(REFEREED RESEARCH)

EFFECTS OF GEOMETRY ON THE PERFORMANCE OF SWIRL NOZZLE

GİRDAP DÜZESİNİN GEOMETRİK ŞEKİLLERİNİN PERFORMANSA ETKİSİ

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Received: 01.03.2014 Accepted: 14.01.2015

ABSTRACT

Placing a swirl nozzle composed of a yarn channel and an air-jet nozzle in a traditional ring spinning frame can reduce yarn hairiness. In this study, two types of swirl nozzles, namely, the circular swirl nozzle and the elliptical swirl nozzle, are designed to optimize the inside structure of the swirl nozzle and improve the yarn quality. Yarn performance is evaluated based on the hairiness, breaking strength, and evenness of the yarn. Experimental results show that the two types of swirl nozzles have effective effects on the ring yarn qualities compared with the traditional method. The mechanisms of the said effects can be explained via yarn de-twisting and re-twisting under the vortex action in the yarn channel. Yarn channels have different effects on yarn properties because of their different airflow patterns. The circular swirl nozzle is found to produce better yarn properties, including S3 value (the total number of hairiness equal to or exceeding 3 mm per 10 m), breaking strength, and evenness than the elliptical swirl nozzle under similar processing parameters.

Keywords: Swirl nozzle, hairiness, yarn channel, cross-sectional shape, ring spinning.

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1. INTRODUCTION

Ring spinning, a widely used method around the world for producing staple yarn, has many advantages such as low cost and a good variety of adaptivity. However, the edging fibers of the sliver are not prone to drawing into the yarn because of the existence of twisting triangles in traditional ring spinning. Thus, hairiness, which has negative effects on the yarn quality, the subsequent processing process, and the appearance of end fabrics, inevitably appears during the ring spinning process (1) . All the aspects mentioned above make ring spinning a hot spot for numerous researchers to develop effective methods that can reduce yarn hairiness during traditional ring spinning. The commonly used methods for decreasing yarn hairiness include singeing, folding, and improving the performance of the ring spinning frame (2). However, the methods above have limited capacities for reducing yarn hairiness. Some new spinning methods, such as compact spinning (3), sirafil-spinning, and siro-spinning (4), have good effects on reducing yarn hairiness and improving yarn performance. However, these new spinning methods have complex designs, require massive investments, and entail costly maintenance. Moreover, yarn hairiness can be reduced using double nozzles, which also have complex structures and high costs. Wang et al. use the jet-ring method to reduce yarn hairiness, results of which have been published in a series of useful research (5, 6). However, four small holes are difficult to ensure on the same section plane (7,8). Setting a swirl nozzle onto a traditional ring spinning frame is a new method for lowering the hairiness level of spun yarn during spinning. The special structure of the new method produces high-velocity rotating airflow that can effectively reduce yarn hairiness (9). The cross-sectional shape of the channel decides the airflow patterns and the performance of the spun yarn. Previous studies have shown that circular and elliptical swirl nozzles are good for tangling fibers (10,11). In the current study, two kinds of swirl nozzles with circular and elliptical cross-sectional shapes of yarn channel are designed to further optimize the internal structure of the swirl nozzle and improve the yarn quality. In addition, the yarn properties of yarn are tested and analyzed, and then the effects of the cross-sectional shapes of the swirl nozzle yarn channel on yarn performance are discussed.

2. EXPERIMENTAL METHOD

2.1. Swirl Nozzle

Figure 1 depicts the schematic sketch of a swirl nozzle. Figure 1(a) shows the front view and Figure 1(b) shows the side view of the swirl nozzle. A swirl air-jet nozzle is composed of two yarn guides ①, namely, a yarn channel ② and an air-inlet ③. Two small ceramic yarn guides are fixed at both ends of the yarn channel, keeping the yarns situated at the center of the yarn channel. The wall of the air inlet is made tangential to the inner walls of the yarn channel to generate an air swirl effect. The swirl nozzle with the circular cross-section of yarn channel is called the circular swirl nozzle, and the swirl nozzle with the elliptical cross-section of yarn channel is called the elliptical swirl nozzle. The diameters of the air-inlets of the two types of swirl nozzles are kept at 1.4 mm. The diameter of the yarn channel of the circular swirl nozzle is 2.0 mm, and the major and minor axes are 3.6 and 1.2 mm, respectively. The cross-sectional areas of both types of yarn channels are the same.

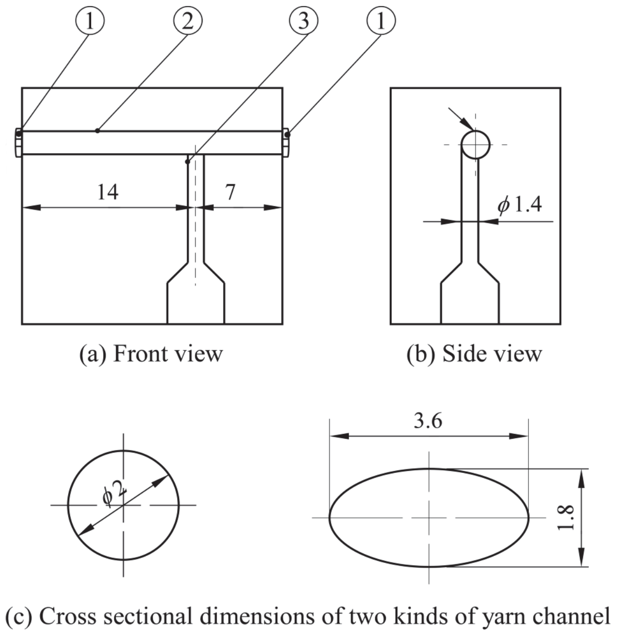


Figure 1. Schematic sketch of a swirl nozzle.

2.2. Swirl Nozzle Ring Spinning System

Figure 2 shows the experimental apparatus. Roving ① is fed into the drafting system ② after a set of delivering roller ③, and then the yarn passes through the nozzle ④, where the yarn ⑤ is acted on by compressed air and the hairiness level can be reduced. Next, the yarn goes through a yarn guide ⑥. Under the action of the ring ⑧ and the traveler ⑨, the yarn is twisted and then wound onto a bobbin ⑦ that is mounted on a spindle ⑩.

Four processing parameters are used in the current experiment. The gauge pressure of compressed air *p* ranges from 0.05 MPa to 0.25 MPa, which is regulated using a regulator and filtered before jetting into the swirl nozzle. The other three processing parameters are chosen based on the previous research (9). The distance *l* (nozzle position) between the swirl nozzle and the front roller in Figure 2 is 6.5 cm, the spindle speed *v* is 12,000 r/min, and the twist factor is 330.

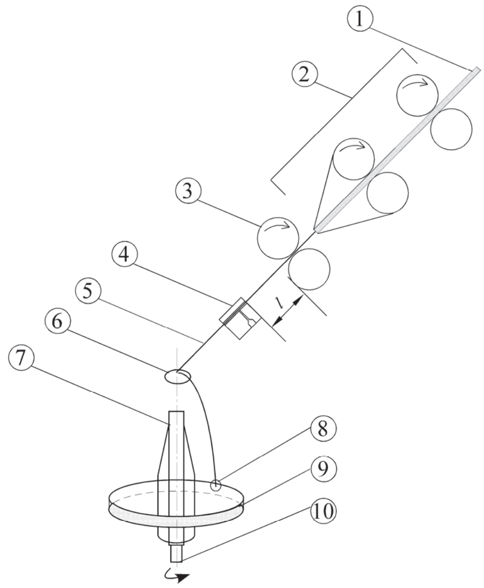


Figure 2. Experimental apparatus.

①roving ② drafting system ③ delivering roller ④ nozzle ⑤ yarn ⑥ pig tail ⑦ bobbin ⑧ ring ⑨ traveler ⑩ spindle

The experiments are conducted on the EJM128K ring spinning frame. In each experiment, four positions are used on the ring spinning frame (Figure 3). In position 1, a swirl nozzle is mounted between the front roller and the bobbin. Positions 2 and 3 are kept empty to decrease the interference of airflow jetted from nozzle (position 1) on yarn formation. In position 4, the traditional method is used to manufacture the yarn. A roving of 5.5 g/10 m is used in the experiment to produce 28 tex Z-twist yarns.

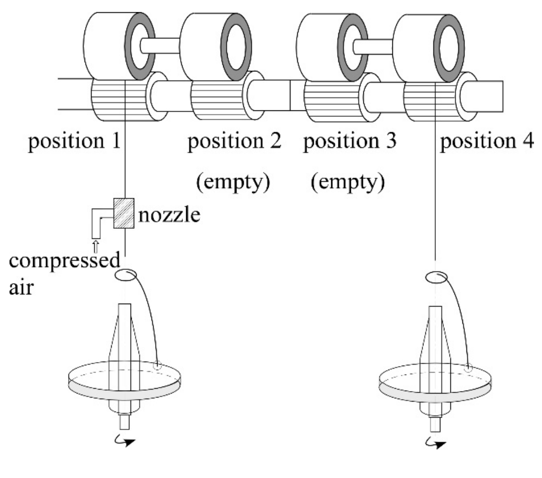


Figure 3. Schematic diagram of conventional ring spinning versus jet-ring spinning.

All the samples are kept under standard conditions (temperature of 20±2 °C and relative humidity of 65±2%) for 24 h prior to testing and tested under standard conditions. Photoelectric-type Zweigle G565 hairiness tester is used to measure yarn hairiness. Statimat ME tensile tester is used to test the tensile properties of yarns. The evenness characteristics of the yarns are tested on the Uster Evenness tester UT-1. Ten samples of each specimen are tested, and then the average value is recorded.

3. RESULTS AND DISCUSSION

3.1. Effects of Yarn Channel Cross-sectional Shape on Hairiness

Figure 4 depicts the relationship between yarn hairiness and supplied air pressure of the traditional, elliptical, and circular swirl nozzle spinning methods. Yarn hairiness efficiently decreases when a swirl nozzle is attached to the ring spinning frame (Figure 4). Furthermore, the cross-sectional shape of the yarn channel significantly affects the performance of the swirl nozzle. The S3 value of the yarn in the circular nozzle decreases sharply when *p* increases from 0.05 MPa to 0.25 MPa. The S3 value decreases to 57.5% when *p* is 0.25 MPa. However, the S3 value of the yarn produced with the elliptical nozzle increases at first compared with that of the yarn produced with traditional method and then decreases with increasing *p*. Higher *p* values seem to be good for reducing yarn hairiness, but too high pressure will increase compressed air consumption and yarn cost accordingly.

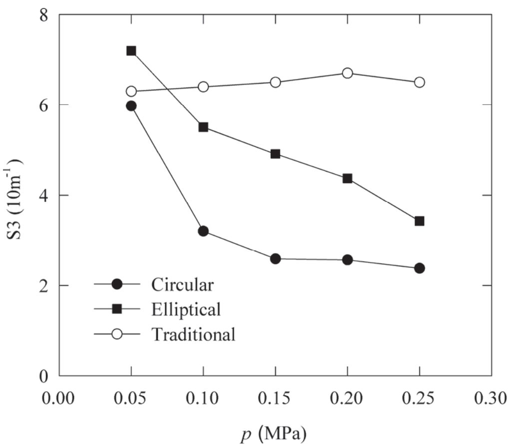


Figure 4. Relationship between yarn hairiness and supplied air pressure of the traditional, elliptical, and circular swirl nozzle spinning methods.

3.2 Effects of Yarn Channel Cross-Sectional Shape on Breaking Strength

Figure 5 depicts the relation between breaking strength and supplied air pressure of the traditional, elliptical, and circular swirl nozzle spinning methods.

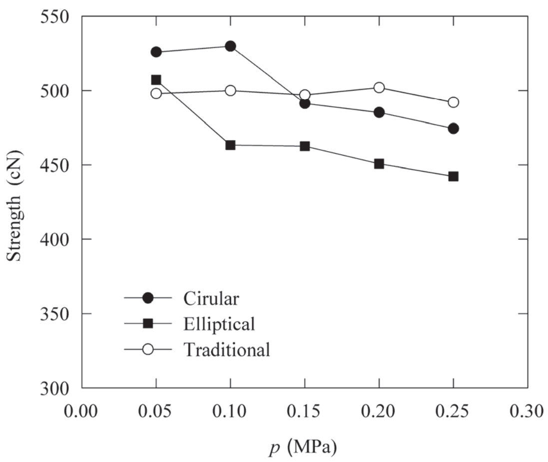


Figure 5. Relationship between yarn strength and supplied air pressure of the traditional, elliptical, and circular swirl nozzle spinning methods

The circular and elliptical swirl nozzles have different effects on yarn breaking strength (Figure 5). Compared with traditional ring-spun yarn, the breaking strength of the yarn produced using the circular swirl nozzle increases at first and then decreases when *p* is increased from 0.05 MPa to 0.25 MPa. Some protruding fibers on the surface of the yarn are coiled into the yarn body when *p* is 0.05 MPa, increasing the yarn breaking strength. However, under the action of the compressed airflow, the hairiness not only coils into the yarn body, but some short fibers are excluded from the yarn body when *p* is high. Thus, the breaking strength of the spun yarn decreases. However, even at the worst point, only 3% of the yarn breaking strength is reduced.

3.3. Effects of Cross-Sectional Shape on the Evenness of Yarn

Figure 6 depicts the relationship between the evenness of the yarn and the supplied air pressure of the traditional, elliptical, and circular swirl nozzle spinning methods.

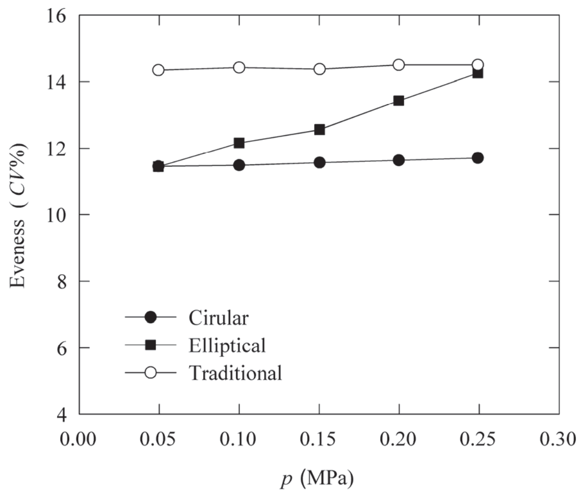


Figure 6. Relationship between the evenness of the yarn and the supplied air pressure of the traditional, elliptical, and circular swirl nozzle spinning methods.

Both the circular and elliptical swirl nozzle spinning methods improve the evenness of the yarn compared with the traditional spinning method, especially at lower *p* values. The evenness of the yarn produced with the elliptical swirl nozzle deteriorate noticeably with increasing *p*. However, the evenness of the yarn produced with the circular swirl nozzle changes a little when *p* increases from 0.05 MPa to 0.25 MPa.

To be convincing and ensure comprehensive comparison, *p* = 0.15 MPa is chosen to produce the spinning yarns with circular and elliptical swirl nozzle. Results of the comprehensive comparison are listed in Table 1. Although the evenness of the yarn can be improved to some extent using the elliptical swirl nozzle, the number of thin places, thick places, and neps of the elliptical swirl nozzle spinning methods are summed up and then compared with those of the traditional method. The faults are known to have negative effects on the mechanical properties of yarn and on the appearance of the fabrics. The circular swirl nozzle is found superior to the elliptical swirl nozzle in terms of the evenness of the yarn.

Table 1. Yarn evenness results of conventional, circular, and elliptical swirl nozzle spinning.

Yarn type	CV %	-50% Thin	+50% Thick	+200% Neps
Conventional	14.25	2	3	0
Circular	11.27	0	1	0
Elliptical	12.54	2	18	87

4. Analysis of Results

Based on the comparisons above, installing a swirl nozzle on the traditional ring spinning frame can improve the performance of the spun yarn to some degree. Furthermore, the cross-sectional shapes of the yarn channel of the swirl nozzles and the supplied air pressure *p* greatly affect the hairiness, breaking strength, and evenness of the yarn produced. The reasons are as follows.

4.1. Mechanism of Reducing Yarn Hairiness Using a Swirl Nozzle

Figure 7 depicts the mechanism of reducing yarn hairiness using a swirl nozzle. Taking a yarn section as an example, the protruding parts on the yarn surface indicates yarn hairiness. For the sake of discussion, a swirl nozzle is divided into parts A and B, which are located at the two sides of the air-jet nozzle. Airflow spreads toward the two ends of the yarn channel and swirls as it moves forward when compressed air is jetted into the yarn channel. The direction of the swirling airflow in part A is opposite to that in part B.

First, yarn with Z-twist enters into part A of the yarn channel. Then, under the action of the compressed air, the yarn is untwisted and most of the fibers move backwards. The protruding fibers on the yarn surface moves forward and are re-twisted with the airflow motion in part B when part B of the yarn channel is reached. Therefore, most of the fibers are coiled into the yarn body and the hairiness level of the yarn is decreased.

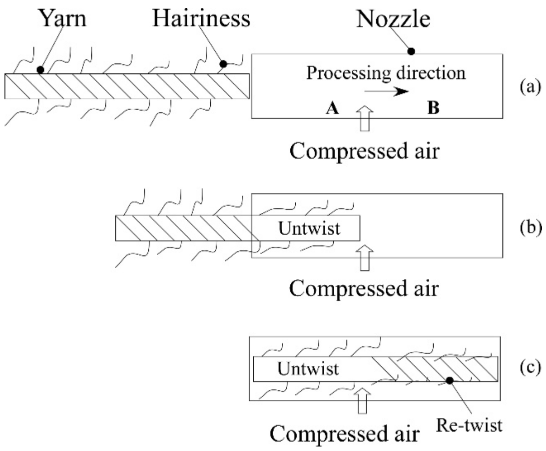


Figure 7. Mechanism of reducing yarn hairiness using a swirl nozzle.

In the process of yarn manufacturing, most yarn breakages take place between the nip of the front roller and the pigtail because of the sudden change in yarn tension and the weak ring lying in the sliver. As mentioned above, the airflow in the yarn channel has an impact on the yarn, forcing the yarn to de-twist and re-twist. Furthermore, re-twisting rearranges the fibers in the surface layer, resulting in hairiness reducing. However, higher supplied air pressure not only reduces yarn hairiness but also removes some fibers, causing the loss of yarn strength.

4.2. Effects of Yarn Channel Shape on Yarn Performance

By keeping the cross-sectional shape of the air-jet nozzle circular, at both ends of the yarn channel cross-section, even vortex is difficult to form in the elliptical swirl nozzle because of the difference in lengths of its major and minor axes. Figure 8 presents the supposed distribution of airflow on the cross-section of yarn channel.

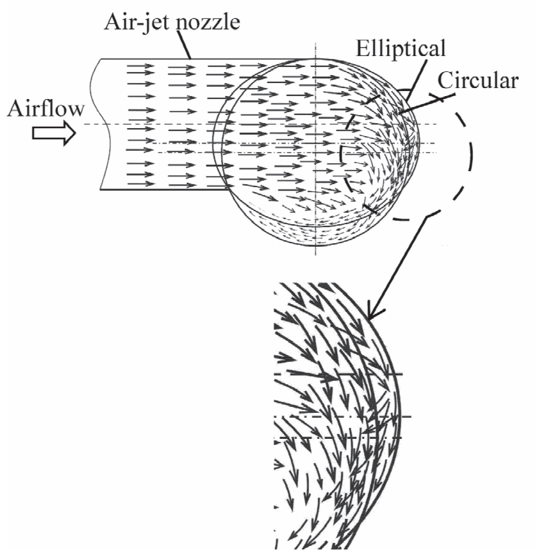


Figure 8. Supposed distribution of airflow on the cross-section of yarn duct.

The airflow velocity at both ends of the yarn channel section is so low that it is unable to make the yarns twist and re-twist along the yarn channel when *p* is less than 0.1 MPa. Furthermore, confusion airflow bumps into the yarn body, increasing yarn hairiness and lowering yarn strength. Some airflows can form regular rotating airflow along the yarn channel when *p* is higher than 0.1 MPa, making the yarn re-twist and then twist, which is good for decreasing yarn hairiness. However, the rest of the airflow is formed into turbulent rotating flows near the two ends of the oval yarn channel, rushing directly into the yarn and making it fluty. Some hairiness is blown out of the yarn body because of the strong hitting and cannot be rolled into the yarn body again, reducing yarn fineness and yarn strength. Thus, its yarn strength is not as good as that of the circular yarn channel's and the traditional ring spinning. Moreover, some hairiness affected by the turbulent rotating airflow twists and tangles with one another before being rolled into the yarn body, causing more slubs and neps. In general, the evenness of yarn processed using the elliptical swirl nozzle is not as good as that using the circular swirl nozzle.

SEM photos of the yarns are taken to compare the appearances of the yarns and observe the effects of various yarn channel cross-sectional shapes of swirl nozzles on yarn hairiness. Figure 9 shows two SEM photos of yarns produced using the elliptical and circular swirl nozzles. The yarns produced using the circular swirl nozzle have less hairiness, whereas the yarns produced using the elliptical swirl nozzle have more slubs and neps. Thus, the yarn channel cross-sectional shape of swirl nozzles have great influence on the yarn quality.

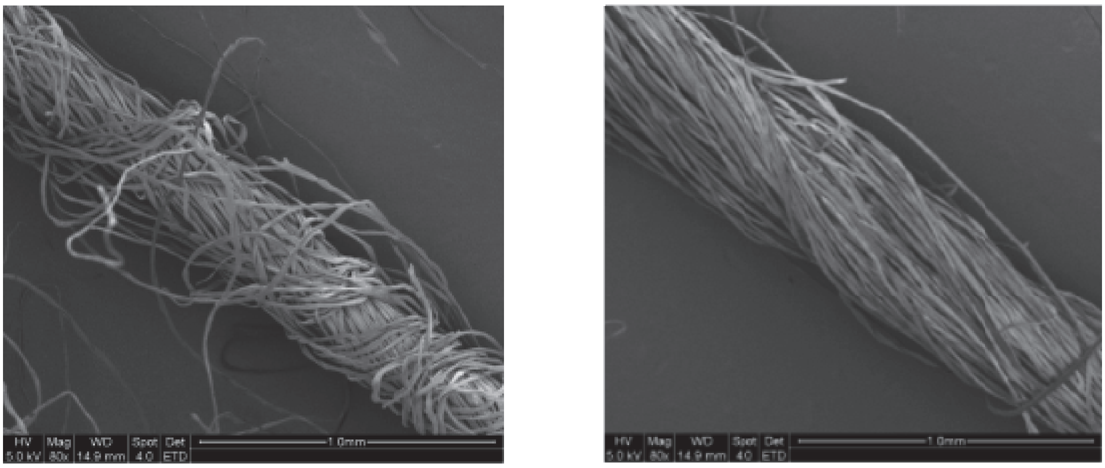
5. CONCLUSIONS

In the current study, two types of swirl nozzles with various cross-sectional shapes of yarn channel are designed to compare their effects on yarn performance based on the hairiness, strength, and evenness of the yarn. Both types of swirl nozzles effectively reduce yarn hairiness because the vortex in the yarn channel coils some protruded fibers on the yarn surface into the yarn body. Compared with the conventional method for diminishing the spinning triangular area, placing a swirl nozzle in the ring spinning frame is simpler and costs lower.

However, higher supplied air pressure decreases yarn fineness and yarn strength accordingly. Moreover, the state of airflow inside yarn channel differs because of the various cross-sectional shapes of the yarn channel in the swirl nozzles. Thus, swirl nozzles with channels of various cross-sectional shapes have different effects on yarn properties. The circular swirl nozzle is found to be superior to the elliptical swirl nozzle based on yarn performance and on the SEM photos.

ACKNOWLEDGEMENTS

The authors are grateful for the financial supported by the Fundamental Research Funds for the Central Universities (No. JUSRP51301A)



(a) (b)

Figure 9. SEM photos of yarn samples (a) Yarns produced using the elliptical swirl nozzle; (b) Yarns produced using the circular swirl nozzle.

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