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# Construction of twin staple-core spun yarn with two points of yarn formation in one twisting process

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## Abstract

In order to diversify the structure of spun yarn as textile material and to develop novel composite spun yarn with good functionality, we investigated how to construct single yarn with a twin staple-core and sheath structure and/or adopt the production method of triplet spun yarn using an experimental ring spinning frame. Fundamentally, the unique spinning conditions were not only the arrangement and the distances of three rovings and the twist level of yarn, but also the types of staple fibers.

The following results were obtained: (1) by adopting the production method of triplet spun yarn with three rovings under the spinning condition with two differing roving distances, the yarn combining side-by-side and sheath-core structures could be constructed by two points of yarn formation and one twisting process without the device for controlling of spinning tension; (2) in the spinning method of twin staple-core spun yarn, it was necessary to control the difference between spinning tensions of the sheath layer and the twin staple-core layer with side-by-side structure under the spinning condition with the lower twist level of yarn and the greater difference between two roving distances; (3) for combining the twin staple-core and the sheath layers, it was important not only to control the greater length of drafted fiber strands for the sheath layer, but also to choose the cut length of the sheath and the core fibers.

## Keywords

twin staple-core spun yarn, two points of yarn formation, one twisting process, three-layered composite single yarn

In recent years, demands for the characteristics of textile products have been diversifying and intensifying. The characteristics of textile products are varied by combining the properties of fibers and the structures of fiber assemblies; the human body, especially the skin, is very sensitive to their differences. Therefore, it is necessary to combine the composition of fiber materials with the diversification of yarn structures in order to improve the properties of textile products.[1–5]

In general, single yarn is produced by one twisting process with one roving on various types of spinning frames and has the simplest structure of spun yarn. Twin spun yarn is produced by one process of twisting together two of the same strands that have been separated in the drafting zone on a modified ring spinning system, resulting in a yarn with the characteristics of a two-fold structure within a conventional single yarn.[6–8] As in the spinning method for twin spun yarn, triplet spun yarn (TSY) with a three-fold structure is made by supplying three of the same rovings.[9] Therefore, in the one twisting process using the same spinning method, it is possible to make a multilayered side-by-side structure by supplying many rovings.

On the other hand, core spun yarn as typical composite yarn is generally made by combining staple fibers

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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 sheath-core structure of yarn can be constructed by utilizing the difference between spinning tensions and/or path lengths in the inner and outer layers in the yarn. Also, for constructing a staple-core layer, it is necessary to control the spinning tension of the drafted fiber strand in the yarn production with one twisting process. Although it will be very difficult to control the tension of the staple fiber strand in the roller drafting system, it is not difficult to control the spinning tensions of drafted fiber strands that simultaneously emerge from the front roller of the spinning frame. Since the spinning tension of drafted fiber strands can be controlled by strand length and/or distance from the front roller nip to the point of yarn formation, the controlling method has merit without the tension device.[10–12] However, the controlling method has hardly been reported up until now. It is important to accomplish the diversification and/or different types of single yarn made from a different spinning condition in the same machine.

Therefore, in order to design and develop novel single yarn, we investigated how to produce twin staple-core spun yarn (TSCSY) and/or combine two spinning methods of twin spun yarn and core spun yarn into one twisting process. In addition, the effects of the fiber properties and the spinning parameters upon the controlling of the yarn structure were examined.

## Models of yarn structure and spinning method

In the spinning method of TSY with the supplying of three rovings, spinning parameters greatly influence the structure of yarn. Figure 1 shows schematic illustrations of the production method for the roving distances, the point of yarn formation, and the cross-sectional views of yarn samples. In adopting the spinning method of TSY, it is possible to set up two types of roving distances; $S1 = S2$ and $S1 < S2$, where $S1$ is the roving distance between the center of A and B, and $S2$ is the distance between the center of B and C. The spinning condition with the same roving distance of $S1 = S2$ has one point of yarn formation. On the other hand, the spinning condition with the different roving distance of $S1 < S2$ will be able to have two points of yarn formation. Furthermore, the structures of single yarn are varied with the spinning tensions of drafted fiber strands emerging from the front roller.

Now, it is assumed that each spinning tension of drafted fiber strands located at the position of A, B, or C is denoted by $TA$, $TB$, or $TC$, respectively. In the case of one point of yarn formation and/or $S1 = S2$, if all of the spinning tensions are controlled by $TA = TB = TC$, a single yarn has a three-layered side-by-side structure. If the spinning tensions are controlled by $TB > TA$ and $TA = TC$, a yarn structure combining side-by-side and sheath-core is constructed. For differentiating these kinds of yarn from each other, the former is called TSY and the latter is called "staple-core twin spun yarn" (denoted by "SCTSY"). On the other hand, in the case of two points of yarn formation and/or $S2 < S1$, if all of the spinning tensions are controlled by $TA = TB$ and $TA + TB > TC$, the resulting single yarn is called TSCSY. If all tensions are controlled by $TA > TB > TC$ (or $TB > TA > TC$), the resulting spun yarn is called "double staple-core spun yarn" (denoted by "DSCSY").

Although the latter three yarns have a sheath-core structure, they can be distinguished from each other as follows: (1) SCTSY has a twin structure in the sheath layer; (2) TSCSY has that structure in the core layer; and (3) DSCSY has a doubled structure in the core layer. Therefore, for combining two spinning methods into one twisting process, it is very important to control each spinning tension and/or strand length for constructing the core and sheath layers and the difference between those spinning tensions.

## Production and observation of yarn

### Materials and methods

Table 1 lists sample rovings made from the same fineness and different cut length of viscose rayon fibers.

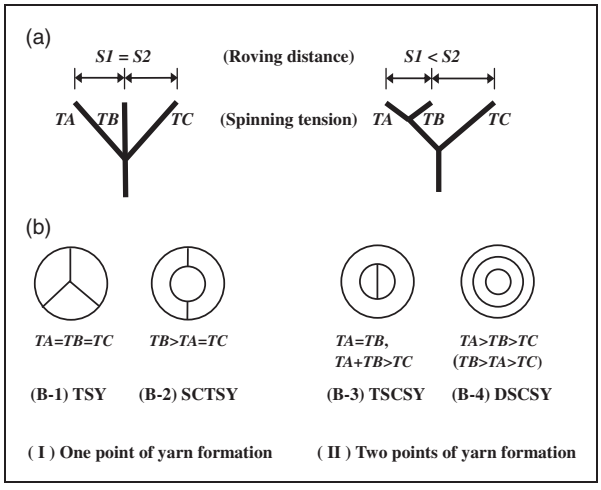


**Figure 1.** Relationship between roving distance, yarn structure, and yarn formation point (TSY: triplet spun yarn; SCTSY: staple-core twin spun yarn; TSCSY: twin staple-core spun yarn; DSCSY: double staple-core spun yarn). (a) Schematic spinning condition of three drafted fiber strands and (b) Cross-section of yarn.

Tensile properties of the rovings, especially the relationship between sample length and breaking load, were observed using an Instron-type constant rate of elongation tensile tester (TOYO MEASURMENT INSTRUMENTS, TENSILON UTM-III-100) with an extension rate of 500 mm/min. There were 10 tests per sample length of roving. The experiment room was a controlled environment of $20 \pm 2$°C and $75 \pm 5$% relative humidity (RH).

Figure 2 shows the production method of TSCSY. Three rovings are supplied into the back roller of a modified ring spinning frame and the drafted fiber strands emerge from the front roller. The supply rovings are separated by three mild steel guides located near the back of the back, middle, and front rollers, and the yarn is produced by one twisting process. The spinning parameters of yarn were mainly the position (and/or arrangement: A/B/C) of each supply roving, the distance between the center of supply rovings (and/or roving distance: *S1* and *S2*), and twist factor (*K*) of yarn.

**Table 1.** Sample fibers and rovings

| Fiber | Fineness (dtex) | Cut length (mm) | Roving size (tex) | Color |
|---|---|---|---|---|
| Rayon 1 | 1.4 | 38 | 590 | Black |
| Rayon 2 | 1.4 | 51 | 590 | Blue |

For estimating a relationship between the tensions of drafted fiber strands under a spinning condition, it is necessary to have the strand lengths from the front roller nip to the point of yarn formation. Now, it is assumed that each length of drafted fiber strand located at the position of A, B, or C is denoted by $L_A$, $L_B$, or $L_C$, respectively, and the length along with the axis of fiber assembly made from drafted strands located at the positions of A and B is denoted by $L_{AB}$. In the spinning of single yarn with the twin staple-core and sheath structure, it may be very important to know the relationship between two lengths of $L_{AB}$ and $L_C$. Then, these lengths were measured by a scale in which each measurement was repeated 10 times per yarn. The linear density of the yarn produced was about 29.5 tex (20 Ne).

Moreover, yarn with a tension of 3 cN was fixed with a resin (OHKEN SHOJI, BIOLITE) and the cross-section of yarn was observed under a microscope (KEYENCE, VHX-500), in which the section was 20 pieces per yarn.

## Results and discussion

### *Effects of spinning parameters*

In applying the spinning method of TSY with three rovings, it is possible to set up two kinds of arrangements: the same rovings and different rovings. In general, TSY is produced from the arrangement of the

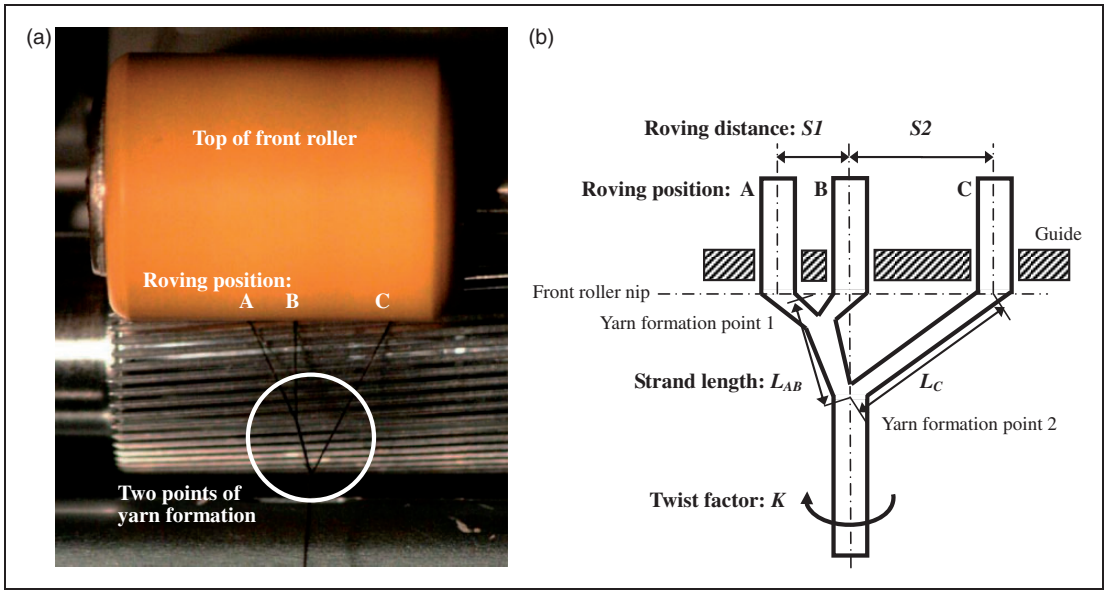


**Figure 2.** Experimental spinning method with three rovings and two points of yarn formation ($S1 < S2$). (a) Real spinning condition and (b) Schematic spinning condition.

same rovings. The production of three-layered composite single yarn needs to have three rovings made from different types of fibers in the arrangement of different rovings. In this paper, the arrangement of different rovings was composed of two rovings located at both positions of A and B made from the same fibers, and the roving located at the side position of C made from another fiber. When the roving distance of *S1* was a minimum length of 3 mm without overlapping each other and the roving distance of *S2* was longer than that of *S1*, the relationship between distances is $S1 < S2$. Also when the roving position of B is fixed and located at the center of the front roller, just above the snail wire in the spinning frame, the length of $L_{AB}$ is shorter than that of $L_C$ in the basic trigonometry and it may be easy to set up the spinning condition of $TA + TB > TC$. Furthermore, each length of $L_A$, $L_B$, $L_C$, or $L_{AB}$ is varied with not only the twist level of yarn but also the arrangement and the distance of rovings.

In the ring spinning frame, as the twist level ($Tw$) of yarn increases with the increasing of the spindle speed ($Rs$) under a constant condition of delivery speed of the front roller, the point of yarn formation moves up in the direction of the front roller and the lengths of drafted fiber strands decrease. Furthermore, when twisting of yarn is given by rotating of the traveler and/or spindle, the twisting of each fiber strand is propagated from the twisting of yarn and the fiber strands have a low level of twist.[6,9] In addition, if the size of the fiber strand with the length of $L_C$ is smaller than that of $L_{AB}$ from the two strands of A and B, it will be easy to increase the twist level of $L_C$ and/or the spinning tension of $TC$. Then, as the strand lengths have a decreasing of $L_C$ and an increasing of $L_{AB}$ and the point of yarn formation 2 moves in the horizontal and right-hand direction of the previous position under the position of C, it may be expected to create an undesirable relationship with all spinning tensions of $TC > TA + TB$.

## Effects of fiber characteristics

Figure 3 shows the relationship between gauge length and breaking load of rovings made from two types of viscose rayon fibers. The breaking load of each roving varies with not only the gauge length but also with the cut length of fibers; that of a roving made from longer fibers is greater than that of a roving made from shorter fibers. When the gauge length is smaller than about 1/2 cut length of fibers in the roving, the breaking load becomes greater. Also, the breaking load can be expected to vary with not only fiber length but also twist and fiber friction. Then, in this spinning

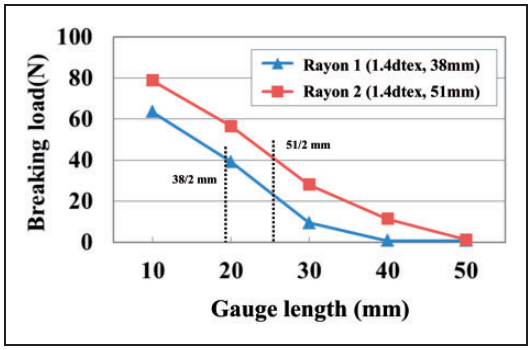


**Figure 3.** Relationship between gauge length and breaking load of roving. (Each broken line indicates the position at 1/2 cut length of each fiber).

method, an essential relationship between the length and the tension of drafted fiber strands under a spinning condition can be estimated by the relationship between the gauge length and the breaking load of roving. Also, the spinning tension of the drafted fiber strand can be controlled by the strand length.

On the other hand, it is well known that finer and longer fibers have a tendency to locate at the center of yarn, whereas coarser and shorter fibers have a tendency to be found near the yarn surface.[13–15] Then, it can be expected that in the cross-section of three-layered composite single yarn made from fibers with differing cut lengths and fineness, the position of each fiber assembly mainly depends on the fiber characteristics. Namely, in the supplying of three rovings, when the roving made from fibers with finer fineness or longer cut length is located at the center position of the roving arrangement, and that with coarser fineness or shorter cut length is located at the side position of the roving arrangement, the controlling of spinning tension in each drafted fiber strand will become easier. In addition, to construct TSCSY with a regulated cross-section made from different types of staple fibers, it is necessary to control the spinning tension of drafted fiber strands emerging from the front roller of the spinning frame. If all spinning tensions are controlled by $TA = TB$ and $TA + TB > TC$, a yarn combining twin staple-core with side-by-side and sheath structures is constructed. Namely, it is necessary to control that $L_A$ and $L_B$ are smaller than about 1/2 cut length of fibers in the strand and $L_C$ is greater than about 1/2 cut length of fibers in the strand, and that $L_C$ is greater than $L_{AB}$.

Furthermore, the condition of fiber assembly in the cross-section of yarn varies with the fiber property and it influences the twisting of fiber strands and the propagating of yarn twist.

**Table 2.** Relationship between spinning condition with two points of yarn formation, twist factor ($K$), and difference between roving distances ($S2 - S1$)

| $S2 - S1$ (mm) | $K$ ($\times$957tpm·tex$^{1/2}$) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 | 5.5 | 6.0 |
| (i) Roving arrangement (A/B/C) = rayon 1/rayon 1/rayon 1 | | | | | | | |
| 6 | × | × | ○ | ○ | ○ | ○ | ○ |
| 5 | × | × | ○ | ○ | ○ | ○ | ○ |
| 4 | × | × | ○ | ○ | ○ | ○ | ○ |
| 3 | × | △ | △ | △ | △ | △ | △ |
| (ii) Roving arrangement (A/B/C) = rayon 2/rayon 2/rayon 1 | | | | | | | |
| 6 | × | × | ○ | ○ | ○ | ○ | ○ |
| 5 | × | × | ○ | ○ | ○ | ○ | ○ |
| 4 | × | ○ | ○ | ○ | ○ | ○ | ○ |
| 3 | × | ○ | ○ | ○ | △ | △ | △ |

where $S1 = 3$ mm; $S1 < S2$; ○: stable spinning condition; △: unstable spinning condition; ×: impossible spinning condition; fiber composition of core/sheath = 67/33%; spindle speed ($Rs$) = 8000 rpm; traveler weight ($Tr$) = 0.04 cN.

## Spinning and structure of twin staple-core spun yarn

Table 2 lists the relationship between conditions and parameters of spinning with two points of yarn formation in the production of yarn samples, where ○ is a stable condition of continuous spinning, △ is an unstable condition of spinning, and × is an impossible condition of spinning. Each spinning condition was defined by the number of end breakages in the spinning time of five minutes as follows: ○ was 0 and △ was greater than 1. In this spinning, the fiber composition of sheath/core was 33/67%, the spindle speed ($Rs$) was 8000 rpm, and the traveler weight ($Tr$) was 0.04 cN. Although the spinning condition was varied with the spinning parameters and the fiber properties, it was possible to set up the stable spinning condition with two points of yarn formation in one twisting process. By supplying three rovings from two different types of fibers and another fiber, the conditions and parameters of spinning were varied with the properties of fiber located at the positions of A and B for constructing the twin staple-core layer. The stable spinning condition with a lower twist factor was especially affected by the cut length of the core fibers. Namely, in a comparison with the two strands made from rayon 1 fibers with cut length of 38 mm, those from rayon 2 fibers with cut length of 51 mm were able to have the spinning parameters with a smaller difference between roving distances and a lower twist factor of yarn. Generally, the optimum twist level of single yarn made from longer fibers is smaller than that from shorter fibers.

Figure 4 shows the relationship between twist factor and each length of $L_A$, $L_B$, $L_{AB}$, or $L_C$ in the stable spinning condition with two points of yarn formation. Each length of $L_A$, $L_B$, $L_{AB}$, or $L_C$ increased with the increasing of the difference between roving distances ($S2 - S1$) and the decreasing of the twist factor ($K$) of yarn. In each case of the arrangement of the same rovings (and/or two strands made from rayon 1 fibers as twin staple-core layer) in Figure 4(a) or that of different rovings (and/or those from rayon 2 fibers) in Figure 4(b), as the length of $L_{AB}$ became a little shorter than that of $L_C$ as sheath layer, it might be expected to have a relationship with all spinning tensions of $TA + TB = TC$ or $TA + TB > TC$. Also, in the same length of $L_{AB}$, the spinning tension of the core strands made from rayon 1 fibers with cut length of 38 mm might be lower than that from rayon 2 fibers with cut length of 51 mm. In particular, when the spinning conditions were a 6 mm difference between roving distances ($S2 - S1$) and a twist factor of 4 ($\times$957 tpm·tex$^{1/2}$), the length of $L_C$ (=about 22 mm) was greater than about 1/2 cut length (=38/2 mm) of the sheath fiber. Therefore, these spinning conditions were expected to construct twin staple-core and sheath structures and desirable spinning tensions of $TA + TB > TC$.

Figure 5 shows typical cross-sectional views of yarn samples made under the stable spinning condition with two points of yarn formation. The schematic illustration was constructed from observation of border lines between three strands of A, B, and C. In two cross-sections of yarn, different types of three-layered structures made from viscose rayon fibers were constructed. Firstly, it is necessary to understand the effects of fiber length under the same condition of the spinning method. Then, a relationship between the construction of twin staple-core and sheath layers and the cut length of staple fibers can be estimated in comparison with

Figures 5(I) and 5(II). In the production of TSCSY, although the side-by-side structure for making the twin staple-core layer was constructed by two drafted fiber strands located at both positions of A and B, the fiber assembled condition of the sheath layer from the drafted fiber strand located at the side position of C varied with increasing the cut length of core fibers. Furthermore, in constructing the structure of the twin staple-core layer with the sheath layer in the cross-sections of yarn samples, the position of the

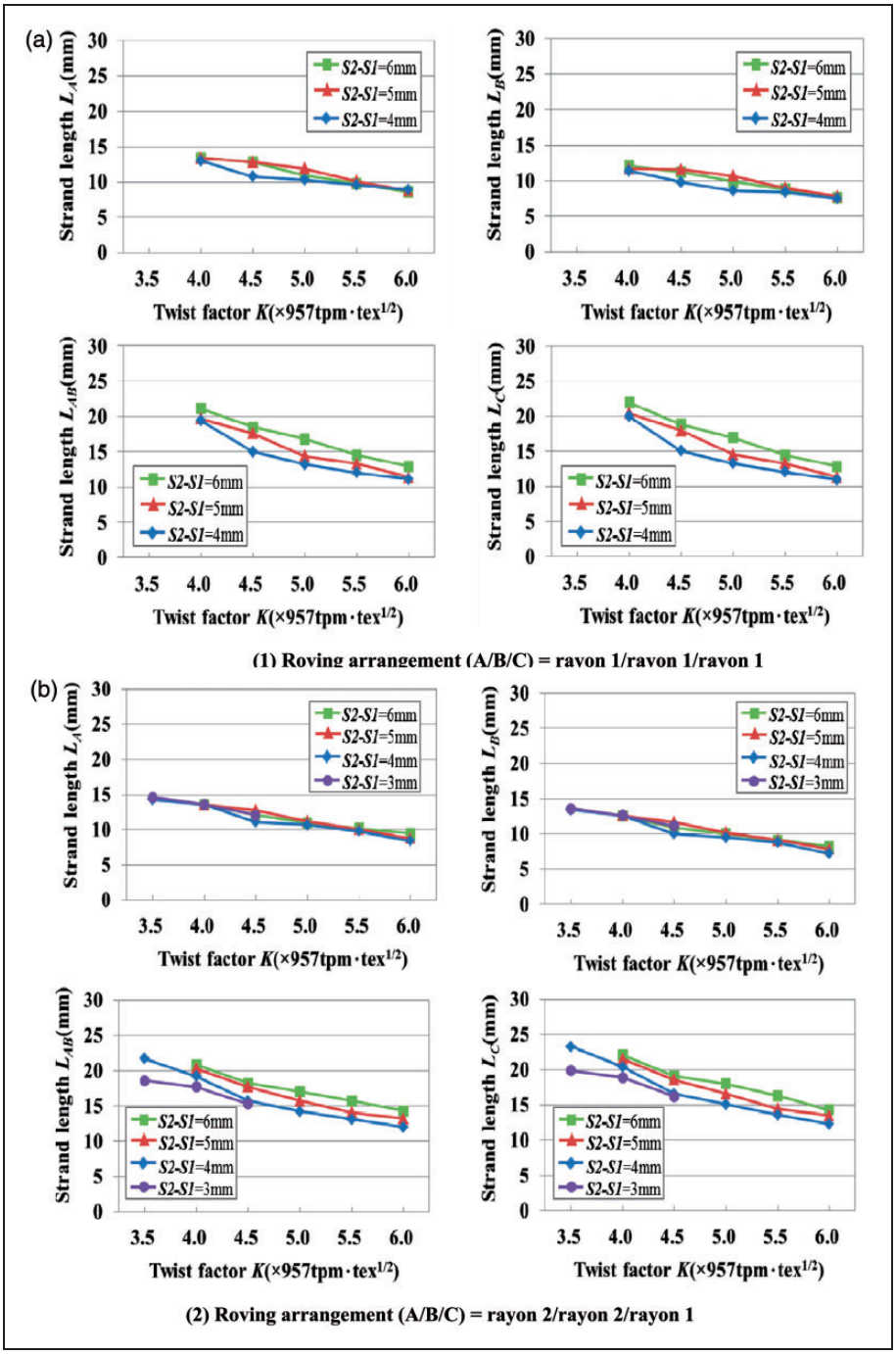


**Figure 4.** (a) Relationship between twist factor and strand lengths of $L_A$, $L_B$, $L_{AB}$, and $L_C$ ($S1 = 3$ mm; $S1 < S2$; fiber composition of core/sheath = 67/33%; spindle speed ($Rs$) = 8000 rpm; traveler weight ($Tr$) = 0.04 cN). (b) Relationship between twist factor and strand lengths of $L_A$, $L_B$, $L_{AB}$, and $L_C$ ($S1 = 3$ mm; $S1 < S2$; fiber composition of core/sheath = 67/33%; spindle speed ($Rs$) = 8000 rpm; traveler weight ($Tr$) = 0.04 cN).

twin staple-core layer made from rayon 1 fibers with the cut length of 38 mm in Figure 5(i) was located near the yarn surface and the sheath layer had no extended condition of fiber assembly. On the other hand, the former from rayon 2 with the cut length of 51 mm in Figure 5(ii) was located near the center of yarn and the latter had a greater extended condition in the direction of yarn diameter. Therefore, in the production of TSCSY, although it was easy to control the construction of the twin staple-core layer at the yarn formation point 1, it was difficult to control the construction of the sheath layer at the yarn formation point 2. The most important control was the difference between the spinning tensions of twin staple-core and sheath layers at the yarn formation point 2 under the spinning conditions with the lower twist level of yarn and the greater difference between the roving distances.

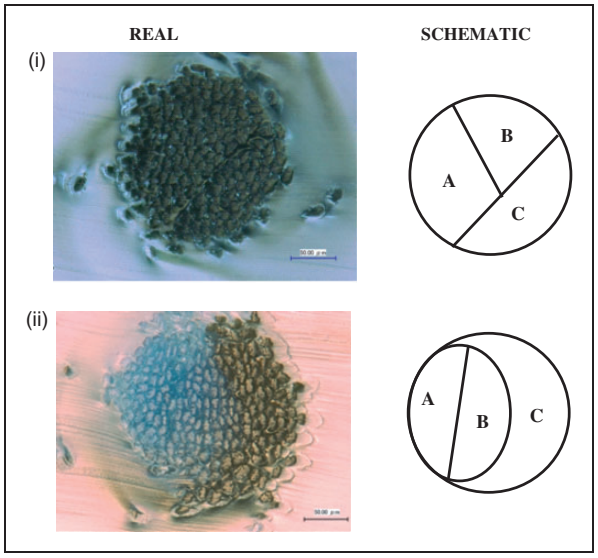


**Figure 5.** Typical cross-sectional views of yarn samples ($S1 = 3$ mm; fiber composition of core/sheath = 67/33%; $Rs = 8000$ rpm; $Tr = 0.04$ cN). (i) Roving arrangement (A/B/C) = rayon 1/rayon 1/rayon 1, $S2 - S1 = 6$ mm, $K = 4.0$ ($\times 957$ tpm* tex$^{1/2}$), $L_{AB}$ = 21.1 >38/2 mm, $L_C$ = 22.0 >38/2 mm. (ii) Roving arrangement (A/B/C) = rayon 2/rayon 2/rayon 1, $S2 - S1 = 6$ mm, $K = 4.0$ ($\times 957$ tpm * tex$^{1/2}$), $L_{AB}$ = 20.8 <51/2 mm, $L_C$ = 22.1 >38/2 mm.

However, the spinning system has many limitations in controlling the spinning parameters: the strand position of B fixed at the center of the front roller, the width of the top front roller (=21 mm), the gauge of the strand guide (=3–9 mm with division of 1 mm) for the distance between drafted fiber strands, the twist factor of yarn (=3.0–6.0 $\times$ 957 tpm·tex$^{1/2}$), and so on. Within the range of spinning parameters in the system, it was difficult to control an optimal difference between the spinning tensions of drafted fiber strands and/or construct the twin staple-core layer with the sheath layer. Accordingly, for improving the covered condition of sheath fibers in the cross-section of yarn, it was necessary to control the spinning tension and/or the length of drafted fiber strands by means of other parameters for the spinning: fiber composition of sheath/core, spindle speed, traveler weight, and so on. When the fiber composition of sheath/core was 50/50%, the length of $L_C$ decreased with

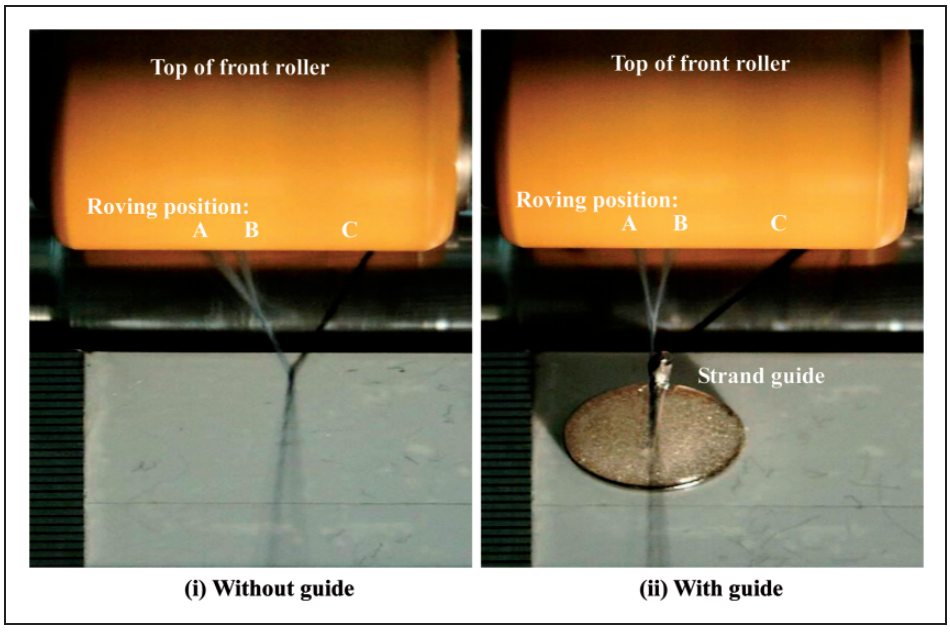


**Figure 6.** Spinning conditions without and with strand guide (roving arrangement (A/B/C) = rayon 2/rayon 2/rayon 1; $S1 = 3$ mm; $S2 - S1 = 8$ mm; $K = 4.0$ ($\times 957$ tpm·tex$^{1/2}$); fiber composition of core/sheath = 44/56%; $Rs = 8000$ rpm; $Tr = 0.09$ cN).

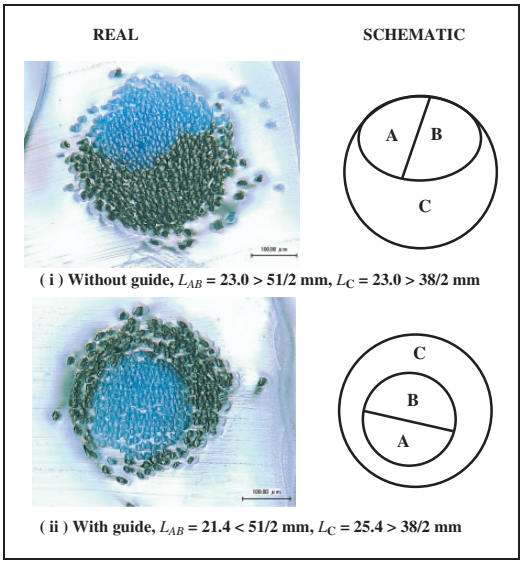


**Figure 7.** Typical cross-sectional views of yarn samples (roving arrangement (A/B/C) = rayon 2/rayon 2/rayon 1; $S1 = 3$ mm; $S2 - S1 = 8$ mm; $K = 4.0$ ($\times 957$ tpm·tex$^{1/2}$), fiber composition of core/sheath = 44/56%; $Rs = 8000$ rpm; $Tr = 0.09$ cN).

the increasing of the spindle speed ($Rs = 8500$ rpm) and/or the traveler weight ($Tr = 0.05$ cN) because the composition of sheath fibers increased and the point of yarn formation 2 moved in the right-hand direction from the previous position. That is to say, as the spinning tension of $Lc$ increases with increasing the composition of the sheath fiber, the point of yarn formation 2 moved in the right-hand direction from the previous position with increasing the angle between the front roller nip, the yarn formation point, and the snail wire. Then, more twist of yarn is propagated into the strand of $Lc$ and the length of $Lc$ decreases.

When the fiber composition of the sheath/core was 56/44% and the roving positions of A and B with the fixed distance of $S1$ (=3 mm) moved from the center of the front roller toward the left-hand side, the length of $L_C$ became barely any better than previously. Therefore, for getting a longer distance of $L_C$ and a fixed condition of the point of yarn formation 2, it was necessary to have a metal guide for drafted strands with a moving position near the point of yarn formation 2. Then, the point of yarn formation 2 could be fixed and located at the optimum position in any place from the front of the front roller to the upper part of the snail wire in the spinning frame. Figure 6 shows the spinning conditions with and without the strand guide in the spinning system.

Figure 7 shows typical cross-sectional views of yarn samples made by changing some parameters and improving the spinning system. The cross-sectional views of Figure 7(i) were nearly equal to that of Figure 5(ii). However, the fiber assembled condition in the cross-section of yarn in Figure 7(ii) had a greater extended condition of the sheath layer in the direction of yarn diameter and a better covering of the twin staple-core layer with the sheath fibers. Namely, the novel three-layered composite single yarn with twin staple-core and sheath structure could be made by the controlling of the spinning parameters and the fiber characteristics under the spinning condition with two points of yarn formation in one twisting process. Further study will be needed to examine differently colored fibers in positions A, B, and C. Also, it will be important to construct the full-covered structure of the twin staple-core layer with the sheath layer in the cross-sections of yarn and to investigate the relationship between the position of the supply roving and the position in the cross-section of yarn.

## Conclusions

In order to diversify the structure of single yarn as textile material and to develop novel composite spun yarn with good functionality, we investigated how to produce TSCSY by combining side-by-side and sheath-core structures into a yarn.

The following results were obtained: (1) by applying the production method of TSY on the experimental ring spinning system, the yarn combining side-by-side with sheath-core structures could be constructed by two points of yarn formation and one twisting process without the device for controlling of spinning tension; (2) in the spinning method of TSCSY, it was necessary to control the difference between spinning tensions of the sheath layer and the twin staple-core layer with side-by-side structure under the spinning condition with the lower twist level of yarn and the greater difference between the roving distances; (3) for combining the twin staple-core and the sheath layers, it was important not only to control the greater length of drafted fiber strands for the sheath layer, but also to choose the cut length of the sheath and the core fibers.

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