Zhuanyong Zou[1, 3],
Shaoming Zheng[2, 3],
Longdi Cheng[3],
Bojun Xi[1],
Jiangwei Yao[1]

[1)] **College of Textiles & Fashion, Shaoxing University,**
508 West Huancheng Road, Shaoxing 312000, P. R. China
E-mail: zouzhy@usx.edu.cn

[2)] **Jinjiang Laboratory, Fujian Fiber Inspection Bureau,**
17 Zhaoyu Road, Cangshan District, Fuzhou 352006, P. R. China

[3)] **Key Lab of Textile Science & Technology, Ministry of Education,**
Donghua University, 2999 North Renmin Road, Songjiang District, Shanghai 201620, P. R. China

Effect of Some Variables on the Fibre Packing Pattern in a Yarn Cross-section for Vortex Spun Yarn

Abstract

This paper examined the influence of various parameters such as fibre fineness, yarn count, distance from the front roller nip point to the hollow spindle, nozzle pressure and yarn delivery speed on the fibre packing pattern in a yarn cross-section for vortex spun yarn. Cross-section images of vortex spun yarns were used to evaluate the fibre packing pattern. Results from different variables influencing the fibre packing pattern for vortex spun yarn were also analysed. The results indicated that the fibre fineness, yarn count, distance from the front roller nip point to the hollow spindle, nozzle pressure and yarn delivery speed are all significant parameters for yarn hairiness and fibre packing density in a vortex spun yarn cross-section.

Key words: *vortex spun yarn, process parameter, fibre packing density, yarn structure.*

Introduction

Vortex spun yarn is formed by the whirled airflow twisting of open-end trailing fibres in a twisting chamber [1, 2]. Compared with ring and open-end rotor spun yarns, vortex spun yarn has lower hairiness and better pilling resistance [3]. The elasticity and yarn tenacity of vortex spun yarn is better than those of air-jet spun yarn [4, 5]. Vortex spinning with a high production speed (450 m/min) can spin the yarn desired by a four roller/apron drafting system, which is accepted as one of the most promising technologies [6, 7].

Previous researchers investigated the structure of vortex spun yarn and made a comparison of the structure of yarns produced by different spinning systems, such as ring spinning, air-jet spinning and open-end rotor spinning [5, 8, 9]. Vortex spun yarn, with a more ring-like appearance and higher number of wrapper fibres compared to air-jet yarn, is mainly composed of core fibres and wrapper fibres. Zou et al. [9] thought that wrapper fibre can be subdivided into migration wrapper fibre and regular wrapper fibre. The ratio of wrapper fibres to core fibres in carded cotton vortex yarns was investigated by Erdumlu et al., showing that wrapper fibres constitute an increasing proportion of the fibres as the yarn becomes finer [10]. Pei et al. utilised the numerical method to analyse the motion characteristics of different types of fibres (cotton, viscose rayon, lyocell, and polyester fibres) and found that polyester fibres in the vortex yarn have the best wrapping effect of all types of fibres [11]. The structure of vortex spun yarn is mainly affected by processing variables such as the distance from the front roller nip point to the hollow spindle, nozzle pressure, delivery speed, fibre properties, and yarn count [10 - 12]. Yarn structure change will result in a variation in the fibre packing pattern in the cross-section of vortex spun yarn. Zheng et al. [13] investigated the fibre packing density and effective fibre packing density of vortex and ring spun yarns, and also calculated and compared the Hamilton fibre migration indexes of bamboo pulp fibre/white

Table 1. *Fibre properties.*

Fiber type	Length, mm	Linear density, dtex	Tenacity, cN/dtex	Elongation at break, %
Fine modal	38.4	1.1	3.50	13.50
Coarse modal	38.4	1.3	3.42	14.32
Viscose	37.5	1.3	2.21	20.46

Table 2. *Yarn formation process parameters.*

Spinning system	MVS system									
Simple No.	1	2	3	4	5	6	7	8	9	10
Fiber type	Fine modal	Coarse modal						Viscose		
Yarn delivery speed,m/min	360							320	350	380
Total draft / Main draft	207/33	223/35	297/40	223/35				223/37		
Nozzle type	75, Holder 130d, 8.8									
Hollow spindle, mm	1.1									
Condenser, mm	4									
Feed ratio / Take up ratio	0.96/1.02									
Nozzle pressure, MPa	0.55					0.45	0.65	0.55		
Distance between front roller and hollow spindle, mm	20			20.5	21	20				
Linear density, tex	19.68		14.76	19.68						

Table 3. *Yarn properties.*

Sample No.		1	2	3	4	5	6	7	8	9	10
Yarn diameter, μm		173.90	169.73	147.38	175.38	170.35	176.93	172.23	172.07	168.19	164.80
Tenacity, cN/tex		16.22	17.022	15.898	16.032	16.009	16.679	16.016	12.415	12.626	12.885
Breaking extension, %		7.825	8.313	7.245	8.724	8.576	8.095	8.269	11.158	11.177	12.139
CVm, %		11.92	12.29	14.18	13.38	12.82	10.87	11.20	12.82	12.74	14.11
Num. of yarn hairiness	1 mm	116.20	133.10	151.20	150.30	105.20	162.60	162.30	117.30	166.90	222.90
	2 mm	1.70	1.80	2.90	2.30	1.90	3.80	3.60	1.30	2.70	6.40
	3 mm	0.20	0.30	0.10	0.10	0.10	0.20	0.00	0.30	0.10	0.60
	4 mm	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
	5 - 9 mm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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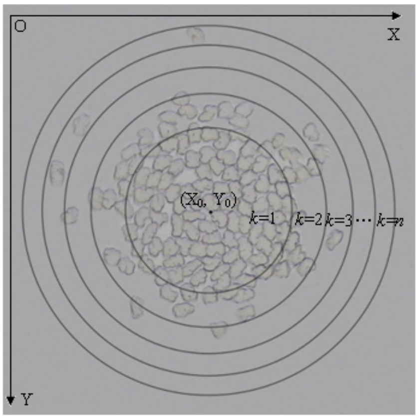

***Figure 1.** Schematic diagram of concentric circles with equal area.*

cotton (70/30) blend yarns with different counts.

However, the fibre packing pattern in the yarn cross-section for vortex spun yarn affected by process parameters has not been discussed thus far. Therefore this paper aims at investigating the influence of process parameters, such as fibre fineness, yarn count, the distance from the front roller nip point to the hollow spindle, nozzle pressure, and delivery speed on the fibre packing pattern in the yarn cross-section for vortex spun yarn.

Material and methods

Material and yarn production

Three fibre types: fine and coarse modal staple fibres as well as viscose staple fibres, were used to produce vortex spun yarns under different process parameters. The properties of these fibres are summarised in ***Table 1***. The modal and viscose staple fibres were produced by the Lenzing Company in Austria. These vortex spun yarns were spun on a MVS (Murata Vortex Spinning) No. 861 using the values of spinning process parameters in ***Table 2***. The preparing of all yarn samples was done by in Dezhou Huayuan Eco-Technology Co., Ltd of China.

Evaluation of fibre packing density in yarn cross-section

In order to calculate the fibre packing density, we should obtain images of the yarn cross-section, which requires us to prepare cross-section slices of the sample. 20 cross-section slices for every sample were prepared to ensure the reliability of data. A yarn cross-sectional image was acquired through observing the cross-section slice magnified 320× by a QUESTAR Hi-Scope Video Microscope System. The yarn cross-sectional images were used to calculate the fibre packing density with software Photoshop CS4 11.0. In this paper, we divided the yarn cross-section into several concentric circles of equal area to calculate the fibre packing density, as shown in ***Figure 1***. The fibre packing density in the k-th radial ring μ_k was calculated as a ratio of the pixel of the fibres P_{fk} in the k-th radial ring to the pixel of this zone P_{yk}, which is shown as

$$\mu_k = \frac{P_{fk}}{P_{yk}} \qquad (1)$$

The detailed procedures of yarn cross-section preparation and evaluation of the fibre packing density in a yarn cross-section are presented in literature [13].

Simple property tests

The humidity adjustment balance of all yarn samples spun by the MVS No. 861 was done firstly in an atmosphere of 20 ± 2 ºC and 65 ± 2% RH. The balancing time of the yarn sample was 48 hours. Then the yarn diameter was tested by a computerised fibre fineness analysis system - YG002C (Dowell Science and Technology (HK) Co., Limited) at 160% magnification. 400 tests per sample were performed and their mean value was used to represent the diameter of this sample. Yarns were tested for irregularity on a capacitive evenness tester (YG135G, Shaanxi Changling Group Co., Ltd in China) with a yarn delivery speed of

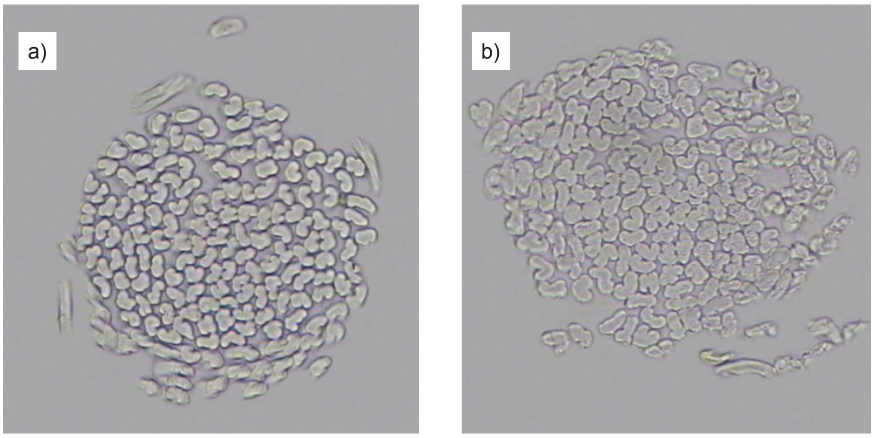

***Figure 2.** Typical cross-sectional views of vortex spun yarns composed of different fineness's fibres; a) fine modal, b) coarse modal.*

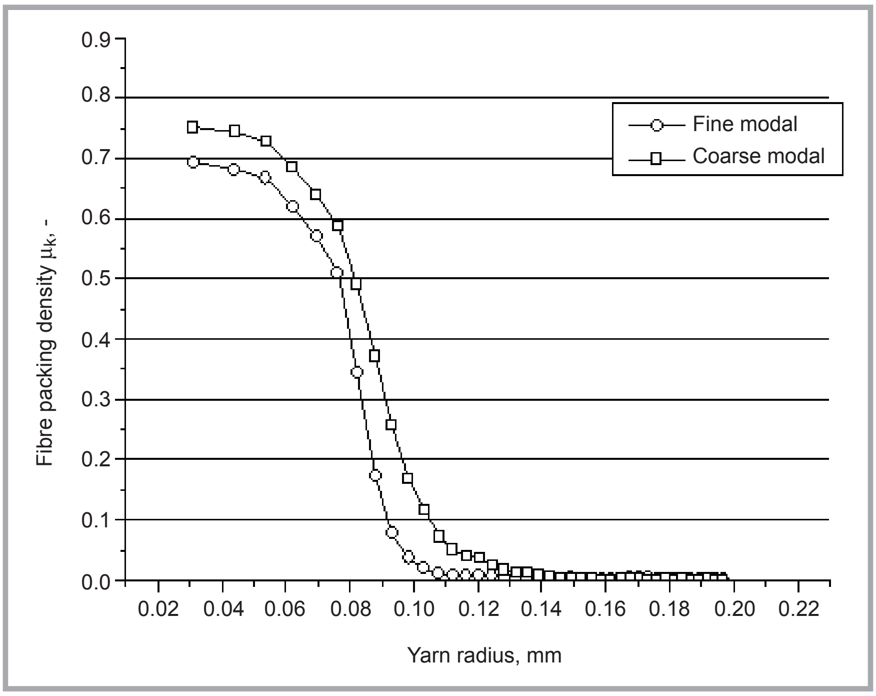

***Figure 3.** Fibre packing density distributions along yarn radius for vortex spun yarns with different fibre finenesses.*

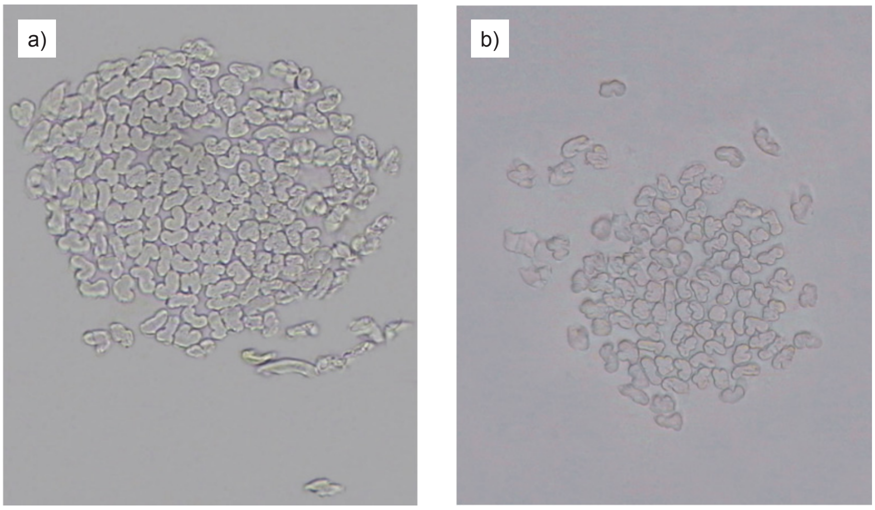

Figure 4. Typical cross-sectional views of vortex spun yarns with different yarn counts; a) 19.68 tex, b) 14.76 tex.

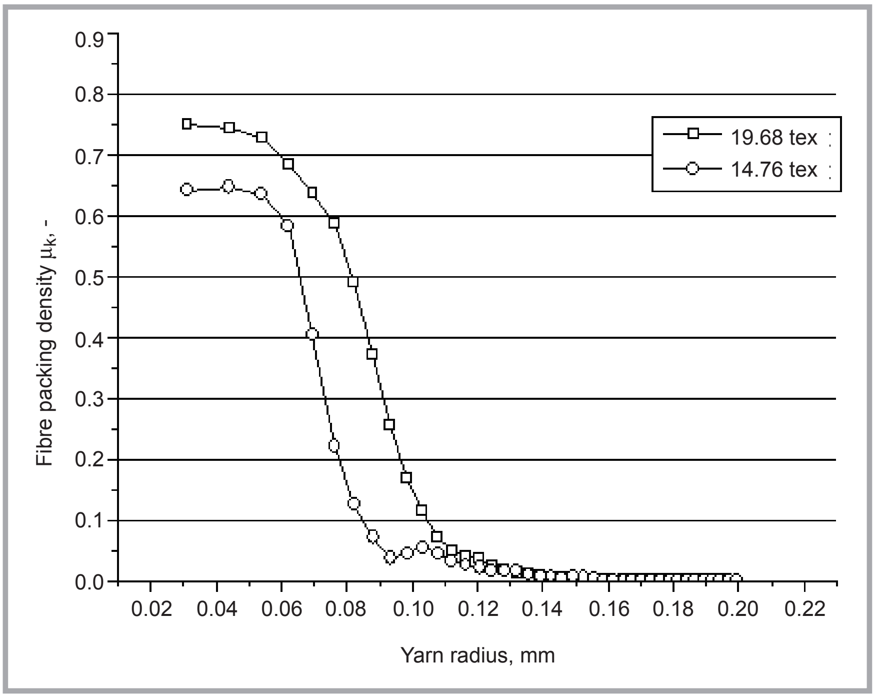

Figure 5. Fibre packing density distributions along yarn radius for vortex spun yarns with different yarn counts.

400 m/min and testing time of 1 minute, for hairiness on a yarn hairiness tester (YG172, Shaanxi Changling Textile Mechanical & Electronic Technological Co., Ltd in China) with the testing speed of 30 m/min and test length of 10 m, and for tenacity and elongation at break at a constant rate of the specimen extension testing machine (YG061, Lai Zhou Electron Instrument Co., Ltd in China) with a test length of 500 mm, extension rate of 500 mm/min and pre-tension of 0.5 cN/tex. The values of irregularity and hairiness for every yarn sample are the means of 10 test results. The mean value of 50 tests was used to represent the tenacity and elongation at break property per sample. All the tests were performed under a standard atmosphere of 20 ± 2 ºC and 65 ± 2% RH.

Results and discussion

Yarn properties

Results of yarn diameter, tenacity, elongation at break, irregularity and hairiness measurements for all samples are given in ***Table 3*** (see page 40). The diameter of vortex spun yarn is affected by the fibre material fineness, the distance between the front roller and hollow spindle, nozzle pressure and yarn delivery speed, but its change range is not so large. Compared with finer vortex spun yarn, coarser vortex spun yarn has higher yarn tenacity. Increasing the nozzle pressure makes the tenacity of vortex spun yarn increase at first, and then decrease. The yarn tenacity of vortex spun yarn is less affected by the yarn delivery speed used in the experiment. However, the yarn tenacity of vortex spun yarn composed of coarse modal fibres is higher than that of yarn composed of finer modal fibres. A higher yarn count and too high yarn delivery speed (380 m/min) make yarn evenness deteriorate. The number of yarn hairiness for all yarn samples is very small and yarn hairiness over 3 mm length is basically eliminated.

Effect of fibre fineness on the fibre packing pattern

Typical cross-sectional views of vortex spun yarns composed of fine and coarse modal fibres, corresponding to yarn samples 1 and 2, respectively, are shown in ***Figure 2***. ***Figure 2*** also validates that vortex yarn composed of coarse modal fibres has more hairiness, the reason for which may be that the whirled airflow in the twisting chamber hardly makes the ends of coarser fibres wrap the surface of the vortex spun yarn, due to the coarser fibre having a higher bending rigidity.

The fibre packing density distributions along the yarn radius for yarn samples 1 and 2 can be observed in ***Figure 3***. We can see that the fibre packing density for vortex spun yarns analysed is not uniform along the yarn cross-section, as it decreases from the yarn center towards the yarn surface. The fibre packing density values along the yarn radius decrease when the spinning fibre material gets finer, which can be due to an increase in the yarn diameter when the same count yarn was spun adopting finer fibres, as seen from ***Table 3***. Compared with the vortex spun yarn composed of finer modal fibres, higher fibre packing density values for the vortex spun yarn composed of coarse modal fibres along the yarn radius may explain the higher yarn tenacity, as shown in ***Table 3***.

Effect of yarn count on fibre packing pattern

Figure 4 shows typical cross-sectional views for vortex spun yarns of 19.68 tex and 14.76 tex, corresponding to yarn samples 2 and 3, respectively. Obviously the fibre number for vortex spun yarn of

14.76 tex is lower than that of 19.68 tex yarn, which can be validated by the change in yarn diameter; namely coarser vortex spun yarn has a bigger yarn diameter compared with finer yarn. From ***Figure 4***, we can also observe high count yarn with more yarn hairiness, in accordance with Ortlek's experimental results [7], which can be confirmed by the experiment values of ***Table 3***. Therefore increasing the count of vortex spun yarn comes at the cost of deteriorating yarn evenness, as shown in ***Table 3***. This can be attributed to the fact that for a fixed nozzle pressure and same fibre material, the force of airflow in the twisting chamber action on the fibres for finer yarn is higher than for coarser yarn because of the smaller fibre number, as a result of which the fibres can be pulled out more easily from the vortex spun yarn trail in the twisting chamber, with yarn irregularity becoming deteriorated [2]. Coarser yarn has higher fibre packing density distributions along the yarn radius for vortex spun yarns, as shown in ***Figure 5***, which can be attributed to the increasing fibre numbers in the yarn cross-section for coarser yarn with the same fibre composition. Higher fibre packing density distributions along the yarn radius for coarser vortex spun yarn may cause higher yarn tenacity compared with finer vortex spun yarn.

Effect of the distance from the front roller nip point to the hollow spindle on the fibre packing pattern

It can be observed from ***Figure 6*** that the yarn hairiness is significantly influenced by the distance from the front roller nip point to the hollow spindle. The yarn hairiness increases initially and decreases thereafter with an increase in the distance from the front roller nip point to the hollow spindle (variation from 20 mm to 21 mm, corresponding yarn samples 2, 4 and 5), as shown in ***Figure 6*** and ***Table 3***. If this distance is short, both ends of fibres are tightly controlled more by the nip point between the front rollers and vortex yarn trail, resulting in producing fewer open-end trailing fibres and making the resultant yarn have less yarn hairiness, which is in accordance with Basal's experimental results [14]. When the distance further increases to 21 mm, the length of the open-end trailing fibre becomes longer, resulting in it wrapping the yarn body easily by the action of whirled airflow in the twisting chamber, thus reducing the yarn hairiness.

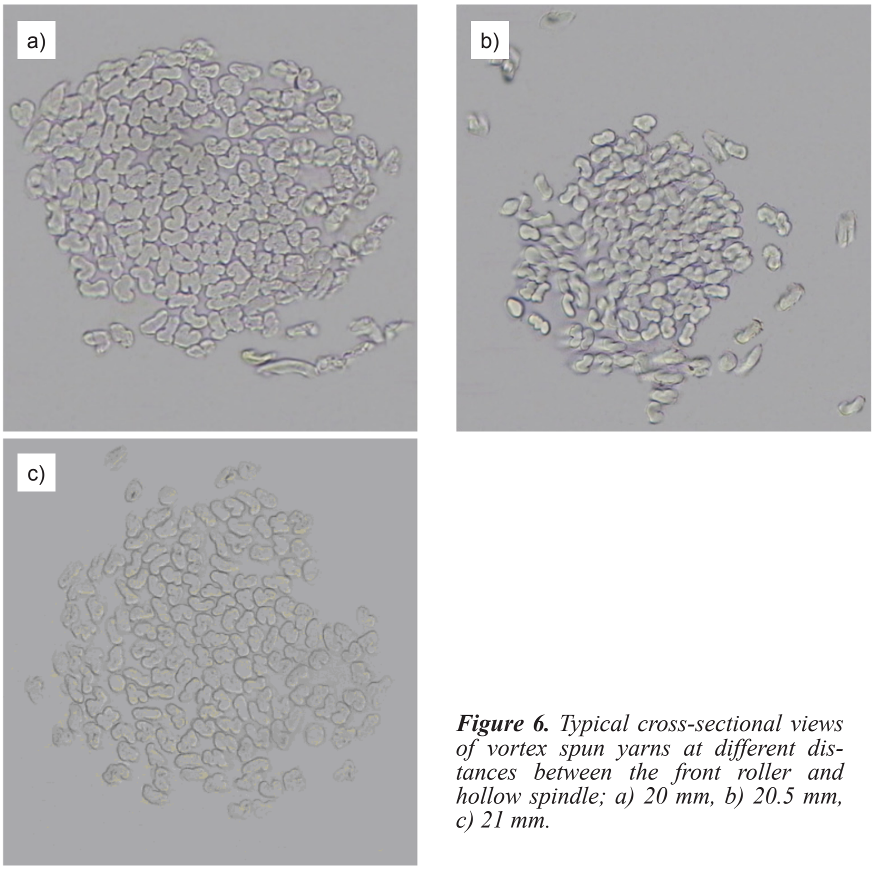

Figure 6. *Typical cross-sectional views of vortex spun yarns at different distances between the front roller and hollow spindle; a) 20 mm, b) 20.5 mm, c) 21 mm.*

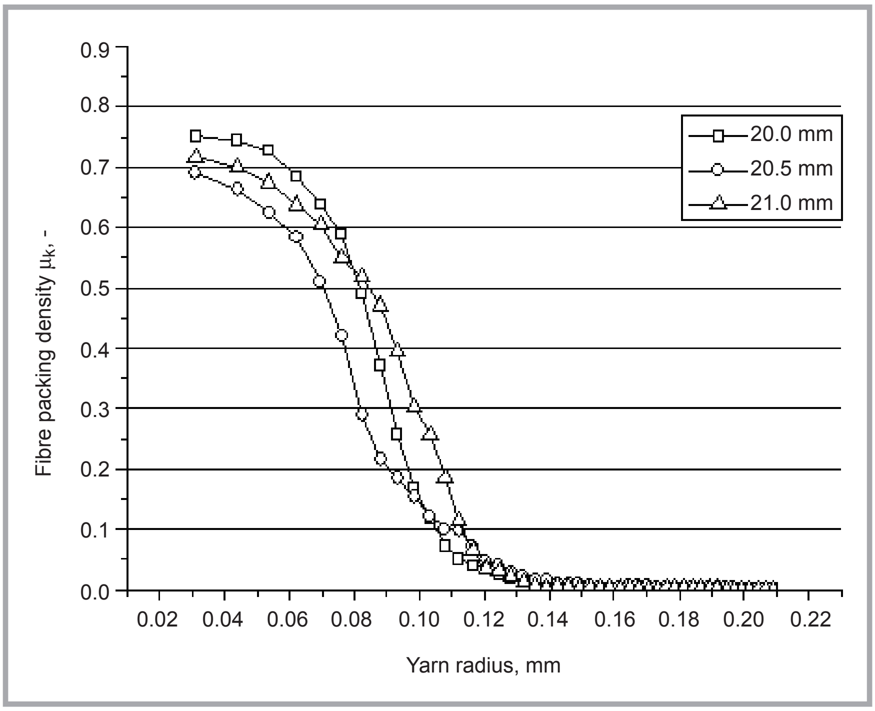

Figure 7. *Fibre packing density distributions along the yarn radius for vortex spun yarns at different distances between the front roller and hollow spindle.*

The fibre packing density distributions along the yarn radius for vortex spun yarns at different distances from the front roller nip point to the hollow spindle are shown in ***Figure 7***. It decreases with an increase in the distance from the front roller nip point to the hollow spindle initially, followed by a little rise. When the distance from the front roller nip point to the hollow spindle is short, the yarn core consists of mostly parallel core fi-

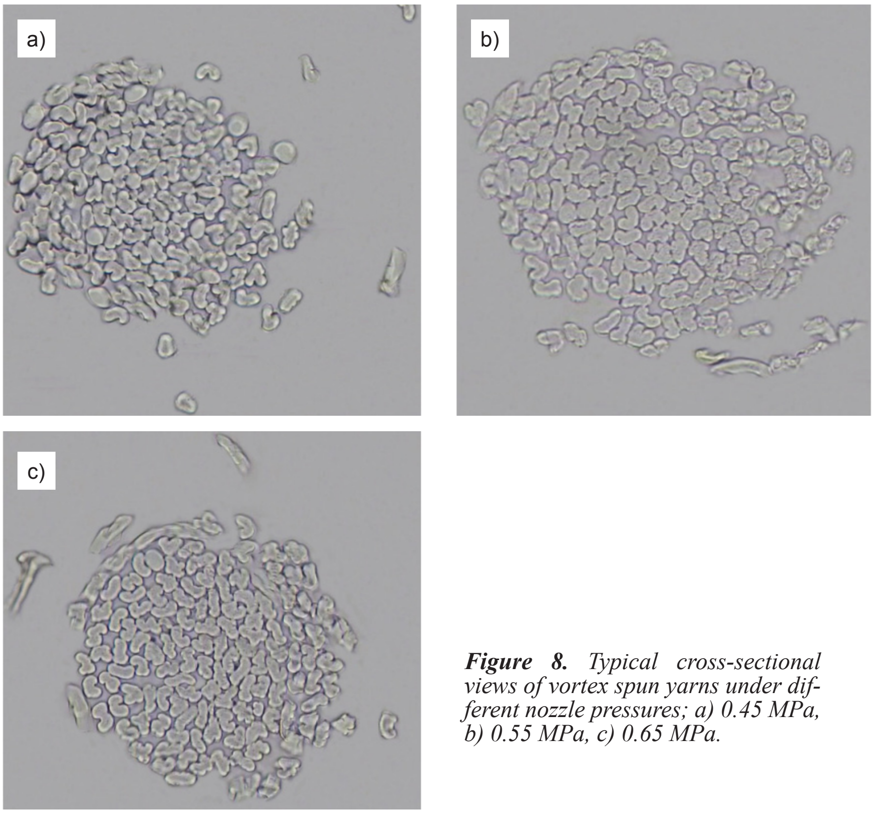

Figure 8. Typical cross-sectional views of vortex spun yarns under different nozzle pressures; a) 0.45 MPa, b) 0.55 MPa, c) 0.65 MPa.

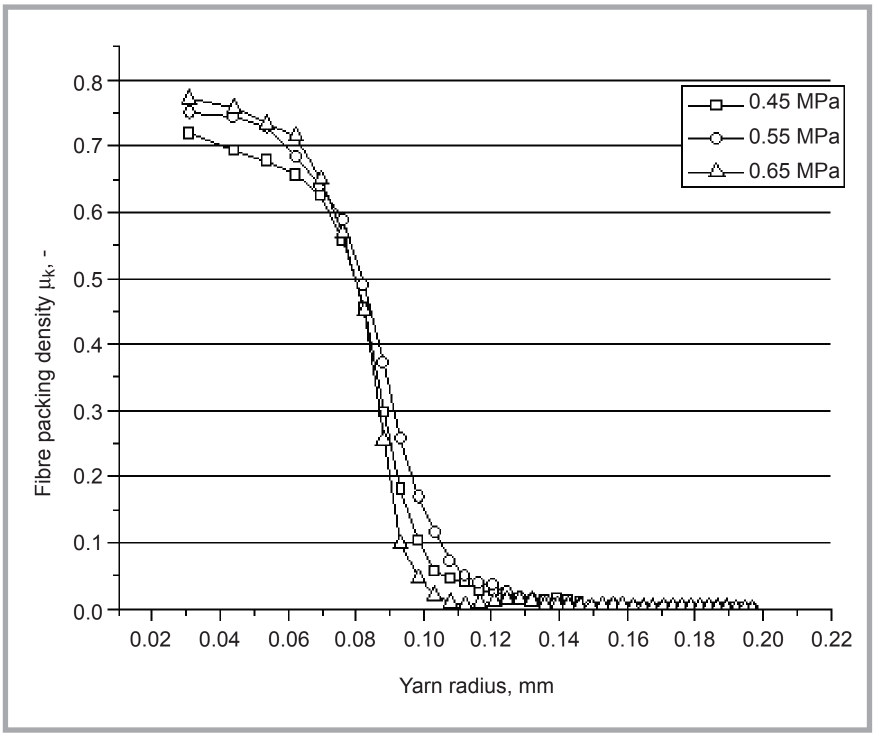

Figure 9. Fibre packing density distributions along the yarn radius for vortex spun yarns under different nozzle pressures.

bres held by fewer wrapper fibres, resulting in a high fibre packing density in the yarn core. With an increasing distance from the front roller nip point to the hollow spindle, the resultant yarn has more wrapper fibres due to less fibre control in the twisting chamber, resulting in lower fibre packing density in the yarn core. When the distance from the front roller nip point to the hollow spindle is up to 21 mm, the wrapper fibres of longer length can more tightly wrap the yarn body by the action of high whirled airflow, which may account for the fact that the fibre packing density in the yarn core increases with an increase in the distance between the front roller nip point and hollow spindle from 20.5 mm to 21 mm.

Effect of nozzle pressure on fibre packing pattern

As can be seen from ***Figure 8***, the yarn hairiness decreases with an increase in the nozzle pressure from 0.45 MPa to 0.55 MPa (corresponding yarn samples 6, 2). The decreased hairiness at higher nozzle pressure can be attributed to the fact that open-end trailing fibres better wrap the yarn body, because of the increase in the whirling force of the nozzle airflow along with the nozzle pressure. However, when the nozzle pressure was adjusted to 0.65 MPa (corresponding yarn sample 7), the yarn has higher yarn hairiness, as shown in ***Table 3***. The possible reason is that the partial open-end trailing fibres arrange disorderly due to the air turbulence being under too high nozzle pressure, with the preceding end of fibre inserted into the yarn tail being pulled out easily as a consequence, thus forming head-end hairiness. This can be used to account for the vortex spun yarn having bigger yarn diameter under a 0.65 MPa nozzle pressure compared with a 0.55 MPa nozzle pressure. The probability of the preceding end of the fibre being pulled out from the yarn tail under too high nozzle pressure was demonstrated in literature [2].

Fibre packing density distributions along the yarn radius for vortex spun yarns under 0.45, 0.55 and 0.65 MPa nozzle pressures are shown in ***Figure 9***. It is observed that the fibre packing density in the yarn core increases with an increase in nozzle pressure, while the fibre packing density in the external part of the yarn body is lowest when the nozzle pressure was adjusted to 0.65 MPa. The higher fibre packing density in the yarn core can be explained by the better wrapping effect of wrapper fibres which hold the fibre bundle tightly together under the higher nozzle pressure. Consequently the higher fibre packing density in the vortex spun yarn core results in the vortex spun yarn having lower fibre packing density in the external part of the yarn body. However, we need to pay attention to the fact that if the nozzle pressure is too high, the more excessive the vibration of the Murata vortex spinner will be, and the more energy consumption will be produced.

Effect of yarn delivery speed on the fibre packing pattern

In ***Figure 10***, we can also see typical cross-sectional views of vortex spun yarns for 320, 350 and 380 m/min yarn delivery speeds (corresponding yarn samples 8, 9 and 10). With an increase in the yarn delivery speed, the yarn hairiness becomes more numerous, which may be explained by the fact that the open-end trailing fibre insufficiently wraps because the time of its staying in the twisting chamber becomes shorter when the yarn delivery speed is improved.

Figure 11 shows the fibre packing density distributions along the yarn radius for vortex spun yarns under different yarn delivery speeds. With an increase in the yarn delivery speed, the fibre packing density in the external part of the yarn body gradually decreases, which can be explained by the wrapper loop number in unit length for trailing-end fibres decreasing with an increase in the yarn delivery speed. Zou et al. [9] found that the twist angles of wrapper fibres decrease along with an increase in the yarn delivery speed, resulting in an increase in the mean pitch of wrapper fibre and then a decrease in the wrapper loop number in unit length for trailing-end fibres. However, the fibre packing density in the yarn core takes on an upward trend when the yarn delivery speed incsreases, the reason for which is that the normal pressure action on the core fibres increases with an increase in the twist angles of wrapper fibres.

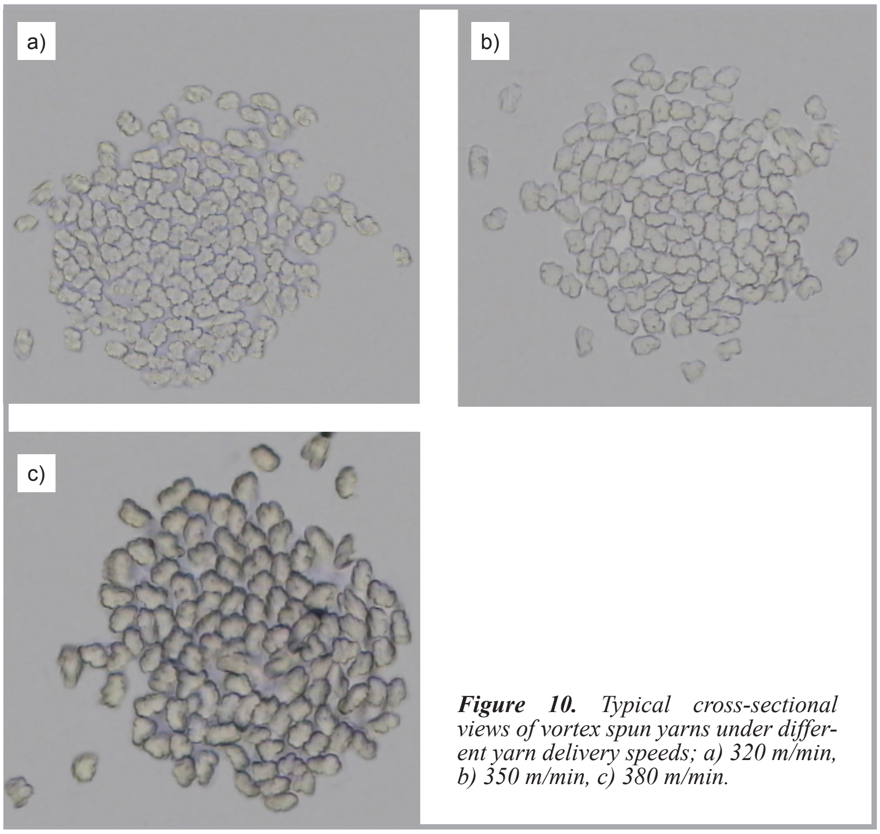

Figure 10. *Typical cross-sectional views of vortex spun yarns under different yarn delivery speeds; a) 320 m/min, b) 350 m/min, c) 380 m/min.*

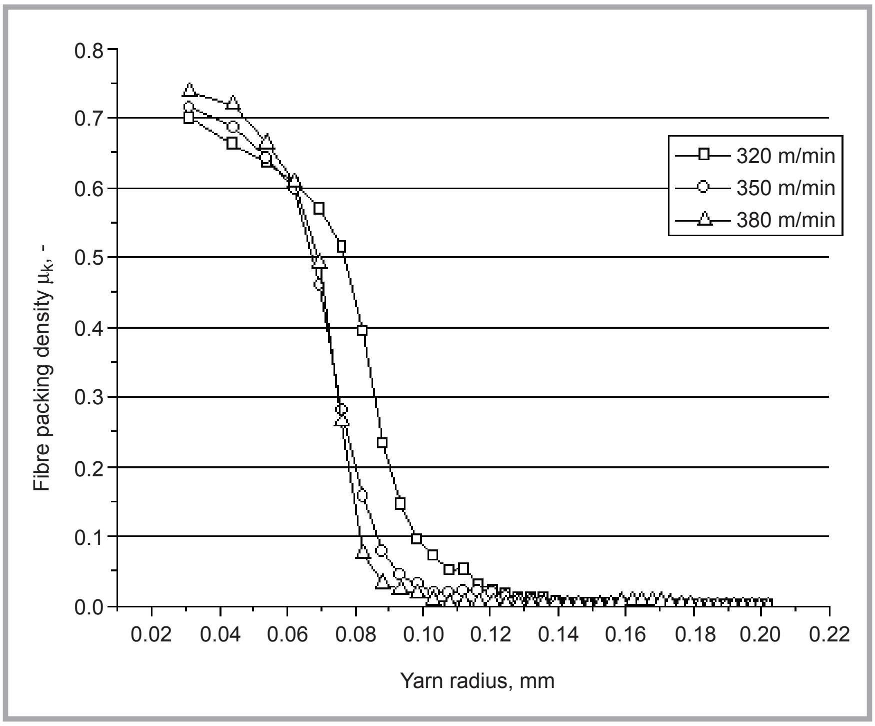

Figure 11. *Fibre packing density distributions along the yarn radius for vortex spun yarns under different yarn delivery speeds.*

Conclusions

This study demonstrates that the fibre packing patterns in the yarn cross-section for vortex spun yarn, including the two aspects of yarn hairiness and fibre packing density, are significantly affected by fibre fineness, yarn count, the distance from the front roller nip point to the hollow spindle, nozzle pressure and the yarn delivery speed.

As the experiment data shows, the hairiness value of vortex spun yarn is very low, especially hairiness over 3 mm in length, which for all samples is almost eliminated. Vortex spun yarns composed of coarse fibres and with a higher yarn count have more yarn hairiness than those composed of fine fibres and coarser yarn, respectively. The hairiness of vortex spun yarn increases initially and decreases thereafter when the distance between the front roller nip point and hollow spindle varies from 20 mm to 21 mm, while an increase in nozzle pressure makes it decrease firstly and then increase with an increase nozzle pressure from 0.45 MPa to 0.65 MPa. The hairiness value of vortex spun yarn becomes bigger with an increase in yarn delivery speed.

The fibre packing density of vortex spun yarn is not uniform along the yarn cross-section, as it decreases from the yarn center towards the yarn surface. Coarser vortex spun yarn and vortex spun yarn composed of coarse fibres have higher fibre packing density distributions along the yarn radius. The fibre packing density initially decreases with an increase in the distance between the front roller nip point and the hollow spindle from 20 mm to 20.5 mm, followed by a little rise. The fibre packing density in the yarn core increases with an increase in nozzle pressure, while the fibre packing density in the external part of the yarn body for votex spun yarn under 0.65 MPa nozzle pressure is the lowest. The fibre packing density in the vortex spun yarn core takes on an upward uptrend with an increase in the yarn delivery speed, which is contrary to that of the external part of the yarn body. The correlation between the yarn formation process and mean fibre packing density in the yarn cross-section as well as yarn the tenacity will be calculated by the statistical analysis method in the following study.

Acknowledgments

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