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Evaluation of the Correlation between the Structure and Quality of Compact Blend Yarns

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Abstract
Pneumatic compact spinning is the most widely used compact spinning technology at present, which is implemented by using negative airflow to condense the fibre bundle and decrease the spinning triangle. Roller-type and Lattice apron-type compact spinning are two major kinds of pneumatic compact spinning now. In this paper, blend yarn qualities spun by one kind of roller-type compact spinning: complete condensing spinning (CCS), and one kind of Lattice apron-type compact spinning: 4-line rollers compact spinning (FRCS) were studied and analysed comparatively. First, 28.1, 18.5 and 12.3 tex JC60/T40 blend yarns and 18.5, 14.8 and 11.8 tex JC35/T65 blend yarns were spun on two kinds of compact spinning systems, respectively, and the effects of the blending ratio on yarn qualities were discussed. Then another two kinds of cotton blended yarns - JC60/R40 and JC60/M40 were spun. 28.1, 18.5, 14.8 tex JC60/R40 and 18.5, 14.8, 11.8 tex JC60/M40 were spun on two kinds of compact spinning systems, respectively. Meanwhile the qualities of spun yarns were analysed by using two methods. First with a high speed camera system - OLYMPUS i-speed3 (OLYMPUS Image Co., Ltd., Japan), the condensing process of a fibre strand in the condensing zones were captured and analysed. Second the cross sections of the spun yarns were presented using a Y172 Hardy's thin cross-section sampling device (Nantong Hongda Experiment Instruments Co., Ltd. , China). The corresponding Hamilton Index was then calculated, and the fibre radial distributions in the yarn cross section were analysed. The results show that the fibre condensing effects are increased with an increase in the ratio of cotton fibre on the blended yarn for both kinds of compact spinning, especially the FRCS. Meanwhile with an increase in the ratio of polyester fibre on the blended yarn, the advantage of CCS with respect to yarn qualities increased. For both JC60/R40 and JC60/M40, cotton fibres are transferred to the outer part of the yarn body. However, the fibres in JC60/R40 yarn spun by CCS and those in JC60/M40 yarn spun by FRCS are distributed more randomly.

Key words: *pneumatic compact spinning, blend yarn, hamilton index method, high speed camera.*

Introduction

Compact spinning is an important new kind of modified ring spinning method which is implemented by adding one kind of fibre condensing device on a ring spinning frame in order to decrease the spinning triangles and improve the spun yarn qualities correspondingly [1 - 3]. At present, pneumatic compact spinning is the most widely used compact spinning method, which is implemented by using negative airflow to condense the fibre bundle and decrease the spinning triangle [4]. Roller-type and lattice apron-type compact spinning are the two major kinds of pneumatic compact spinning now, in which the hollow roller and lattice apron are the fibre condensing devices, respectively [5]. Lattice apron-type compact spinning is the most widely used compact spinning method at present, including 3-line rollers compact spinning and 4-line rollers compact spinning [6]. For roller-type compact spinning, the surface structure of the hollow roller is one of the most important parameters, and determines the spun yarn qualities directly [7]. One important kind of hollow roller has been equipped on Rieter's COM4 compact spinning system (Riter Group , Switzerland), in which the surface structure of the hollow roller is a circular hole. However, the price of COM4 is very high. CCS is another kind of roller-type compact spinning developed by our group and Changzhou Hengji Textile Machinery LTD, in which a kind of steel hollow roller with a strip groove structure on the surface is equipped [8]. CCS can be used for modification of the traditional ring spinning system directly, and the price is also lower. Therefore, in this paper, the blend yarn qualities spun by CCS and FRCS are researched and analysed comparatively. With the development of compact spinning, it is now not only used to spin pure cotton yarn, but also other cotton fibre types and wool [9 - 11]. For example, the differences between wool single jersey made from compact and conventional ring-spun yarns composed of surface-modified fibres with different anti-felting treatments were studied in [9], and hairiness results of a Zweigle G566, Uster Zweigle Hairiness Tester 5 (UZHT5) and Uster Tester 5 S800 (UT5) (Uster Technologies AG, Switzerland) were compared for cotton-tencel blended ring, compact and vortex yarns in [11]. Therefore the adaptability of each kind of compact spinning is an important step of the application of compact spinning and has attracted more and more attentions recently [1]. In this paper, the adaptability of CCS to blend yarn are mainly researched and compared with one kind of lattice apron-type compact spinning - FRCS.

In the paper, to analyse the qualities of compact blend yarns, cross sections of the yarns spun were obtained by using a Y172 Hardy's thin cross-section sampling device, and then the corresponding Hamilton Index was calculated, after which fibre radial distributions in the yarn cross section were analysed. The results show that for both JC60/R40 and JC60/M40 the cotton fibres are transferred to the outer part of the yarn body, while those in the JC60/R40 yarn spun by CCS and in the JC60/M40 yarn spun by FRCS are distributed more randomly. In

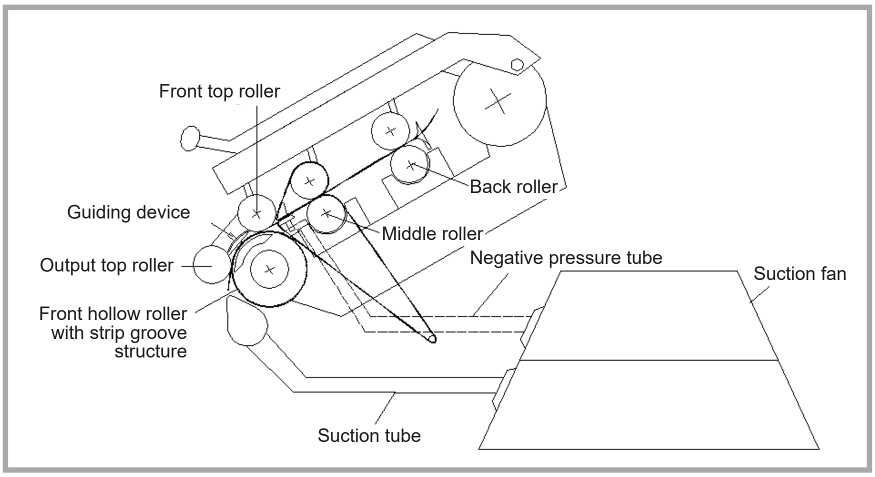

Figure 1. *Structure of the CCS system [8].*

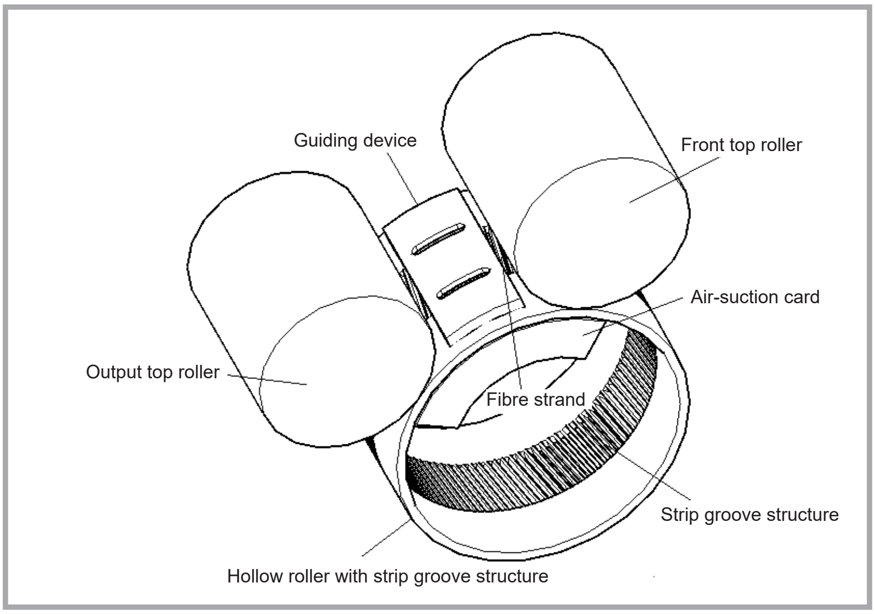

Figure 2. *Condensing zone of CCS system [8].*

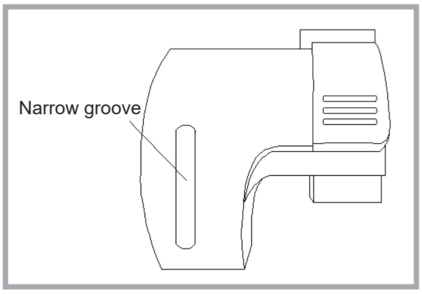

Figure 3. *Structure of the Air-suction card [8].*

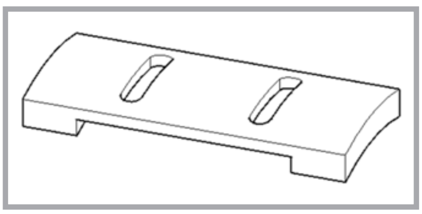

Figure 4. *Structure of the Guiding device [8].*

our future studies, the impact of changes in the structure of compact yarns modified by their compaction on the spun yarn qualities will be studied further by using a statistical tool, namely the Pearson correlation coefficient.

CCS system

CCS is a kind of pneumatic compact spinning in which the front roller of the ring spinning frame is replaced by a kind of hollow roller with a strip groove structure on the surface [8]. The structure of CCS is shown in ***Figure 1***, and corresponding condensing zone of CCS in ***Figure 2***. The hollow roller is made of stainless steel with 56 HRC hardness, and the diameter is 50 mm, and on the surface structure of the hollow roller, there are strip grooves of 1 mm width, which are different from the perforated drum used in COM4. There are two top rollers above the hollow roller: the front top roller and output top roller, and the area between them is the condensing zone, see ***Figure 2***. To produce the condensing negative pressure, a kind of air-suction card is attached to the hollow roller, and a narrow groove is located on the upper surface of the air-suction card, see ***Figure 3***. In the spinning, the negative pressure airflow can be affected by the fibre strand located in the condensing zone through the narrow groove of the air-suction card and strip groove structure of the hollow roller. Meanwhile to improve the condensing effect, a kind of guiding device is installed above the hollow roller in the condensing zone, see ***Figure 4***.

Polyester/cotton yarn spinning qualities

In this section, 28.1, 18.5 and 12.3 tex JC60/T40 blend yarns and 18.5, 14.8 and 11.8 tex JC35/T65 blend yarns were spun on CCS and FRCS, respectively, and the effects of the blending ratio on yarn qualities were studied. Yarns were also spun on a QFA1528 ring spinning frame modified by two compact spinning systems, respectively.

JC60/T40 blend yarn spinning qualities

Spinning test

Combed JC60/T40 roving of 478 tex was used as raw material. The cotton and polyester fibre properties used are shown in ***Tables 1*** and ***2***. Details of the spinning parameters are shown in ***Table 3***. Then, 28.1, 18.5 and 12.3 tex JC60/T40 blend yarns were spun, respectively. Then the evenness (CV), hairiness and breaking strength of the spun yarns were measured. The test results were obtained in the following steps. First we took ten bobbin yarns as measuring samples and then conditioned them for at least 48 hours under standard conditions (65 ± 2% RH and 20 ± 2 °C). For each bobbin yarn, the hairiness was tested ten times using a YG172A hairiness tester (Shaanxi Changling Textile Mechanical & Electronic Technological Co., Ltd., China) at a speed of 30 m/min, with a test time of 1 minute. Then the average value of ten test results was taken as the hairiness of this one bobbin yarn. The breaking force of yarns was also tested ten times on YG068C fully automatic single yarn strength tester (Suzhou changfeng textile mechanical and electrical technology co., LTD, China) at a speed of 500 mm/min with a pretension 1.8 cN/tex, and the average value of ten tested results was taken as the breaking force of this one bobbin yarn. The evenness was obtained once by an Uster tester 5-S800 evenness tester at a speed of 400m/min, with a test time of 1 minute, the value of which accepted as the evenness of this one bobbin yarn. Finally the average values of ten bobbin yarns were taken as the corresponding qualities of the spun yarn. Corresponding results are given in ***Table 4***.

Yarn evenness is one of the most significant properties in evaluating yarn performance. From ***Table 4***, it is evident that for all three kinds of compact spun yarns, comparing with FRCS, CCS has better evenness CV, and the advantage is more obvious with a decrease in the linear density of yarns. Yarn strength is another of the most important properties in evaluating yarn performance. As shown in ***Table 4***, it is easy to see that for the low yarn count 28.1 tex and medium count yarn 18.5 tex, the difference in breaking tenacity between the two systems is tiny, while the elongation at break of FRCS is better. For the high count yarn 12.3 tex, comparing with FRCS, CCS has better breaking tenacity and elongation at break. Hairiness is also one of the most vital properties of spun yarn. From ***Table 4***, it is also easy to see that for all three kinds of compact spun yarns, comparing with CCS, FRCS has less long hairiness (≥ 3 mm).

Fibre condensing process

In this section, to analyse the properties of spun yarns produced by the two compact spinning systems, the condensing process of the fibre strand in the condensing zones of CCS and FRCS were captured by using a high speed camera system - OLYMPUS i-speed3.

The fibre strand condensing process in the condensing zones of CCS and FRCS are shown in ***Figures 5*** & ***6*** (see page 58), respectively, for 28.1, 18.5 and 12.3 tex yarns. The condensing process of fibre strands in the condensing zones of CCS is shown in ***Figure 5***. From ***Figure 5***, it is easy to see when the fibre strand is the output from the nip line of the front hollow roller as the fibres are made to close to the surface of the hollow roller and arranged parallel to each other. Then the fibres move forward along with the rotation of the hollow roller, and the width of the strand decreases gradually under the condensing force. The spinning triangle is then decreased greatly. The condensing process of fibre strands in the condensing zones of FRCS is shown in ***Figure 6***, from which it is evident when the fibre strand is exported from the nip line of the front roller, the fibres are made too close to the surface of the lattice apron under the condensing force of airflow, and one of the border fibres begin to flip to another border and cover other fibres. The weak twisting would act upon the fibre strand in this process, which makes it compact and decreases the spinning triangle greatly. Therefore, comparing with CCS, there is weak twisting acting on the fibre strand in the condensing zone in FRCS.

From the figures, it is easy to see that the condensing effect is increased with an increase in the linear density of yarns since the fibres number is decreased for both compact spinning systems. For yarn evenness, the fibres containing short cotton fibres and long polyester fibres in the condensing zone of CCS can be condensed to the center of the parallel strand, and the two kinds of fibres can be distributed more uniformly in the strand during the condensing process. However, in the FRCS, the distributions of two kinds of fibres with different lengths in the strands are made non-uniform under the weak twisting in the condensing zone. Therefore, comparing with FRCS, CCS has better evenness CV for JC60/T40 blend spun yarns. For the yarn strength, the cohesion force among fibres in the yarn spun by CCS is weaker since the fibres are condensed to the center of parallel strand, which is not a benefit for yarn strength. However, although the cohesion force among fibres in the yarn spun by FRCS is stronger, the uniformity of fibre distributions is worse. Therefore

Table 1. *Properties of the cotton fibre.*

Fibre length, mm	Uniformity ratio, %	Fibre strength, N/tex	Elongation at break, %	Micronaire value
28.4	47.8	22.8	7.0	4.3

Table 2. *Properties of the polyester fibre.*

Fibre length, mm	Uniformity ratio, %	Fibre strength, N/tex	Elongation at break, %
38.0	1.3	52.0	45.0

Table 3. *Spinning parameters.*

Linear density of yarns, tex	Yarn twist factor	Draft multiple	Spacer, mm	Ring traveler,	Negative pressure, Pa	
					FRCS	CCS
28.1	320	17.01	3.00	6903 1/0	2400	2200
18.5	340	25.91	2.75	6903 3/0	2400	2200
12.3	355	38.86	2.50	C1 EL udr 5/0	2400	2200

Table 4. *Testing results of yarn qualities.*

Linear density of yarns, tex	Spinning method	Evenness CV, %	Thin, -50%/km^{-1}	Thick, +50%/km^{-1}	Neps, +200%/km^{-1}	Breaking tenacity, cN/tex	Elongation at break rate, %	≥ 3 mm hairiness/10 m^{-1}
28.1	CCS	9.18	0	1.25	3.75	19.93	7.62	12.91
	FRCS	9.63	0	1.25	1.25	19.86	8.19	10.93
18.5	CCS	11.21	0	5.01	17.14	18.47	6.41	11.82
	FRCS	11.69	0	0	19.21	18.51	7.61	9.11
12.3	CCS	12.79	0	12.26	23.23	17.31	5.89	8.22
	FRCS	12.99	3	17.31	29.12	16.53	5.92	7.81

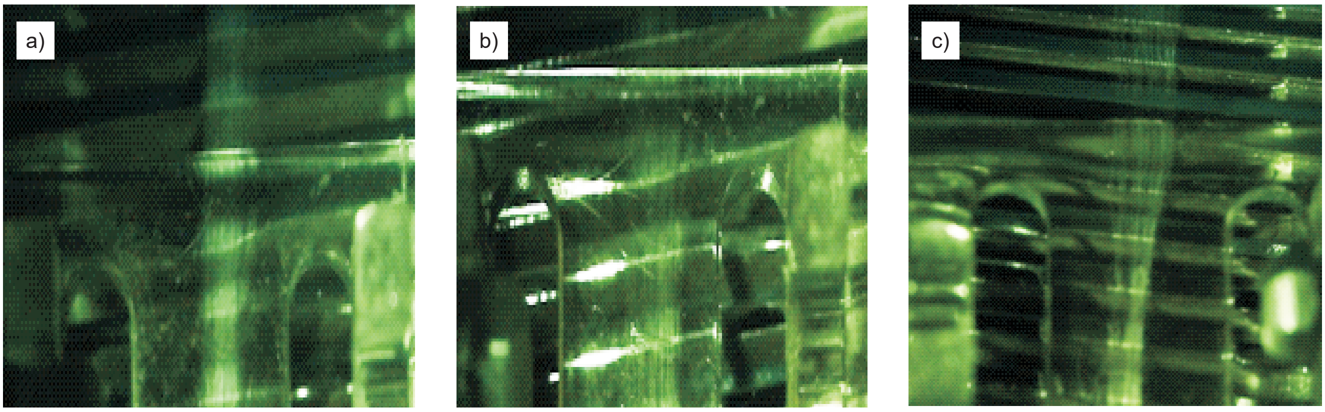

Figure 5. *Fibre strands condensing process of JC60/T40 blend yarns spun by CCS; a) 28.1 tex, b) 18.5 tex, c) 12.3 tex.*

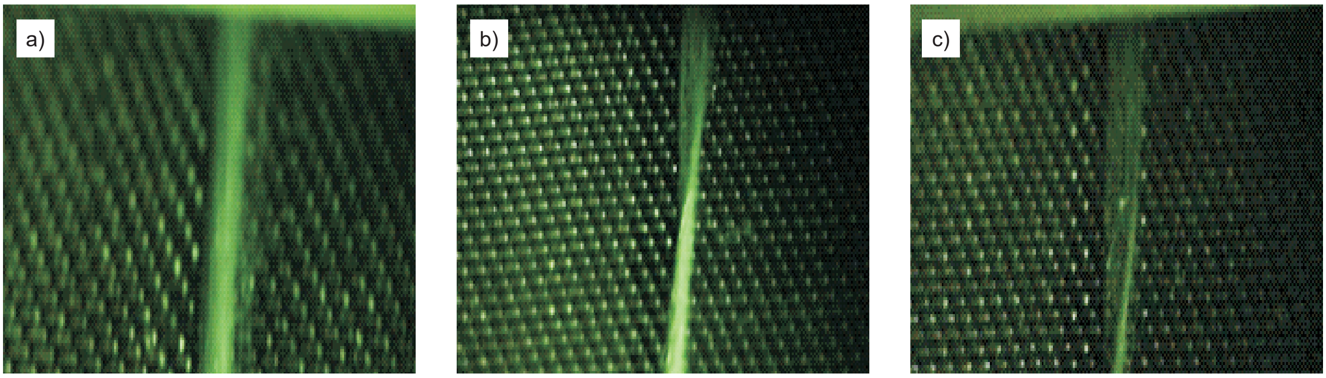

Figure 6. *Fibre strands condensing process of JC60/T40 blend yarns spun by FRCS; a) 28.1 tex, b) 18.5 tex, c) 12.3 tex.*

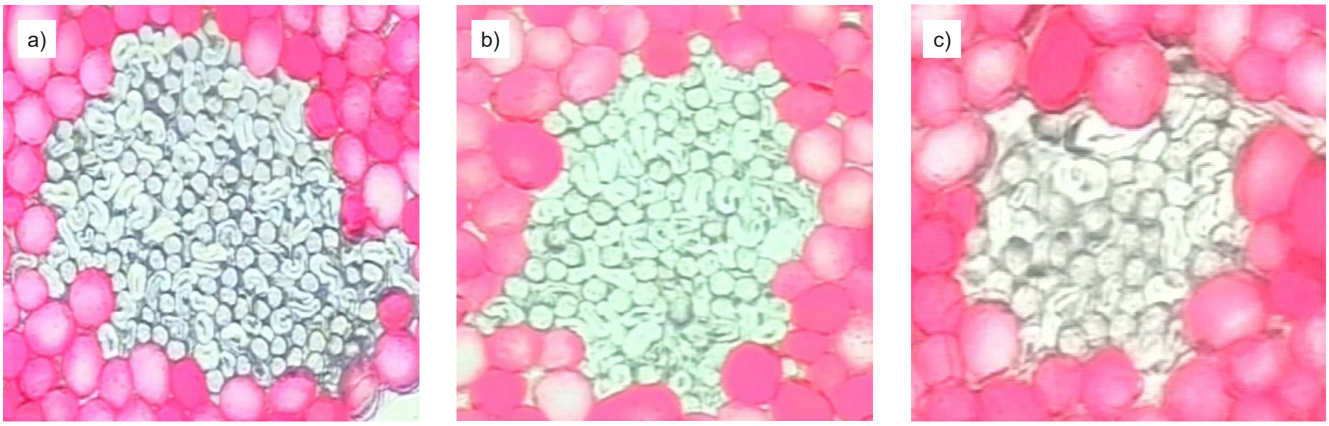

Figure 7. *Cross sections of JC60/T40 blend yarns spun by CCS; a) 28.1 tex, b) 18.5 tex, c) 12.3 tex.*

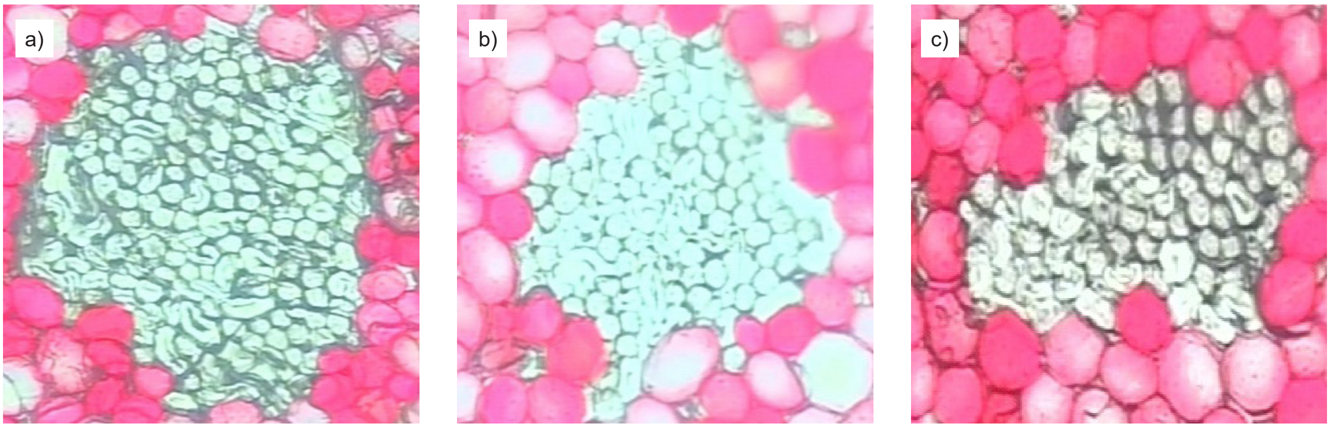

Figure 8. *Cross sections of JC60/T40 blend yarns spun by FRCS; a) 28.1 tex, b) 18.5 tex, c) 12.3 tex.*

the difference in breaking tenacity between the two compact spinning systems is tiny. For yarn hairiness, there are more border fibres in the yarn spun by CCS since the fibres are condensed to the centre of the parallel strand, while border fibres in the yarn spun by FRCS can be rolled into the yarn body more easily under the weak twisting in the condensing zone, which is beneficial for reducing long yarn hairiness. Meanwhile the collision between the border fibres and ring traveler can possibly produce ends of border fibres and form hairiness. Therefore, comparing with FRCS, CCS has more long hairiness (≥ 3 mm).

Fibre radial distributions in the yarn cross section

In this section, to analyse the properties of spun yarns produced by the two compact spinning systems further, the cross sections of the spun yarns were presented by using a Y172 Hardy's thin cross-section sampling device, and the corresponding Hamilton Index was calculated and analysed.

By using a Y172 Hardy's thin cross-section sampling device, the chip of blend yarns could be obtained. Then with the help of an MOTTC B1 microscope and corresponding fineness meter (MOTIC CHINA GROUP Co., Ltd., China), cross sections of the JC60/T40 blend yarns spun by CCS and FRCS were obtained as shown in ***Figures 7*** & ***8***, respectively. Here, cotton fibre is circular, and polyester fibre is waist-round. From the figures, it is easy to see that the two kinds of fibres are randomly distributed in the blend yarns spun by both compact spinning systems.

Then the Hamilton Index was calculated and analysed according to the cross sections of the spun yarns obtained [12]. 28.1 tex JC60/T40 blend yarns were taken as an example in the following analysis. To obtain more accurate results, 20 chips of each kind of blend yarn were made and corresponding cross sections received. Then the average value was taken as the test result.

Table 5. *Fibre relative volume distribution.*

Spinning method	Layer	1	2	3	4	5	Total
	Layer difference	-2	-1	0	1	2	
CCS	Polyester fibre	5.10	19.30	21.80	10.20	2.90	59.30
	Cotton fibre	12.88	32.20	51.52	28.98	4.83	130.41
	Total of each layer	17.98	51.50	73.32	39.18	7.73	189.71
FRCS	Polyester fibre	5.90	19.20	21.30	13.70	0	60.10
	Cotton fibre	8.05	28.98	45.08	41.86	9.66	133.63
	Total of each layer	13.95	48.18	66.38	55.56	9.66	193.73

Table 6. *Moment of fibre volume distribution.*

Fibre	Spinning method	Moment of fibre volume distribution			
		$[FM_A]_P$	$[FM_U]_P$	$[FM_I]_P$	$[FM_O]_P$
Cotton	CCS	-19.32	-22.56	-	44.46
	FRCS	16.1	-0.83	-	72.85
Polyester	CCS	-13.5	-10.26	-77.27	-
	FRCS	-17.3	-0.37	-74.05	-

Table 7. *Migration index of the fibre.*

Spinning method	Fibre	Migration index, %
CCS	Cotton	+4.84
	Polyester	-4.84
FRCS	Cotton	+22.98
	Polyester	-22.98

First the coefficient of volume transfer of polyester fibre is set as 1, and the relative volume distribution can be obtained, as shown in ***Table 5***. Then the moment of volume distribution of the two kinds of fibres could be calculated directly, the results of which are shown in ***Table 6***. From ***Table 6***, it is easy to see that for cotton fibre, we have $[FM_A]_P > [FM_U]_P$, hence the cotton would be transferred outwardly preferentially, and then the $[FM_0]_P$ of the cotton fibre was calculated. However, for polyester fibre, we have $[FM_A]_P < [FM_U]_P$, thus the polyester fibres would be transferred inwardly preferentially, and then the $[FM_I]_P$ of the cotton fibre was calculated. Finally the migration index of the fibre could be calculated, the results of which are shown in ***Table 7***.

From ***Table 7***, we know that although in both compact spinning systems, the polyester fibres would be transferred to the center of the yarn body, while the cotton fibres would be transferred to the border of the yarn body, the migration trend of both being obviously different. That is, comparing with FRCS, the fibres in the 28.1 tex JC60/T40 blend yarns spun by CCS were more difficult to transfer, which makes fibres in the yarn body distribute more randomly, which is beneficial for improving yarn evenness and possibly strength. Meanwhile in the yarns spun by FRCS, the stronger transferral makes the cotton fibre distribute mainly in the outer layer of the yarn body, especially in the fourth, and the stronger friction force of cotton fibre makes the fibre end out of the yarn body more difficult, which is beneficial for reducing long yarn hairiness.

JC35/T65 blend yarn spinning qualities

Spinning test

Combed JC35/T65 roving of 498 tex was used as raw material. Details of spinning parameters are shown in ***Table 8***. Then, 18.5, 14.8 and 11.8 tex JC35/T65 blend yarns were spun on the two kinds of compact spinning systems, respectively. Then

Table 8. *Spinning parameters.*

Linear density of yarns, tex	Yarn twist factor	Draft multiple	Spacer, mm	Ring traveler	Negative pressure, Pa	
					FRCS	CCS
18.5	340	26.70	2.75	6903 3/0	2400	2200
14.8	350	33.74	2.75	C 1 EL udr 4/0	2400	2200
11.8	355	42.20	2.50	C 1 EL udr 5/0	2400	2200

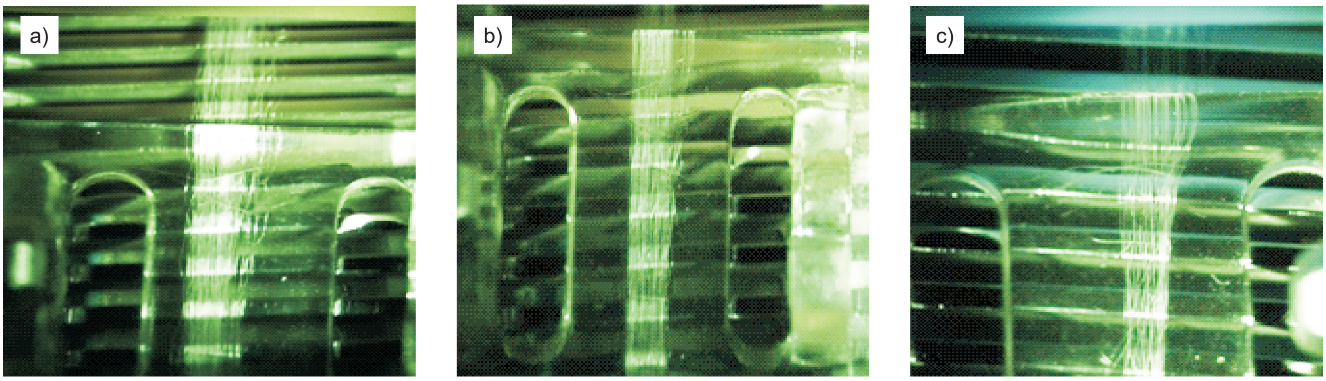

Figure 9. *Fibre strands condensing process of JC35/T65 blend yarns spun by CCS; a) 18.5 tex, b) 14.8 tex, c) 11.8 tex.*

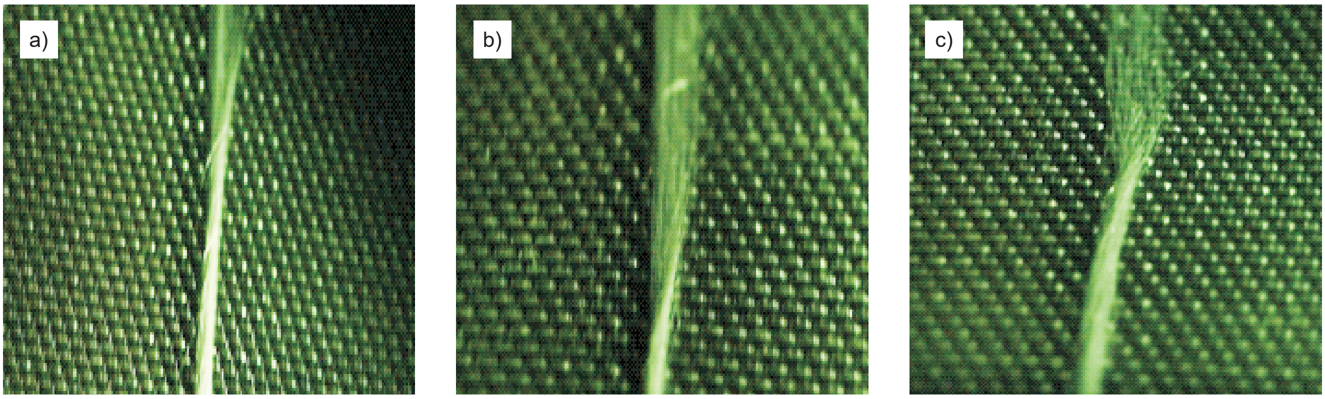

Figure 10. *Fibre strands condensing process of JC35/T65 blend yarns spun by FRCS; a) 18.5 tex, b) 14.8 tex, c) 11.8 tex.*

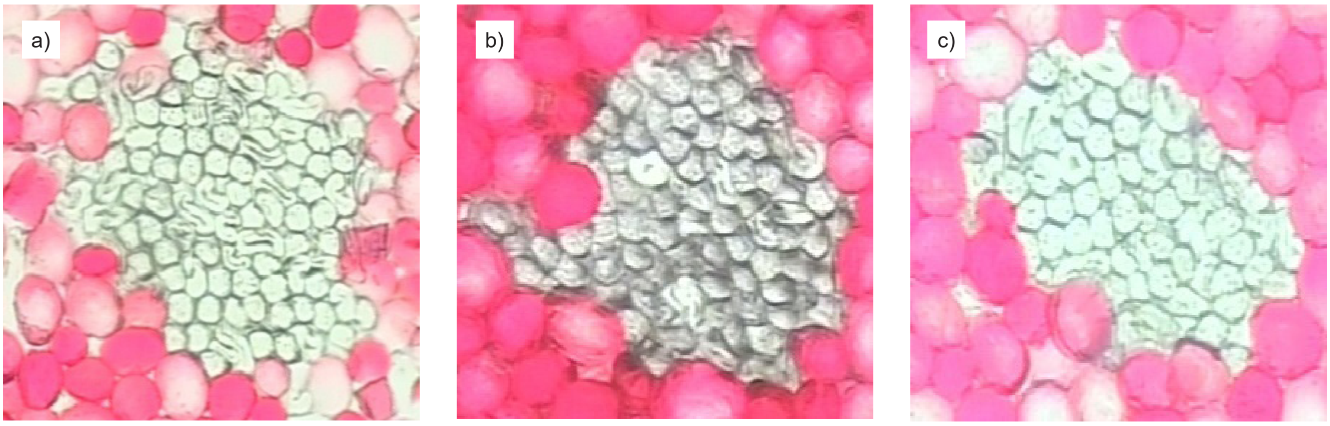

Figure 11. *Cross sections of JC35/T65 blend yarns spun by CCS; a) 18.5 tex, b) 14.8 tex, c) 11.8 tex.*

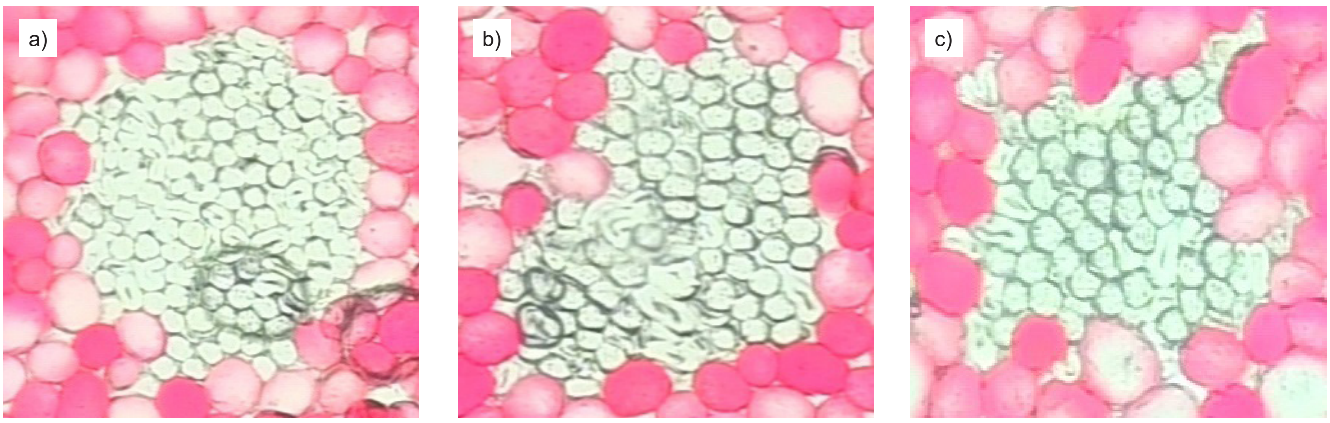

Figure 12. *Cross sections of JC35/T65 blend yarns spun by FRCS; a) 18.5 tex, b) 14.8 tex, c) 11.8 tex.*

Table 9. Testing results of yarn qualities.

Linear density of yarns, tex	Spinning method	Evenness CV, %	Thin, -50%/km^{-1}	Thick, +50%/km^{-1}	Neps, +200%/km^{-1}	Breaking tenacity, cN/tex	Elongation at break rate, %	≥ 3 mm hairiness/10 m^{-1}
18.5	CCS	11.29	0	0	20	21.76	8.32	5.41
	FRCS	12.51	0	5	0	21.74	8.46	6.62
14.8	CCS	12.52	0	15	35	22.53	8.33	5.32
	FRCS	13.48	5	20	15	20.28	8.12	11.43
11.8	CCS	13.61	5	20	25	19.45	7.11	7.52
	FRCS	14.82	10	20	30	20.19	7.21	7.31

the evenness (CV), hairiness and breaking strength of the spun yarns were measured, corresponding results of which are given in ***Table 9***.

From ***Table 9***, it is evident that for all three kinds of compact spun yarns, comparing with FRCS, CCS has better evenness CV and fewer thin and thick places, and a little more neps. Moreover the improvement in evenness CV is higher than that of JC60/T40 blend yarns. For yarn strength, the difference in breaking tenacity between the two systems is tiny for the relatively low linear density (yarn count) 18.5 tex and relatively high linear density (yarn count) 11.8 tex, and comparing with FRCS, CCS has a little worse breaking tenacity, but a little better for the relatively medium linear density (yarn count) 14.8 tex. Meanwhile the elongation at break of the blend yarns spun by the two systems is similar. For yarn hairiness, comparing with FRCS, CCS has less long hairiness for the relatively low linear density (yarn count) 18.5 tex and medium linear density (yarn count) 14.8 tex, especially for 14.8 tex yarn, while for the relatively high linear density (yarn count) 11.8 tex, long hairiness is similar for the two systems.

Fibre condensing process

By using a high speed camera system - OLYMPUS i-speed3, the fibre strand condensing process in the condensing zones of CCS and FRCS could be observed, shown in ***Figures 9*** and ***10***, respectively. From the figures, it is also easy to see that there is weak twisting acting on the fibre strand in the condensing zone in FRCS, while fibres in the condensing zones of CCS are condensed to the centre of the parallel strand.

From the figures, it is also shown that with an increase in the linear density of yarns, the condensing effect is increased. Meanwhile, comparing with the JC60/T40, the condensing effect is a little weaker in JC35/T65 for both compact spinning systems, since there is more polyester fibre in this case. That is, with an increase in the fibre length, the condensing effect would be decreased.

For yarn evenness, since there is more long polyester fibre, the parallel condensing process in CCS is more beneficial for uniform distribution of the two kinds of fibre, while the condensing effect under the weak twisting in the condensing zone of FRCS would be weaker, which makes the distributions of the two kinds of fibres with different lengths in the strands more non-uniform. Therefore, comparing with FRCS, CCS has better evenness CV for JC35/T65 blend spun yarns, and the improvement is higher than that of in the JC60/T40 blend yarns. For yarn strength, in the 14.8 tex yarn, the main cause of yarn breakage is the fibre breaking since there are relatively more fibres in the yarn body; hence CCS has better breaking tenacity. However, in the 11.8 tex yarn, the main cause of yarn breakage is fibre slippage since there are relatively fewer fibres in the yarn body; hence FRCS has better breaking tenacity. For yarn hairiness, the weaker condensing effect under the weak twisting in the condensing zone of FRCS would produce more border fibres, and the weakened effect would be increased with a decrease in the linear density of yarns.

Fibre radial distributions in the yarn cross section

By using a Y172 Hardy's thin cross-section sampling device and MOTTC B1 microscope, cross sections of the JC35/T65 blend yarns spun by CCS and FRCS were obtained, shown in ***Figures 11*** & ***12***, respectively. Then, taking 11.8 tex JC35/T65 blend yarn as an example, the Hamilton Index was calculated and analysed.

The relative volume distribution was obtained, shown in ***Table 10***, and the corresponding moment of volume distribution of the two kinds of fibres were calculated, given in ***Table 11***. From ***Table 11***, it is easy to see that the cotton fibres would be transferred outwardly preferentially, and the polyester fibres would be transferred inwardly preferentially. Then the migration index of the fibre was calculated, shown in ***Table 12*** (see page 62).

From ***Table 12***, it is shown that, comparing with CCS, the migration trend of the two kinds of fibres in the 11.8 tex JC35/T65 blend yarns spun by FRCS is much more obvious. Therefore fibres in

Table 10. Fibre relative volume distribution.

Spinning method	Layer	1	2	3	4	5	Total
	Layer difference	-2	-1	0	1	2	
CCS	Polyester fibre	3.20	12.80	12.10	7.90	1.10	37.10
	Cotton fibre	3.22	8.05	12.88	9.66	0	33.81
	Total of each layer	6.42	20.85	24.98	17.56	1.10	70.91
FRCS	Polyester fibre	6.10	12.90	13.20	4.90	1.90	39.00
	Cotton fibre	0	4.83	16.10	12.88	1.61	35.42
	Total of each layer	6.10	17.73	29.30	17.78	3.51	74.42

Table 11. Moment of fibre volume distribution.

Fibre	Spinning method	Moment of fibre volume distribution			
		$[FM_A]_P$	$[FM_U]_P$	$[FM_I]_P$	$[FM_O]_P$
Cotton	CCS	-4.83	-6.64	-	19.76
	FRCS	11.27	-2.44	-	24.8
Polyester	CCS	-9.1	-7.29	-33.69	-
	FRCS	-16.4	-2.69	-29.93	-

Table 12. Migration index of the fibre.

Spinning method	Fibre	Migration index, %
CCS	Cotton	+6.86
	Polyester	-6.86
FRCS	Cotton	+50.3
	Polyester	-50.3

Table 13. Properties of the rayon fibre.

Fibre length, mm	Uniformity ratio, %	Fibre strength, N/tex	Elongation, %
38.0	1.3	23.0	15.0

the yarn body distribute more randomly in CCS and the blend yarns have better evenness CV. Meanwhile in the yarns spun by FRCS, although cotton fibres are mainly distributed in the outer layer, there are also a lot of polyester fibres therein (see ***Table 10***), which makes the short cotton fibres end out of the yarn body more easily and produce hairiness correspondingly.

Another two kinds of cotton blend yarn spinning qualities

In this section, the qualities of another two kinds of blend yarns - JC60/R40 and JC60/M40 spun by two kinds of compact spinning systems were studied. 28.1, 18.5, 14.8 tex JC60/R40 and 18.5, 14.8, 11.8 tex JC60/M40 were spun on a QFA1528 ring spinning frame modified by two compact spinning systems, respectively.

JC60/R40 blend yarn spinning qualities

Spinning test

Combed JC60/R40 roving of 512 tex was used as raw material. The rayon fibre properties used are shown in ***Table 13***. Details of the spinning parameters are shown in ***Table 14***. Then 28.1, 18.5 and 14.8 tex JC60/R40 blend yarns were spun on two kinds of compact spinning systems, respectively. Then, the evenness (CV), hairiness and breaking strength of the spun yarns were measured, and corresponding results are given in ***Table 15***.

From ***Table 15***, it is shown that that for yarn evenness CV, comparing with FRCS, CCS is better for the relatively low linear density (yarn count) 28.1 tex, while is worse for the relatively middle Linear density (yarn count) 18.5 tex and relatively high linear density (yarn count) 14.8 tex. For yarn breakage, comparing with FRCS, CCS has a little higher breaking tenacity for the relatively low linear density (yarn count) 28.1 tex, and is similar for the relatively middle linear density (yarn count) 18.5 tex, and a little lower for the relatively high linear density (yarn count) 14.8 tex. CCS has a little higher elongation at break for all three kinds of blend yarns. For long yarn hairiness, comparing with FRCS, CCS is a little more for the relatively low linear density (yarn count) 28.1 tex, while it is less for the relatively medium linear density (yarn count) 18.5 tex and relatively high linear density (yarn count) 14.8 tex.

Fibre condensing process

The fibre strand condensing process in the condensing zones of CCS and FRCS is shown in ***Figures 13*** & ***14***, respectively, obtained using a high speed camera system - OLYMPUS i-speed3. From the Figures, it is also shown that there is weak twisting acting on the fibre strand in the condensing zone in FRCS, while fibres in the condensing zones of CCS are condensed to the center of the parallel strand.

For 28.1 tex blend yarn, the fibre is relatively more, and the fibres in the yarn body spun by CCS are distributed more uniformly under the parallel condensing effects, while fibres in the yarn body spun by FRCS are distributed more relatively non-uniformly under the weak twisting condensing effects, which gives 28.1 tex blend yarn spun by CCS better evenness and breakage. Meanwhile a little more border fibres can be rolled into the yarn body under the weak twisting condensing effects in FRCS, leading to less yarn long hairiness correspondingly. For the 18.5 and 14.8 tex blend yarns, the fibre is relatively less. Although fibres in the yarn body spun by CCS are distributed more uniformly, the bending and overlapping of fibres would happened in the twisting process since the friction of rayon fibre is large, which makes blend yarns spun by CCS have worse evenness. Meanwhile the parallel condensing effects of CCS is more beneficial for reducing the production of fibre ends in the twisting since the fibre is relatively less, leading to less long yarn hairiness.

Table 14. Spinning parameters.

Linear density of yarns, tex	Yarn twist factor	Draft multiple	Spacer, mm	Ring traveler	Negative pressure, Pa	
					FRCS	CCS
18.5	320	18.22	3.00	6903 1/0	2400	2200
14.8	340	27.75	2.75	6903 3/0	2400	2200
11.8	350	34.69	2.75	C 1 EL udr 4/0	2400	2200

Table 15. Testing results of yarn qualities.

Linear density of yarns, tex	Spinning method	Evenness CV, %	Thin, -50%/km^{-1}	Thick, +50%/km^{-1}	Neps, +200%/km^{-1}	Breaking tenacity, cN/tex	Elongation at break rate, %	≥ 3 mm hairiness/10 m^{-1}
18.5	CCS	10.18	0	17.50	7.52	14.85	5.04	16.31
	FRCS	10.31	0	8.75	8.75	14.43	4.55	13.32
14.8	CCS	12.23	0	15.21	37.51	13.43	4.75	9.31
	FRCS	12.08	0	20.02	27.52	13.41	4.01	12.44
11.8	CCS	13.44	2.51	62.51	52.54	12.56	4.13	9.13
	FRCS	13.15	5.24	12.52	37.51	12.84	3.93	11.83

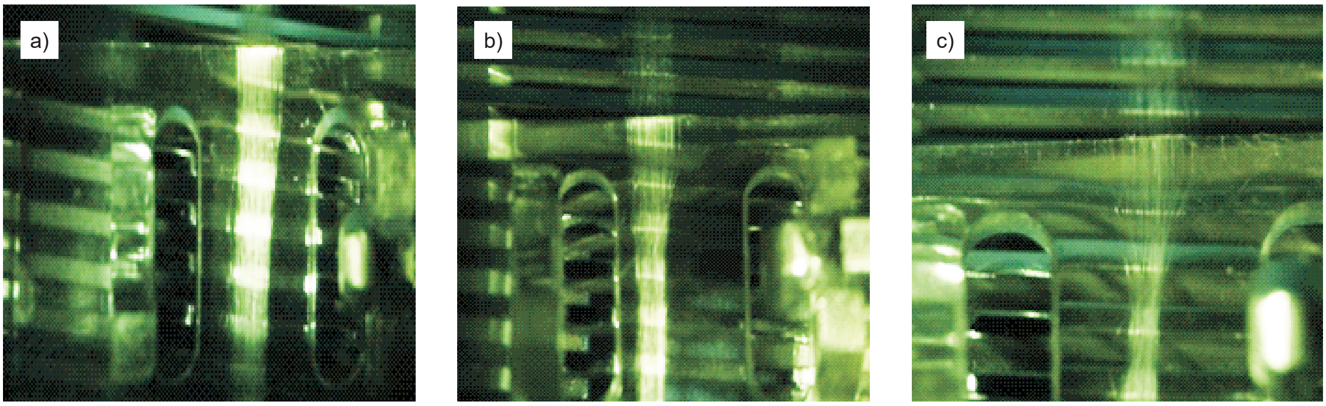

Figure 13. *Fibre strands condensing process of JC60/R40 blend yarns spun by CCS; a) 28.1 tex, b) 18.5 tex, c) 14.8 tex.*

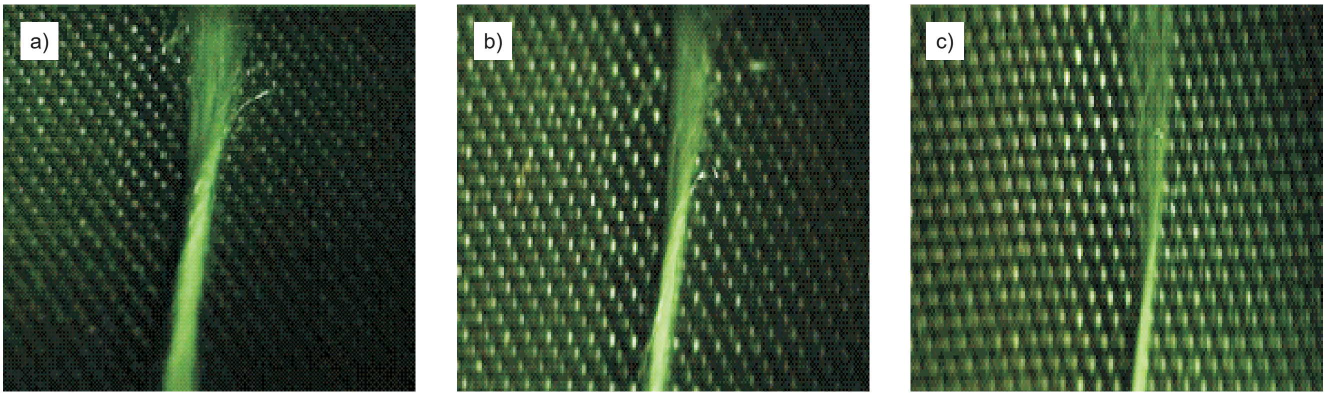

Figure 14. *Fibre strands condensing process of JC60/R40 blend yarns spun by FRCS; a) 28.1 tex, b) 18.5 tex, c) 14.8 tex.*

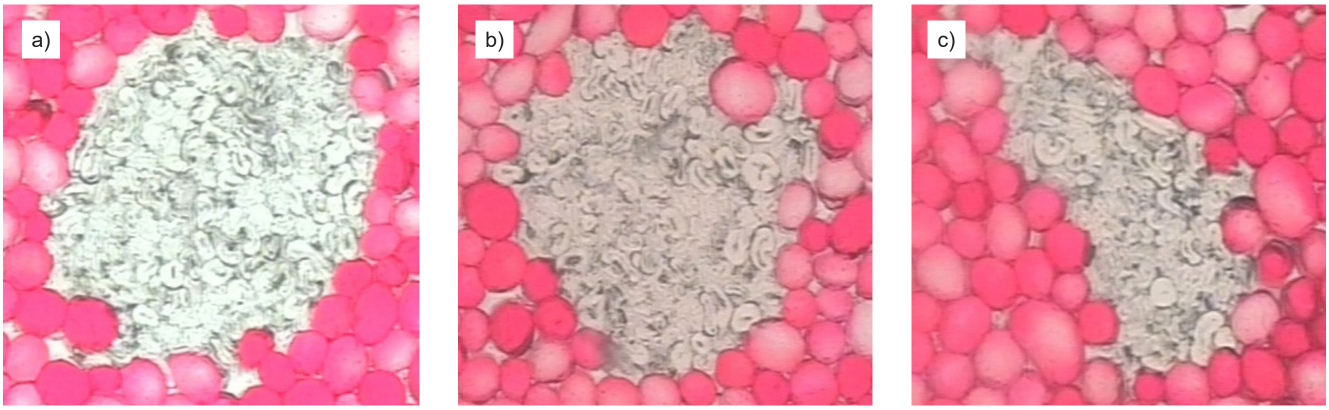

Figure 15. *Cross sections of JC60/R40 blend yarns spun by CCS; a) 28.1 tex, b) 18.5 tex, c)14.8 tex.*

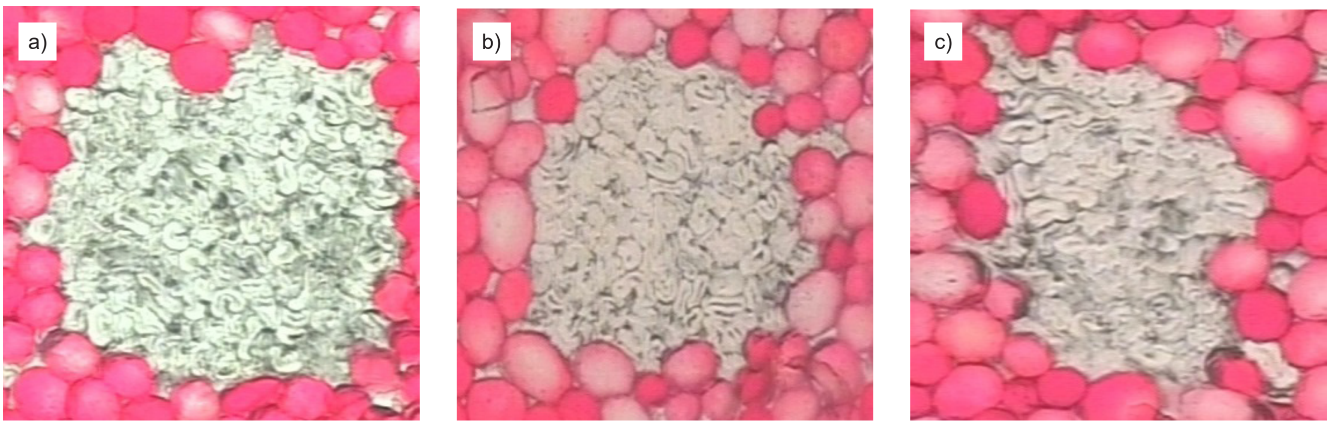

Figure 16. *Cross sections of JC60/R40 blend yarns spun by FRCS; a) 28.1 tex, b) 18.5 tex, c) 14.8 tex.*

Table 16. *Fibre relative volume distribution.*

Spinning method	Layer	1	2	3	4	5	Total
	Layer difference	-2	-1	0	1	2	
CCS	Polyester fibre	4.10	13.90	15.20	13.80	2.90	49.90
	Cotton fibre	2.94	7.84	7.84	10.78	2.94	32.34
	Total of each layer	7.04	21.74	23.04	24.58	5.84	82.24
FRCS	Polyester fibre	5.10	11.20	12.90	11.90	6.20	47.30
	Cotton fibre	0.98	3.92	5.88	16.66	2.94	30.38
	Total of each layer	6.08	15.12	18.78	28.56	9.14	77.68

Table 17. *Moment of fibre volume distribution.*

Fibre	Spinning method	Moment of fibre volume distribution			
		$[FM_A]_P$	$[FM_U]_P$	$[FM_I]_P$	$[FM_O]_P$
Cotton	CCS	2.94	0.17		36.26
	FRCS	16.66	7.65		39.52
Polyester	CCS	-2.50	0.27	-35.82	
	FRCS	2.90	11.91	-19.96	

Table 18. *Migration index of the fibre.*

Spinning method	Fibre	Migration index, %
CCS	Cotton	+7.68
	Polyester	-7.68
FRCS	Cotton	+28.27
	Polyester	-28.27

Table 19. *Properties of the rayon fibre.*

Fibre length, mm	Uniformity ratio, %	Fibre strength, N/tex	Elongation, %
38.0	1.3	34.0	13.0

Fibre radial distributions in the yarn cross section

Cross sections of the JC60/R40 blend yarns spun by CCS and FRCS were obtained, shown in ***Figures 15*** & ***16*** (see page 63), respectively. Then, taking 18.5 tex JC60/R40 blend yarn as an example, the Hamilton Index was calculated and analyzsed.

The relative volume distribution was obtained, given in ***Table 16***, and the corresponding moment of volume distribution of the two kinds of fibres were calculated, shown in ***Table 17***. From ***Table 17***, it is obvious that the cotton fibres would be transferred outwardly preferentially, and the Rayon fibres would be transferred inwardly preferentially. Then the corresponding migration index of the fibre was calculated, given in ***Table 18***.

From ***Table 18***, it is seen that, comparing with CCS, the migration trend of two kinds of fibres in the JC60/R40 blend yarns spun by FRCS are more obvious, but the difference is smaller than for polyester/cotton blended yarn. Therefore there are bending and overlapping phenomena of fibres in the blend yarns spun by CCS, leading to worse evenness. Meanwhile the main cause of yarn breakage is the fibre breaking in FRCS, whereas it is fibre flipping in CCS. Therefore since the friction of Rayon fibre is large comparing with FRCS, CCS has a little higher breaking tenacity for the relatively low linear density (yarn count) 28.1 tex, similar for the relatively medium linear density (yarn count) 18.5 tex, and a little lower for the relatively high linear density (yarn count) 14.8 tex.

JC60/M40 blend yarn spinning qualities

Spinning test

Combed JC60/M40 roving of 517 tex with a measured twist factor of 100.9 was used as raw material. The model fibre properties used are shown in Table 19. Details of the spinning parameters are shown in ***Table 20***. Then, 18.5, 14.8 and 11.8 tex JC60/M40 blend yarns were spun on two kinds of compact spinning systems, respectively. Then the evenness (CV), hairiness and breaking strength of the spun yarns were measured, corresponding results of which are given in ***Table 21***.

From ***Table 21***, it is shown that that for yarn evenness CV, comparing with FRCS, CCS is a little better for the 18.5 tex yarn, while it is worse for 14.8 and 11.8 tex yarn. For yarn breakage, comparing with FRCS, CCS has

Table 20. *Spinning parameters.*

Linear density of yarns, tex	Yarn twist factor	Draft multiple	Spacer, mm	Ring traveler	Negative pressure, Pa	
					FRCS	CCS
18.5	340	28.02	2.75	6903 3/0	2400	2200
14.8	350	35.03	2.75	C 1 EL udr 4/0	2400	2200
11.8	355	43.80	2.50	C 1 EL udr 5/0	2400	2200

Table 21. *Testing results of yarn qualities.*

Linear density of yarns, tex	Spinning method	Evenness CV, %	Thin, -50%/km^{-1}	Thick, +50%/km^{-1}	Neps, +200%/km^{-1}	Breaking tenacity, cN/tex	Elongation at break rate, %	≥ 3 mm hairiness/10 m^{-1}
18.5	CCS	11.71	0	25.25	15.12	16.27	4.62	10.31
	FRCS	11.85	1.25	15.21	30.21	16.42	4.46	9.12
14.8	CCS	12.38	0	10.16	20.14	16.76	4.42	9.84
	FRCS	12.15	0	7.52	25.21	17.55	4.85	8.45
11.8	CCS	12.94	0	45.02	30.02	16.37	4.24	8.41
	FRCS	12.78	0	30.13	50.05	16.54	4.16	6.93

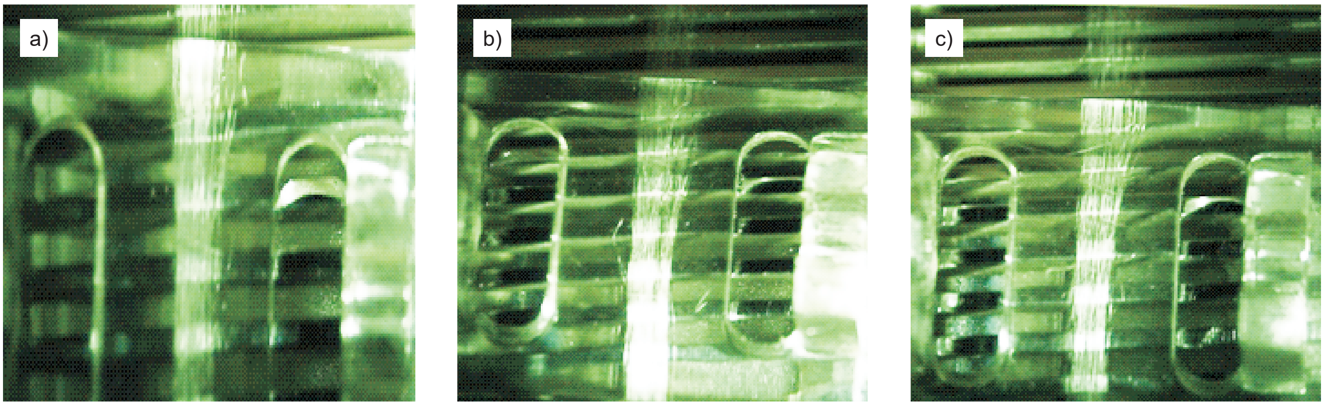

Figure 17. Fibre strands condensing process of JC60/M40 blend yarns spun by CCS; a) 18.5 tex, b) 14.8 tex, c) 11.8 tex.

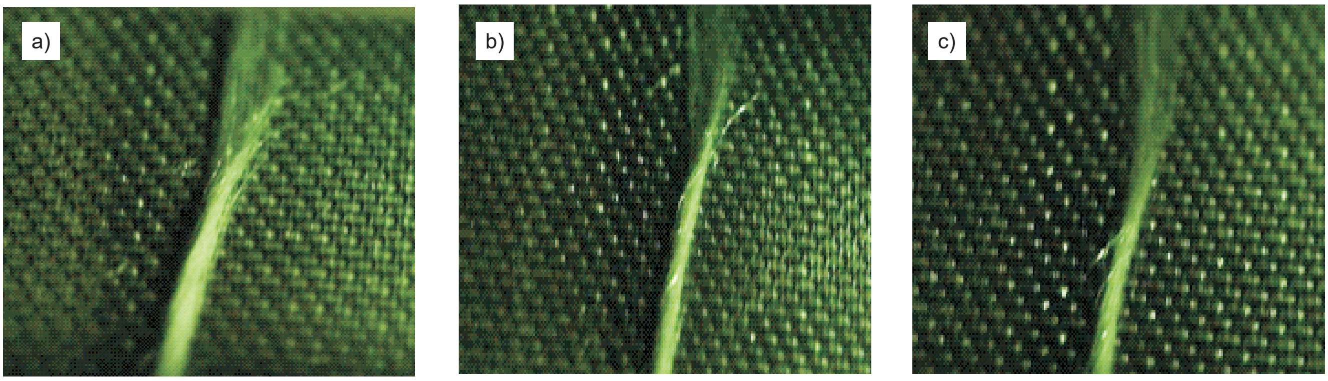

Figure 18. Fibre strands condensing process of JC60/M40 blend yarns spun by FRCS; a) 18.5 tex, b) 14.8 tex, c) 11.8 tex.

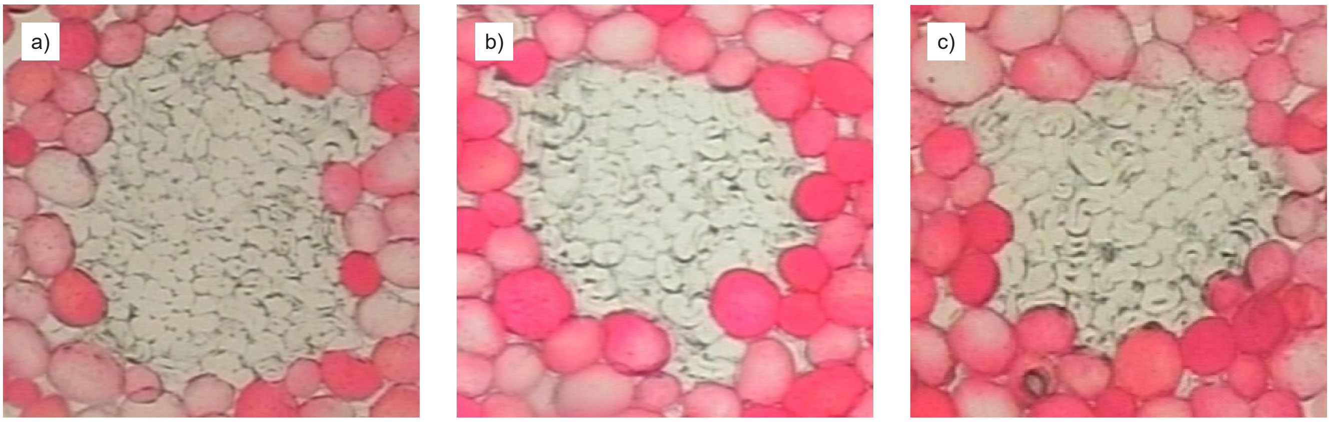

Figure 19. Cross sections of JC60/M40 blend yarns spun by CCS; a) 18.5 tex, b) 14.8 tex, c) 11.8 tex.

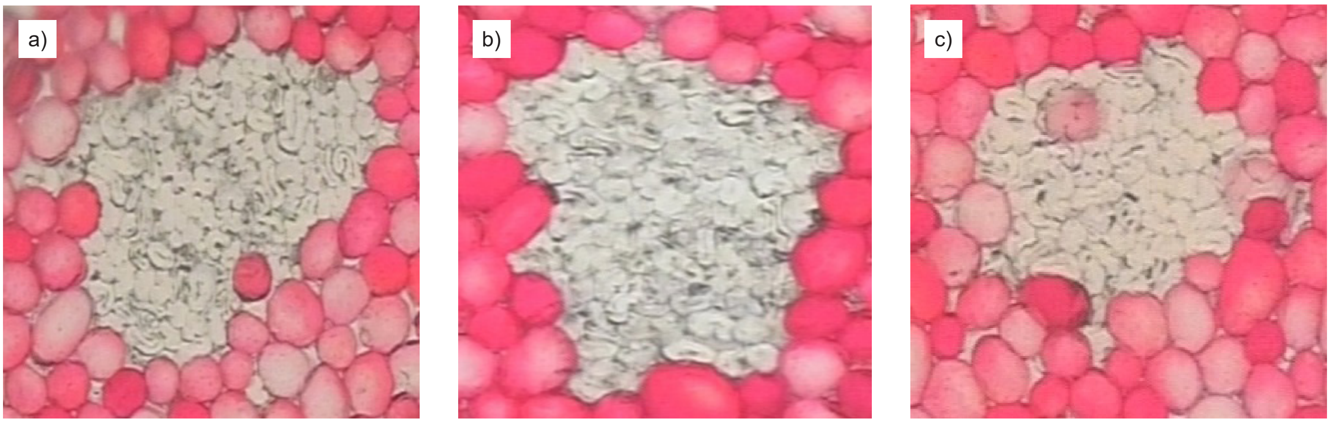

Figure 20. Cross sections of JC60/M40 blend yarns spun by FRCS; a) 18.5 tex, b) 14.8 tex, c) 11.8 tex.

Table 22. Fibre relative volume distribution.

Spinning method	Layer	1	2	3	4	5	Total
	Layer difference	-2	-1	0	1	2	
CCS	Polyester fibre	5.90	15.10	17.20	5.80	1.90	45.90
	Cotton fibre	5.64	9.87	16.92	19.74	1.41	53.58
	Total of each layer	11.54	24.97	34.12	25.54	3.31	99.48
FRCS	Polyester fibre	6.10	10.90	15.90	9.10	3.20	45.20
	Cotton fibre	4.23	16.92	18.33	14.10	1.41	54.99
	Total of each layer	10.33	27.82	34.23	23.20	4.61	100.19

Table 23. Moment of fibre volume distribution.

Fibre	Spinning method	Moment of fibre volume distribution			
		$[FM_A]_P$	$[FM_U]_P$	$[FM_I]_P$	$[FM_O]_P$
Cotton	CCS	1.41	-8.56	-	32.16
	FRCS	-8.46	-8.81	-	32.42
Polyester	CCS	-17.30	-7.33	-48.05	-
	FRCS	-7.60	-7.25	-48.48	-

Table 24. Migration index of the fibre.

Spinning method	Fibre	Migration index, %
CCS	Cotton	+24.5
	Polyester	-24.5
FRCS	Cotton	+0.85
	Polyester	-0.85

lower breaking tenacity for all three kinds of blend yarns, and CCS has a little higher elongation at break for 18.5 and 11.8 tex yarn, while it is a little lower for 14.8 tex yarn. For long yarn hairiness, comparing with FRCS, CCS is a little more for all three kinds of blend yarns.

Fibre condensing process

By using a high speed camera system - OLYMPUS i-speed3, the fibre strand condensing process in the condensing zones of CCS and FRCS was obtained, shown in ***Figures 17*** and ***18*** (see page 65), respectively. From the figures, it is also seen that in the condensing zone of FRCS, there is weak twisting acting on the fibre strand, while fibres in the condensing zones of CCS are condensed to the center of the parallel strand.

Since modal fibre has large bulkiness and a small cohesion force, the cohesion force of fibres in the modal/cotton yarns spun by CCS is lower under the parallel condensing effects, and the yarn breaking tenacity is lower correspondingly, while the cohesion force of fibres in yarns spun by FRCS is higher under the weak twisting condensing effects, and the yarn breaking tenacity is higher correspondingly. Meanwhile, comparing with FRCS, CCS is a little better for 18.5 tex yarn since fibres in the yarn body are relatively more, while there are relatively more thin places for 14.8 and 11.8 tex yarn since fibres in the yarn body are relatively fewer and the cohesion force of the modal fibre is small, leading to worse evenness. Furthermore there are more border fibres in the blend yarns spun by CCS under the parallel condensing effects, and the friction coefficient between the yarn and traveller is large, which makes the border fibre end out of the yarn body more easily, leading to more long yarn hairiness correspondingly.

Fibre radial distributions in the yarn cross section

The cross sections of three kinds of JC60/M40 blend yarns spun by CCS and FRCS were obtained, shown in ***Figures 19*** and ***20*** (see page 65), respectively. Then, taking 18.5 tex JC60/M40 blend yarn as an example, the Hamilton Index was calculated and analysed.

The relative volume distribution was obtained, given in ***Table 22***, and the corresponding moment of volume distribution of the two kinds of fibres were calculated, shown in ***Table 23***. From ***Table 23***, it is obvious that the cotton fibres are preferentially transferred outwardly, and the modal fibres are preferentially transferred inwardly. Then the corresponding migration index of the fibre was calculated, shown in ***Table 24***.

From ***Table 24***, it is seen that, comparing with FRCS, the migration trend of the two kinds of fibres in JC60/M40 blend yarns spun by CCS is more obvious, with the difference being much larger than for polyester/cotton blended yarn and rayon/ cotton blend yarns. Therefore the fibres in modal/cotton blend yarns spun by FRCS are distributed more uniformly, while cotton fibres in modal/cotton blend yarns spun by CCS are mainly distributed in the outer layers, which makes the qualities of blend yarn spun by CCS possibly a little worse.

Conclusions

In this paper, the qualities of blend yarns spun by pneumatic compact spinning systems were studied. Polyester/cotton blended yarns, Rayon/cotton blend yarns and Modal/cotton yarns were spun on a QFA1528 ring spinning frame modified by two pneumatic compact spinning systems CCS and FRCS, respectively. Then the spun yarns' qualities were researched and analyzed comparatively using two methods. First, by using a high speed camera system - OLYMPUS i-speed3, with which the condensing processes of the fibre strand in condensing zones was captured. It is shown that there is weak twisting acting on the fibre strand in the condensing zone in FRCS, while fibres in the condensing zones of CCS are condensed to the center of the parallel strand. Secondly cross-sections of the spun yarns were presented using a Y172 Hardy's thin cross-section sampling device, and the corresponding Hamilton Index was calculated. It is shown that for all three kinds of cotton blend yarns, the cotton fibres are transferred to the outer part of the yarn body, and the other kind of fibre to the inner part of the yarn body. However, comparing with CCS, the migration trend of the two kinds of fibres in polyester/cotton-polyester/cotton and rayon/cotton blend yarns spun by FRCS is more obvious, while it is much less obvious in modal/cotton blend yarns.

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