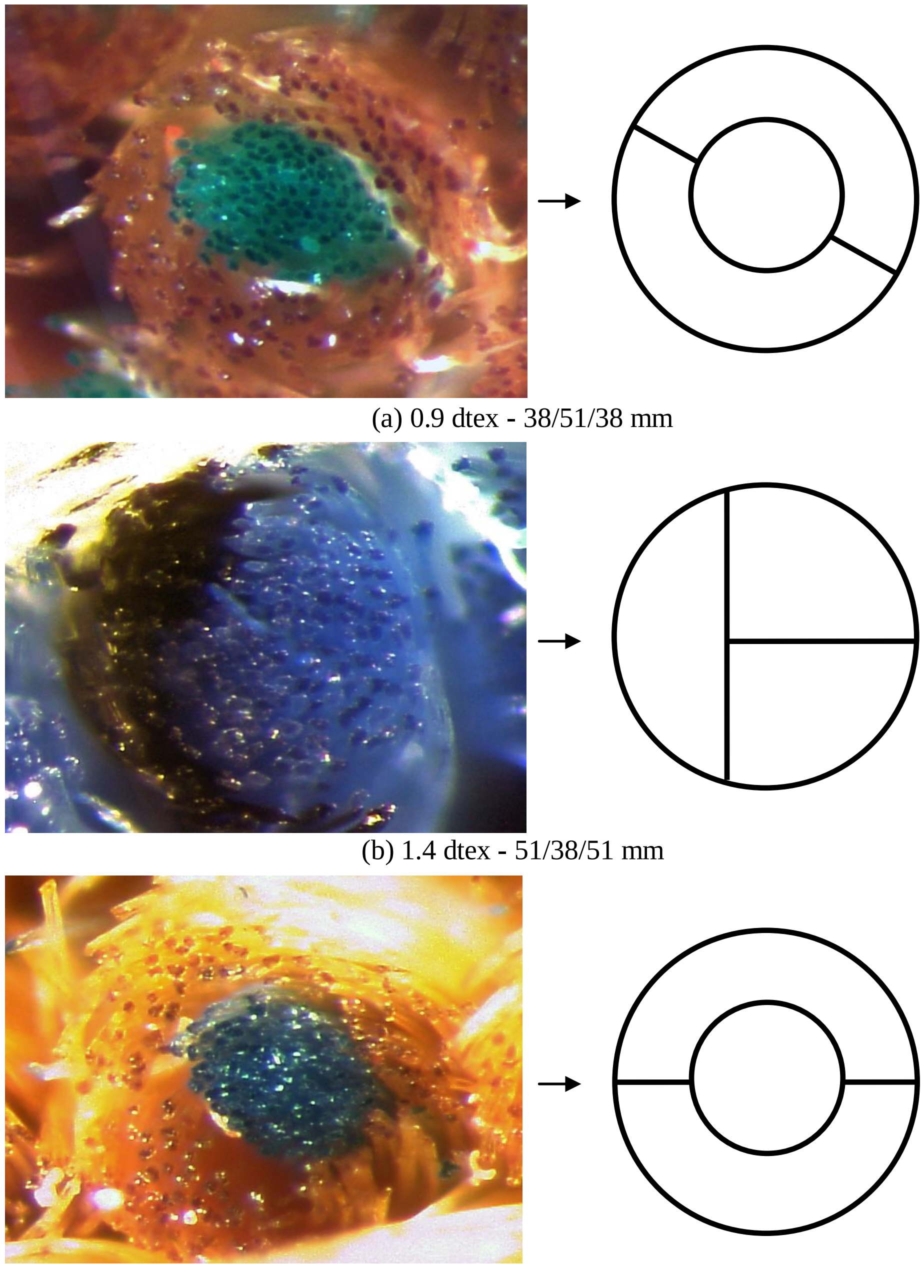
(c) 38/51/38 mm – 1.4/0.9/1.4 dtex
*L*1 = 22.7 mm, Greater tension
*L*2 = 24.4 mm, Lower tension



(d) 51/38/51 mm – 0.9/1.4/0.9 dtex
*L*1 = 25.6 mm, Lower tension
*L*2 = 27.1 mm, Lower tension

Figure 5 Appearances of yarns from fibers of DFDL.

Real Schematic illustration



(a) 0.9 dtex - 38/51/38 mm

(b) 1.4 dtex - 51/38/51 mm

(c) 0.9/1.4/0.9 dtex – 38/51/38 mm

Figure 6 Typical cross-sectional views of yarns.