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Effect of wrapped Fibre on tenacity of viscose vortex yarn

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Effect of wrapped fibre on tenacity of vortex yarn has been studied by spinning experiments, SEM observation and an ideal twisting model, which will help industry to predict and improve the yarn quality. The spinning results show that the changes in the wrapped fibres (including the number of wrapped fibre and the wrapping angle) determine the yarn tenacity. With the increase in nozzle pressure, the number of wrapped fibre increases significantly, the tenacity of the yarn increases, and the change in wrapping angle is just a little. On the other hand, with the increase in the nozzle orifice angle, the wrapping angle and the yarn tenacity increase, which shows a good agreement with the ideal twisting model results. Therefore, the tenacity of vortex yarn mainly depends on the number of wrapped fibre and the wrapping angle.

Keywords: Tenacity, Viscose fibre, Vortex yarn, Wrapping angle, Wrapped fibre

1 Introduction

Yarn structure refers to the arrangement of fibres in the yarn[1,2]. Yarn performance mainly depends on the yarn structure, and hence the study of yarn structure is very important[3,4]. The structure of vortex yarn was observed by Basal and Oxenham[5,6] by scanning electron microscopy. They confirmed that the structure of vortex yarn includes the core fibres and wrapped fibres. They compared the structure of vortex yarn and air-jet yarn and confirmed that the wrapping angle and the number of wrapped fibre in vortex yarn are more than that in air-jet yarn, which made the core fibre to be gripped by the wrapped fibre more effectively. This is because of the reduction in number of slip fibres and hairiness, thus improving the tenacity of vortex yarn. In addition, they also counted and classified the different configurations of fibre in vortex yarn by using the CCD camera and tracer fibres. Finally, they concluded that the fibre configurations can be divided into straight fibres, head hook fibres, tail hook fibres, hooks at both ends fibres, ring and entanglement fibres. Yang *et al*[7,8]. studied the vortex yarn by using SEM and tracer fibre and confirmed that the fibres in vortex yarn can be divided into the parallel fibres and the spiral wrapped fibres; the inner parallel fibres were the core fibres and the fibres were almost straight. The outer layer fibres were the wrapped fibres which provide the tenacity of vortex yarn. There are different structural classes, considering the length of vortex yarn and the classification are used to investigate the structural characteristics of the vortex yarns. According to Tyagi, *et al*[9-12], there are mainly four parts, viz Class 1—this part of the yarn has tight regular wrappings and a crimped configuration; Class 2—this part has a straight configuration with long regular wrappings; Class 3:—this structure has irregular wrappings with varying angles, in this class, yarn sections with a very low proportion of wrapper fibres or loose wrappings also exist; and Class 4—this structure has no wrappings, in this class, core fibres are generally untwisted or with some residual twist. All these varying structural parts are observed along the yarn length concurrently. In this study, we examined the part having a straight configuration with long regular wrappings for measuring the wrapping angle.

The tenacity of vortex yarn is mainly determined by considering the number of wrapped fibre and the wrapping angle α (the angle of wrapped fibres' envelope line to the yarn axis). The more the number of wrapped fibre and the bigger the wrapping angle, the higher is the yarn tenacity[13,14].

In vortex spinning, the nozzle pressure and the nozzle orifice angle are the two important parameters in yarn twisting. The nozzle pressure determines the airflow sucked into the nozzle[15-17]. The greater the nozzle pressure, the higher is the vortex speed formed by airflow, and therefore, the more is the yarn

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twists[18]. The nozzle orifice angle determines the axial, radial and tangential air velocities, and hence it affects the decomposition and condensation of the fibre bundle, as well as twisting and spinning process[19]. Ortlek & Ulku[20] investigated the effects of nozzle pressure and delivery speed and other process parameters in 100% carded cotton vortex spun yarns. Tyagi and Sharma[9] studied the effects of nozzle pressure, delivery speed and nozzle distance on the performance and low-stress characteristics of polyester-cotton yarns spun on MVS. In our study, the material is viscose fibre, because it is soft and a compensation for the hard characteristics of vortex yarn[21]. In our previous studies[7, 15, 16, 21], the tenacity of viscose vortex yarn was found to be increased with the increase in nozzle pressure from 0.4Mpa to 0.6Mpa. So, there are both parallel and opposite findings available in the literatures. May be different spinning materials need different nozzle pressure and result in different trend of tenacity of vortex yarn, which is worth for further study in this direction.

Many researches are involved in the study of wrapped fibre on vortex yarn [22-24], but most of these are qualitative, and the study on the principle of the wrapped fibres' contribution with regard to the yarn tenacity is found scarcely. The present work was therefore undertaken to study the effect of wrapped fibre on the tenacity of viscose vortex yarn, by changing the nozzle pressure and the nozzle orifice angle to change the number of wrapped fibre and the wrapping angle, for improving the yarn quality.

2 Materials and Methods

Viscose fibre sliver having the weight 3.2g/m, fibre length×fineness 38 mm×1.24 dtex, fibre strength 2.32cN/dtex, and fibre elongation 22.17% were used for the study.

Viscose vortex yarn of the length 1000μm (1mm) was used for the microphotograph study using scanning electron microscope (model: DXS-10A, magnification ×45000 times, and resolution 100 Å) (Fig .1). There are obvious internal and external layer parts; the internal layer parts being core fibres, and the external layer parts being wrapped fibres.

The number of wrapped fibres can be directly seen from the image; and the wrapping angle α can be calculated by the following formula:

$$\tan \alpha = \frac{a}{b} \qquad \text{... (1)}$$

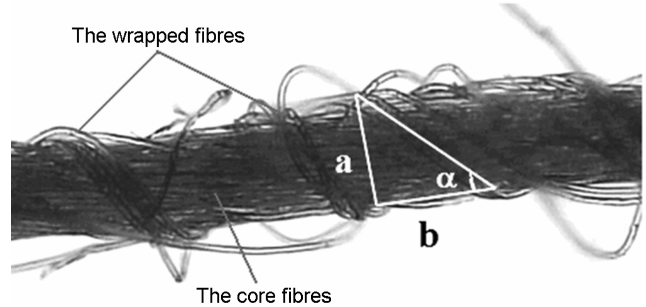

Fig 1—Structure of viscose vortex yarn under scanning electron microscope

where α is the wrapping angle; *a*, the appearance diameter of the yarn (the yarn fineness); and *b*, the projection length of the inclined length of wrapped fibre on the direction of yarn axis.

The values of *a* and *b* were tested by instrument calibration ruler. The yarn tenacity was tested on Uster Tensorapid at the testing speed of 500 mm/min and a gauge length of 500 mm. All tests were carried out under standard atmospheric conditions of 20 ± 2°C temperature and 65 ± 2% relative humidity. The samples were conditioned for 24 h before the tests.

3 Results and Discussion

In this study, the spinning parameters (nozzle pressure and nozzle orifice angle) are kept within a reasonable range. All the yarns were produced in Murata 861 (running in mill), considering the spinning conditions as spinning speed 390m/min and total draft 160.

3.1 Effect of Wrapped fibre on Yarn Tenacity

At different Nozzle Pressure

Four different nozzle pressures, viz 0.45, 0.5, 0.55, 0.6Mpa, were used in the spinning experiments, keeping the nozzle orifice angle at 45°. Yarns were taken from 10 bobbins at each nozzle pressure to get the average tested yarn tenacity (the yarn on each bobbin were tested 30 times). Photograph of each sample at each nozzle pressure was taken by SEM (Fig. 2) to get the values of *a* and *b*, as shown in Table 1.

Figure 2 shows that with the increase in nozzle pressure, the number of wrapped fibre increases, and the wrapping angle α changes little, and almost remains as the same. It is also observed from Table 1 that with the increase in nozzle pressure, the wrapping angle α changes a little, and the yarn tenacity increases. When the nozzle pressure is 0.45MPa, the wrapping angle α is 40.28°, and the yarn tenacity is 8.02cN/tex. On the other hand, when the nozzle

Table 1— Effect of the number of wrapped fibre on yarn tenacity in different nozzle pressure

Sl.No	0.45MPa				0.5MPa				0.55MPa				0.6MPa			
	a µm	*b* µm	α deg	Tenacity cN/tex	*a* µm	*b* µm	α deg	Tenacity cN/tex	*a* µm	*b* µm	α deg	Tenacity cN/tex	*a* µm	*b* µm	α deg	Tenacity cN/tex
1	170.04	206.37	39.49	7.56	244.56	256.02	43.69	9.19	260.67	268.59	44.14	10.15	267.51	271.35	44.59	10.98
2	171.96	198.87	40.85	8.22	221.67	235.02	43.33	8.91	280.86	291.81	43.91	10.08	277.05	282.78	44.41	10.89
3	212.10	265.92	38.58	7.14	219.72	237.51	42.77	8.79	246.48	256.29	43.88	9.88	280.86	294.24	43.67	10.79
4	181.53	222.27	39.24	7.27	229.29	247.23	42.84	8.76	263.67	285.00	42.77	9.97	256.38	262.86	44.28	10.83
5	213.99	244.29	41.22	8.34	206.37	226.02	42.40	8.49	286.59	298.23	43.86	9.83	216.12	227.37	43.55	10.71
6	223.56	255.72	41.16	8.29	263.73	294.18	41.88	8.09	261.78	271.56	43.95	9.67	219.72	239.04	42.59	10.62
7	231.18	276.12	39.94	8.11	265.59	288.30	42.65	8.65	256.02	284.85	41.95	9.78	208.26	221.73	43.21	10.69
8	210.18	246.03	40.51	8.18	292.35	313.92	42.96	8.73	261.78	288.93	42.18	9.84	250.38	259.86	43.94	10.80
9	227.37	252.27	42.03	8.67	275.13	308.64	41.71	8.48	256.02	280.11	42.43	9.82	233.19	245.13	43.57	10.61
10	223.56	268.86	39.74	8.42	303.81	336.63	42.07	8.53	250.56	267.78	43.10	9.86	256.02	267.51	43.74	10.69
Average	-	-	40.28	8.02	-	-	42.63	8.66	-	-	43.22	9.89	-	-	43.76	10.76
CV%	-	-	2.18	5.21	-	-	1.15	2.47	-	-	1.69	1.08	-	-	1.01	0.90

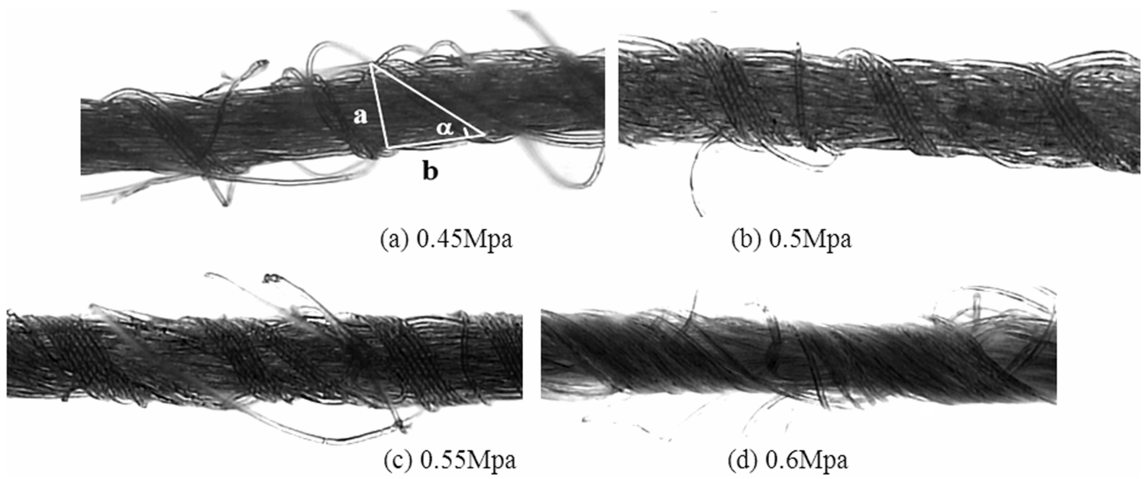

Fig. 2—Structure of yarns at different nozzle pressures

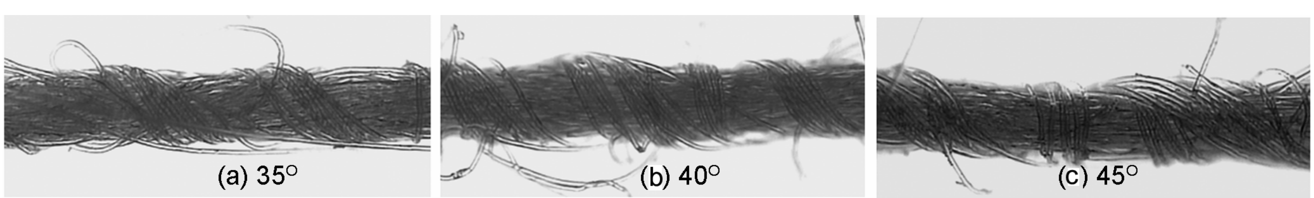

Fig.3 —Structure of yarns at different nozzle orifice angles

pressure is 0.6 MPa, the wrapping angle α is 43.76°, and the yarn tenacity is 10.76 cN/tex. Thus, the larger the wrapped fibres and the wrapping angle, the stronger is the yarn.

Therefore, with the increase in nozzle pressure, the number of the wrapped fibre and the yarn tenacity increase, but the change in wrapping angle is found just a little.

At different Nozzle Orifice Angle

Three different nozzle orifice angles, viz35°, 40°, 45°, were selected in the spinning experiments, the nozzle pressures was kept 0.55Mpa. Spinning experiments were carried out for 10times (i.e. 10 bobbins) for each nozzle orifice angle to get the average tested yarn tenacity (the yarns on each bobbin were tested 30 times to get the results). A photograph of each the yarn sample ateach nozzle angle was taken by SEM (Fig. 3) to get the values of *a* and *b*, as shown in Table 2.

Figure 3 shows that with the increase in nozzle orifice angle, the wrapping angle increases. It can also be seen from Table 2 that with the increase in nozzle orifice angle, the wrapping angle increases, which causes an increase in yarn tenacity.

In order to fully illustrate the effect of wrapping angle on yarn tenacity, a twisting model in ideal condition (assumed that the fibre without transfer and elongation) was made to analyze. The model is shown in Figs 4 (a) - (e). In this model, O_1, O_2, O_3 and O_4 represent the cross-sections of yarns respectively; θ represents the angular displacement (variable); α represents the wrapping angle (variable); r represents the diameter of yarn (the yarn fineness); MN represents a short length fibre on AB, set MN= l, l is a fixed value; ρ represents the radius curvature of the arc on MN (variable) and φ represents the central angle of the arc on MN (variable). The model is described below:

Table 2— Effect of wrapping angle on yarn tenacity at different nozzle orifice angles

Sl.No	35°				40°				45°			
	a µm	*b* µm	α deg	Tenacity cN/tex	*a* µm	*b* µm	α deg	Tenacity cN/tex	*a* µm	*b* µm	α deg	Tenacity cN/tex
1	236.94	284.70	39.80	8.92	242.79	265.05	42.49	9.50	215.94	203.82	46.65	11.23
2	252.21	300.00	40.05	9.07	229.32	263.67	41.01	9.41	208.26	205.35	45.40	10.81
3	221.64	268.86	39.50	8.89	229.35	267.51	40.61	9.28	191.40	187.26	45.63	10.89
4	199.29	256.05	37.89	8.81	208.29	240.75	40.87	9.35	187.26	177.96	46.46	11.18
5	212.10	275.13	37.63	8.79	173.88	204.54	40.37	9.15	202.53	193.83	46.26	11.01
6	213.99	301.89	35.33	8.19	177.72	212.10	39.96	9.11	178.20	175.77	45.39	10.79
7	187.29	244.83	37.42	8.65	175.89	206.37	40.44	9.21	179.61	185.70	44.04	10.59
8	196.89	155.75	37.59	8.73	181.53	217.83	39.81	8.86	175.77	187.74	43.11	10.33
9	206.40	293.22	35.14	8.06	194.88	227.10	40.63	9.30	192,.99	194.94	44.71	10.63
10	215.91	297.75	35.95	8.24	183.45	210.18	41.12	9.49	183.78	192.99	43.60	10.51
Average	-	-	37.63	8.64	-	-	40.73	9.27	-	-	45.13	10.80
CV%	-	-	3.57	3.28		-	1.26	1.58	-	-	2.23	2.10

35° ,40°and 45°are orifice angle

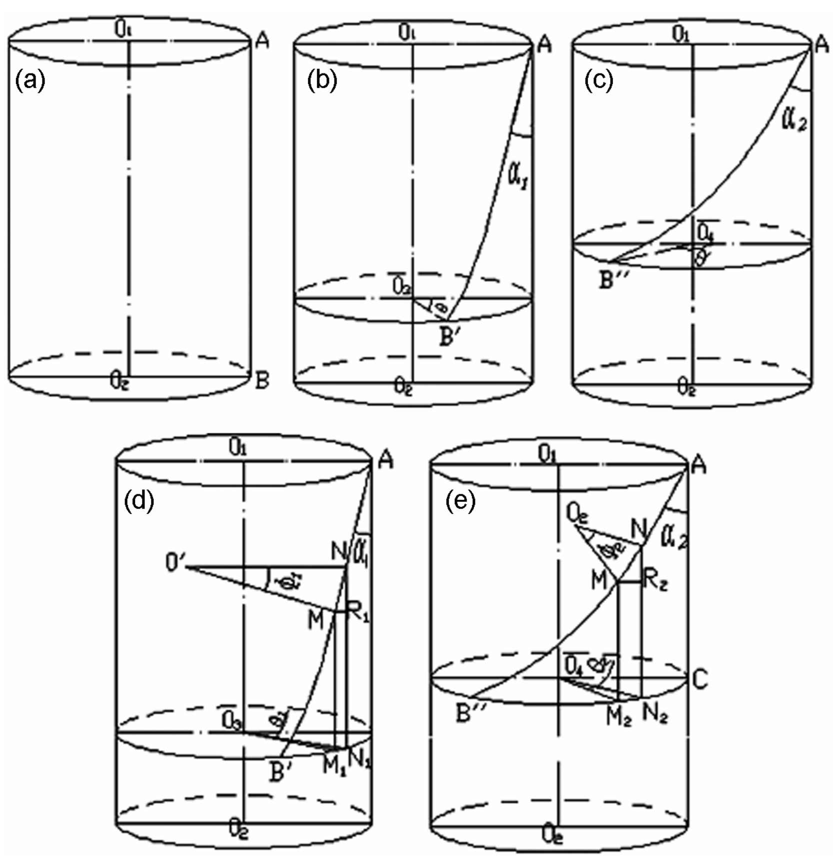

Fig 4—Deformation model of the outer layer fibre (wrapped fibre) when the yarn is twisted under ideal condition

(i) a length of the yarn (the yarn length is a fixed value L) was used for the study, assuming that the yarn is a cylinder in the ideal state (the fibre without transfer and elongation). In Fig.4 (a), O_1, O_2 are the two cross-sections of the yarn ends and AB is the length of fibre which is kept equal to the yarn length *L*, as it will be easy to make a comparison between before and after twisting. The state of fibre AB before twisting in yarn surface is shown in Fig.4 (a).

(ii) fibre transfer and friction are ignored, the B end of fibre AB raises to the point B' of the cylinder surface in cross-section O_3 due to the twisting, as shown in Fig.4 (b). On further twisting, B end of fibre AB continues to rise to point B" of the cylinder surface in cross-section O_4, as shown in Fig.4 (c). Figures 4 (b) and (c) can conclude that with the increase in twisting degree, the wrapped angle α increases, and hence the angular displacement θ also increases, which shows that α and θ have a positive correlation ($\alpha \propto \theta$).

(iii) Figures 4 (d) and (e) show a short length fibre MN on AB to research and MN=*l*, where *l* is a fixed value. Here ρ represents the radius curvature of the arc on MN, and it is a variable. With the increase in twist, α increases, spiral degree of the fibre MN increases [consider that the position of fibre MN in Fig.4 (e) is higher than that in Fig. 4 (d) due to the twist], radian of arc MN increases, radius curvature ρ decreases, as MN=l=$\rho \bullet \varphi$ is a fixed value, and central angle φ increases. This shows that θ and φ have a positive correlation ($\theta \propto \varphi$).

(iv) As shown in Fig.4 (e), in fan triangle $M_2O_4N_2$, the arc length of

$$M_2N_2 = r \bullet \theta . \quad \text{... (2)}$$

Unfold cylindrical helix in Fig.4 (e) shows similar triangles ΔAB''C and ΔNMR_2 (Fig.5), where $\angle MNR_2 = \alpha$, in the small triangle ΔMNR_2, $MR_2 = M_2N_2 = r \bullet \theta$, according to sine principle, as shown below:

$$\sin\alpha = \sin\angle MNR_2 = \frac{MR_2}{MN} = \frac{r \cdot \theta}{l} \quad \text{... (3)}$$

$$\therefore \theta = \frac{l}{r} \cdot \sin\alpha \quad \text{... (4)}$$

(v) Consider fibre MN (MN=*l* is a fixed value) to make mechanical analysis, as shown in Fig. 6.

Here φ represents the central angle of MN, which is a variable. When the yarn under axial extension,

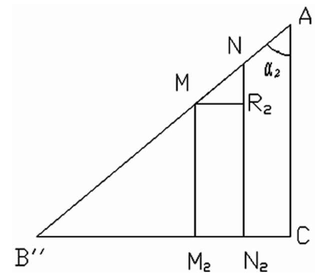

Fig. 5—Unfold figure of cylindrical helix in Fig.4 (e)

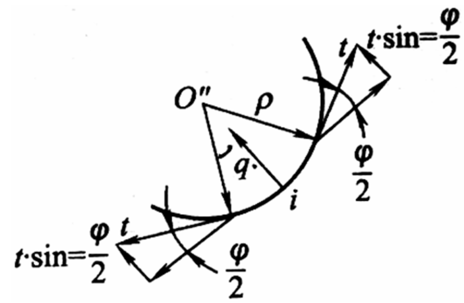

Fig. 6 —Force decomposition of wrapped fibre to yarn core [25]

(if ignore transfer and friction of fibre MN,) and the tension *t* (assume tension *t* is a fixed value) at both ends of fibre MN exist, *q* represents the centripetal force of fibre MN to the yarn; set *q* equals to the sum of the projection of tension *t* at both ends of fibre MN along the central normal direction, as shown below:

$$q = 2t \bullet \sin\frac{\varphi}{2} \quad \text{... (5)}$$

When φ is very small, $\sin\frac{\varphi}{2} = \frac{\varphi}{2}$, so

$$q = t \bullet \varphi \quad \text{... (6)}$$

Combine the analysis results of Eq.(2) and Eq.(3), and we know $\alpha \propto \varphi$, hence

$$t \bullet \theta = t \bullet \frac{l}{r} \cdot \sin\alpha \propto t \bullet \varphi = q . \quad \text{... (7)}$$

Because *t*, *l* and *r* are the fixed values, $0 < \alpha < \frac{\pi}{2}$, therefore,

$$\alpha\ \alpha \propto\ q \quad \text{... (8)}$$

That is to say, α and *q* have a positive correlation; with the increase in α (the wrapping angle), the *q* value (the centripetal force of the wrapped fibre to yarn core) increases, and hence the yarn tenacity increases.

4 Conclusion

4.1 The changes in wrapped fibres , including the number of wrapped fibre and the wrapping angle, determine the yarn tenacity.

4.2 With the increase in nozzle pressure, the number of the wrapped fibre increases significantly, the yarn tenacity increases, but the change of the wrapping angle is found just a little. With the increase in the nozzle orifice angle, the wrapping angle increases, the yarn tenacity increases accordingly, and hence the yarn quality improves.

4.3 Therefore, the tenacity of viscose vortex yarn is mainly determined by the number of the wrapped fibre and the wrapping angle. They both are conducive to the formation of the yarn tenacity. The more the number of wrapped fibre and the bigger the wrapping angle, the higher is the yarn tenacity. The ideal twisting model analysis can provide a reasonable basis for predicting the quality of the yarn, because the spinning experimental results are well consistent with the ideal twisting model results.

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