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Yarn properties developments with diagonally slotted roller on ring spinning machine

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To develop new ring spinning process, the diagonally slotted rollers (DSR) of various angles (15°, 30° and 45°) have been designed, manufactured and then fitted below and parallel to the top front draft rollers of a ring spinning frame. The yarn samples of 20 tex are produced in conventional ring spinning, Solo spinning and newly developed DSR spinning methodologies. In ring spinning process, the escaped fibre ends from the strand surface in the spinning triangle do not entangle with other fibres when the yarn is twisted and therefore they make the yarn hairs. In DSR rollers, the slot walls provide a condition to prevent escaping of fibre ends from the strand and keep the fibre ends on the strand surface in the twisting process. The experimental results show that the yarns produced with DSR roller of 30° slot angle (DSR30) have less S3 value of hairiness and a cleaner appearance than conventional ring-spun yarns. The hairiness of the yarns of DSR30 and Solo spinning processes do not have a statistically significant difference. Also, the improvement in ring-spun yarn tenacity and elongation is much larger for newly developed DSR spinning process in comparison with Solo spinning process. Consequently, it is concluded that the DSR spinning methodology improves the hairiness and mechanical properties of ring-spun yarns even more successfully in comparison with the Solo spinning method.

Keywords: Diagonally slotted roller, DSR spinning, Ring spinning, Solo spinning, Spinning triangle

1 Introduction

Among the yarn production methods, the ring spinning remains the most popular. This method of yarn production processes various kinds of fibres and produces wide range of yarn counts for different end use applications. However, the conventional ring spinning method has many disadvantages and limitations which cause lower economical comparative advantage and lower productivity of this system. Among the disadvantages of this system, the high fibre protrusion from the yarn surface is an important issue which causes yarn hairiness. The yarn hairiness is originally created in the twisting zone of the ring spinning which is traditionally called spinning triangle[1]. The geometry of this spinning triangle has been proven to be decisive in influencing several yarn properties, including yarn hairiness and strength. Many research works have been done on spinning triangle, considering the mechanism of hair formation to develop the new systems to overcome this disadvantage of conventional ring spinning[1-15].

The Solo spinning is a technology which provides the means to produce a single yarn that can be successfully woven as either warp or weft. It offers significant benefits in terms of efficiency and productivity. The SolospunTM system uses a spinning frame attachment consisting of a pair of slotted rollers. According to Prins *et al.*[2], Solo spinning significantly reduces yarn hairiness and fibre security is improved. In the Solospun rollers, the slots divide the drafted fibre strand into a number of sub-strands. The special twisting mechanism of Solospun entangles a lot of hairs into the yarn body, so the hairiness of Solospun yarns is reduced, especially for long hairs. Therefore, Solospun yarns have a cleaner appearance and better abrasion resistance; they can thus be woven directly with no need for yarn plying[3]. Cheng and Wang[4] showed that the hair length distribution of the Solospun yarns follows an exponential law, just like conventional ring-spun yarns. They also concluded that the Solospun yarns have fewer hairs in different hair length groups and lower variations in hairiness.

One of the other devices developed to improve the yarn properties is the compact spinning system. Compact or condensed spinning systems modify the drafting process of the conventional spinning frame to

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condense the staple fibres to achieve a much smaller spinning triangle[5]. Today, there are a number of designs of compact spinning technology offered by different machine manufacturers commercially such as Rieter's Com4 spin, Suessen's EliTe and LMW's RoCoS systems, but they all use the same principle, namely convergence of the strand of fibres at the end of the draft region and eliminating the spinning triangle. It is well known that yarn produced using the compact spinning technique has superior yarn structure and quality, especially in terms of hairiness and strength[6]. China Ningbo Dechang Precision Textile Machinery Company Limited introduced a device of compact spinning with inspiratory groove system in which a slot-roller is added in front of the front bottom roller of the ring spinning frame and rotated relying on the friction between them[7]. In this device, the compact spinning with inspiratory groove compacts fibres by airflow and the shape of the inspiratory groove.

Siro spinning is one of the most important novel ring spinning technologies, and Sirospun yarn has good strength similar to doubled yarns[8]. By the end of 1990 the commercial installation of Sirospun spindles is estimated to be about 175 000, which was about 7% of world capacity of worsted yarn spindles. Sun and Cheng[9] showed that the cotton Sirospun yarn is superior in tenacity, evenness, hairiness, and abrasion resistance in comparison with single ring-spun yarn. They also indicated that the cotton Sirospun yam is less hairy and more extensible than two-plied yarn.

Najar *et al.*[10] combined the Solospun and Sirospun processes into a single Solo-Siro spun process for worsted yarns. They showed that the hairiness (S3 value) of Solo-Siro spun yarns was significantly less than that of both Sirospun and normal ring-spun yarns, and the tenacity of the Solo-Siro spun yarns was higher than that of the normal ring-spun yarns.

Other modifications of the ring spinning system are the JetRing spinning system[11], Compact-jet spinning system[12] and Embeddable and locatable spinning (ELS) technologies[13]. As Prins *et al.*[2] mentioned, the Solospun roller's operation is to interrupt the path of the drafted fibre strand, nipping it against the bottom front draft roller. The surface of the Solospun rollers is made up of four segments. The 'slots' in the solo roller, which runs parallel to the strand, separates each strand into multiple sub-strands. At the front draft roller nip, the width of the strand is approximately same as that of conventional ring spinning system. To decrease the width of the strand at the front draft roller nip, the rollers with diagonal slots of various angles were designed and the properties of yarns produced with them were evaluated in comparison with those of conventional ring-spun yarns.

This study is aimed at quantifying the effect of slots angle on the yarn mechanical properties and apparent characteristics such as hairiness through a controlled experiment using 20/80 wool/polyester as fibre material. Conventional worsted ring-spun yarns are compared with yarns produced by slotted rollers of various diagonal angles. We then evaluated the hairiness of yarns produced from each roller and compared the strength and elongation of various spinning methodologies.

2 Materials and Methods

In the Solospun rollers, the slots divide the drafted fibre strand into a number of sub-strands. In this spinning method, the width of the main twist triangle is the same as conventional ring spinning system. To prevent the end of fibres from escaping from the main strand body, a diagonally slotted roller (DSR) was designed with various slot angles to positively lead the end of fibres in two sides of the twist triangle to the yarn body and reduce the protrusion of the fibres from the body of the yarn. The key element of the newly developed spinning system is a pair of diagonally slotted rollers fixed on the conventional ring spinning frame. Unlike the Solo roller, the 'slots' in the DSR roller are not in parallel with the strand and runs with an angle to the strand which is called slot angle. The slots are symmetrically made up from two edges toward the roller centre to provide a convergent path for the fibres in the strand at the twist triangle. DSR rollers have multi-slot surface to lead fibres into the yarn end. This is a big difference from compact spinning with inspiratory groove which compacts fibres by airflow and single slot of the inspiratory groove[15]. In DSR roller, the slots separate each strand into multiple sub-strands and positively lead them into the entangled yarn structure. At the front draft roller nip, the width of the strand is approximately same as that of conventional ring spinning system. Therefore, the drafting process of this system is similar to ring spinning, but the principle of its twist triangle formation is different due to the strand width reducing function of the slotted roller.

In a conventional ring spinning, the fibre strand coming from the draft zone is flat and almost all fibres are parallel to the axis of the strand. In this new system, the width of the strand begins to reduce gradually from the nip of the front rollers and consequently composes a twist triangle, the slots of DSR rollers lead the fibres and the width of the strand begins to positively reduce by the walls of diagonal slots and consequently composes a twist triangle.

In the spinning system using a DSR roller, a drafted strand enters the nip of a DSR roller which has a lot of small grooves that positively lead the drafted fibres into the main twist triangle from both sides and prevent them from escaping from the entangled yarn structure body giving a lower hairiness to the yarn. The angle of the slots on the DSR roller is one of the most important parameters which properly lead the fibre ends into the entangled yarn structure. To consider the effect of slot angle on yarn properties, we designed and produced DSR rollers of various slot angles and attached them on a ring spinning frame to produce the samples.

This technology is based on an initial clip-on, roller attachment developed for solo spinning system[2]. The DSR spun technology is developed to attach the standard long-staple (worsted) spinning frames. The DSR roller attachment holds a pair of DSR rollers on the shaft of each pair of top front draft rollers of the spinning frame. Each DSR roller is positioned just below and parallel to (but not in contact with) its corresponding top front draft roller. The DSR rollers are rotated, being in contact with the bottom front draft rollers. Figure 1 shows a schematic of a DSR roller and its various views. As Fig. 1 shows, the surface of the DSR rollers is made up of a series of diagonal slots that are symmetrically made up from two edges towards roller centre to provide a convergent path for the fibres in the strand at the twist triangle. In this figure, α is the angle of slots having the values 15°, 30° and 45° (Fig. 2).

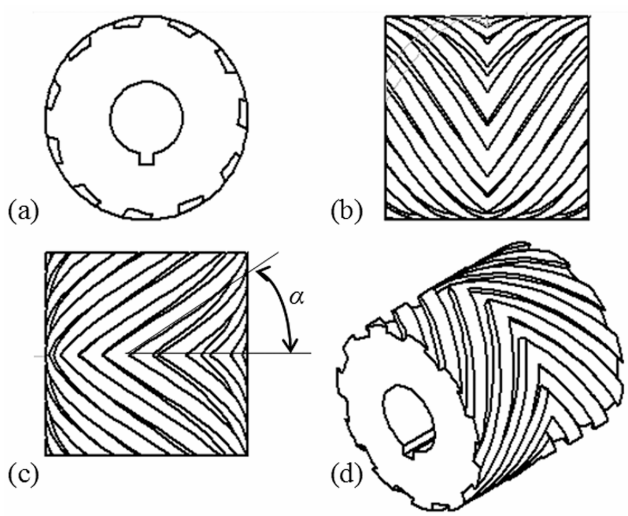

Fig. 1– A schematic of DSR roller (a) side view, (b) front view, (c) top view, and (d) tree-dimensional (perspective) view [α = angle of slots relative to direction of roller]

For this study, a pair of DSR rollers was fitted below and parallel to the top front draft rollers of a 6-spindles laboratory worsted ring spinning frame (Fig. 3). We could produce DSRspun, Solospun and conventional ring-spun yarns at the same time using the same machine settings and a 450 tex finisher worsted roving composed of 80:20 polyester/wool. The wool fibres mean diameter (fineness) and length were 21 µm (3.5 dtex) and 75 mm respectively. The polyester fibres mean fineness and length were 3.7 dtex and 75 mm respectively. The roving was also prepared in a conventional spinning process. A total draft ratio of 22.62 was used to produce yarn samples of count 20 tex and twist 650 t.p.m. The traveller number was 26, and all the travellers were replaced before commencing the yarn production for each experiment.

According to this study, the roving was drafted in the drafting zone of a ring machine, the Solo roller and DSR roller were fitted below and parallel to the top front draft rollers, the yarn samples were spun with various slot angles of DSR rollers, solo roller and conventional ring system, and their properties were studied and compared.

Conventional ring-spun yarns (ring); Solospun yarns (solo); and DSRspun yarns of different slot angles, such as 15° (DSR15), 30° (DSR30) and 45° (DSR45) were prepared.

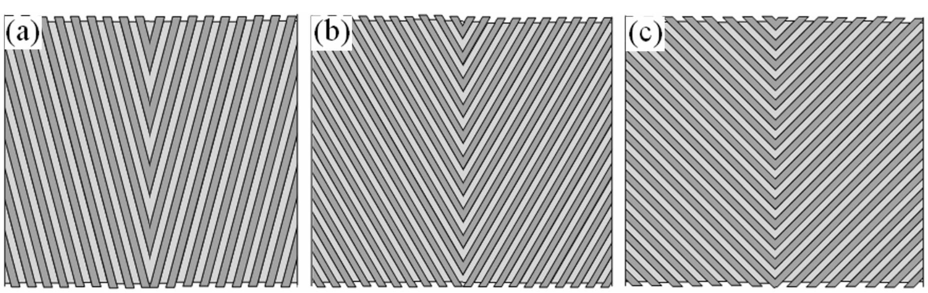

Fig. 2– A schematic of slots on the surface of DSR rollers (a) 15°, (b) 30°, and (c) 45°

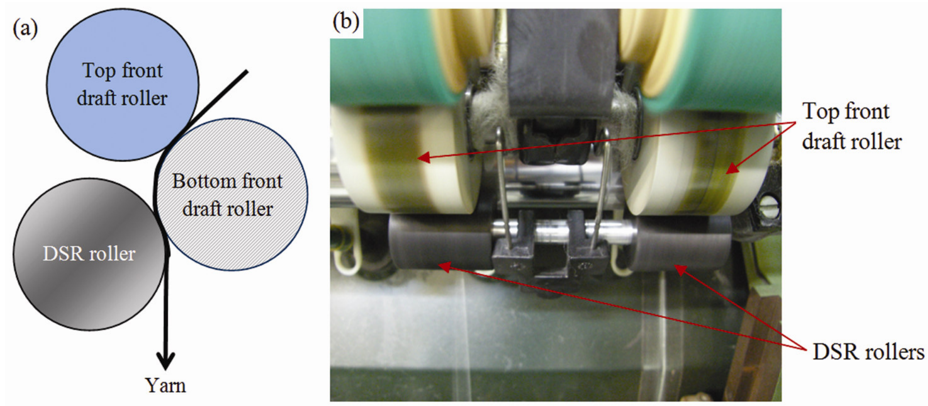

Fig. 3– Method of installation of DSR rollers on the drafting zone of ring spinning frame [(a) A schematic of side view, (b) A photograph of front view]

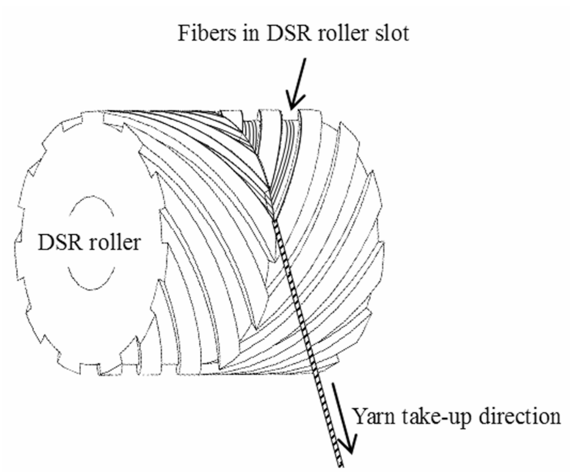

Fig. 4– A schematic model of DSR rollers and fibre path in the slots before twisting

In this study, we discuss the fact that the hairiness of DSRspun yarns is less than that of conventional ring-spun yarns as a result of the positive leading of the fibres into the twisted yarn structure. We use a schematic model to describe this phenomenon (Fig. 4).

The dark lines on the roller show the path of fibres in the slots of the DSR roller. When the fibres in the nip line of DSR roller and bottom front draft roller are positioned, they are being pushed out by the rotation of the rollers and being pulled out by the yarn take up tension. The tension in the fibres push them into the slots. When a fibre end is released from the roller nip, there is not enough positive force to keep its straight form. Therefore, while the fibres ends within the strand may approximately keep them straight by the neighbour fibres, some fibres ends may escape from the strand sides. The escaped fibre ends do not entangle with other fibres when the yarn is twisted and therefore they make the yarn hairs. In DSR rollers, the slot walls provide a condition to prevent escaping of fibre ends from the strand and keep the fibre ends on the strand surface in the twisting process.

To prevent the inherent differences between the spindles, all the yarn samples are spun on same spindle with approximately same environment. We produced about 250 g of yarn for each type of sample.

For this study, we used a Zweigle G565 hairiness meter to measure the hairiness of yarns. The test speed was 50 m/min and the pre-tension was 5 cN. For a comprehensive examination of yarn hairiness, the number of hairs longer than or equal to 3mm per 100 meters of yarn length (S3) was measured.

We tested 100 m of yarn in each test and conducted 5 tests for each yarn sample. The total length of each yarn type tested for each experiment was 500 m. We used the average hairiness values of S3 to represent the hairiness of each yarn type. To measure the mechanical properties of the yarns and to consider the effect of slot angle on the yarn mechanical properties, the strength and elongation of the samples were measured with an Instron instrument.

3 Results and Discussion

The S3 value was measured and then used as a means of comparing the hairiness level between the different yarn preparation methods. This parameter was selected on the basis of the findings by Barella *et al.*[14] that indicate long hairs have much greater impact on fabric properties. Hairiness measurements were performed on all yarns after spinning. Five measurements on each yarn type were conducted. The average results, expressed in hairs per 100 m, were used for comparison.

The twisting mechanism of the DSRspun process is found very similar to that of Solospun yarn; that is, drafted strands are first divided into several sub-strands twisted weakly, and then these sub-strands are twisted into a yarn. While the 'slots' in the solo roller runs parallel to the strand, in the DSR rollers they run diagonally. The special twisting mechanism of DSRspun keeps a lot of hairs into the yarn body and entangles them into the yarn structure, so the hairiness of DSRspun yarns is reduced in comparison with ring-spun yarn, especially for long hairs. However, the difference in slots arrangement of Solo and DSR rollers may explain the difference of their yarn hairiness.

The hairiness results (S3/100m) of conventional ring-spun yarns, Solospun yarns and DSRspun yarns are 316 (ring), 224 (Solo), and 251 (DSR15), 208 (DSR30) and 283 (DSR45) respectively. The S3 value for the Solospun and DSRspun yarns are less than that of conventional ring-spun yarn. The S3 value of 30° slot angle yarns (DSR30) is approximately 65.6% to that of conventional ring-spun yarns and 92.9% to that of Solospun yarn, while the S3 value of Solospun yarns is approximately 70.5% to that of conventional ring-spun. These results suggest that the diagonally slotted rollers greatly affect the yarn hairiness. This is due to the fact that the fibre ends in the roller slot are positively leaded by the slot walls and do not escapes from the yarn surface at the twisting process. From these results, it is concluded that DSR30 spun yarns have less hairiness and a cleaner appearance than conventional ring-spun yarns and consequently the fibres in the DSR30 spun yarns are squeezed tighter in the yarn structure (Fig. 5).

The results of statistical analyses (Table 1) show that the differences in the S3 value of hairiness of the DSR30 spun yarns and conventional ring-spun yarn are statistically significant at the 5% level. Similarly, the differences in the hairiness of the Solospun yarns and conventional ring-spun yarn are statistically significant at the 5% level of significance. Also, there are significant differences in hairiness of DSRspun yarn of various slot angles at the 5% level of significance. This indicates that the properly designed DSR rollers affect the ring-spun yarn hairiness as much as Solo rollers. Among other results, statistical analyses show that the differences in the S3 value of hairiness of the DSR30 spun yarns and Solospun yarn are not statistically significant even at the 10% level of significance. This means that the hairiness of the yarns of DSR and Solo spinning processes do not have a significant difference.

Compared to the conventional ring spinning technology, one of the main advantages of both Solospun and DSRspun is that their yarns are less hairy. However, it is observed that the slot angles have a great effect on yarn hairiness and it is important to use a DSR roller of appropriate slot angle to obtain the least hairy yarn. The fibre ends on two sides of the spinning triangle create most of the hairs on the yarn, their path control is important to reduce the hairiness of the yarn. In practice, the diagonal slots on DSR rollers provide a proper path for these fibres in which the optimum slot angle depends on dimension of spinning triangle. In a spinning triangle, the gradient of the fibre path on sides of strand is the same as triangle sides. In DSRspun yarns, we guess

Table 1– Statistical analysis of means S3 values of hairiness per 100 m

[Means for groups in homogeneous subsets are displayed]

Type of yarn	5% levels of significance				10% levels of significance			
	1	2	3	4	1	2	3	4
Ring	–	–	–	316	–	–	–	316
Solo	224	–	–	–	224	–	–	–
DSR15	–	251	–	–	–	251	–	–
DSR30	208	–	–	–	208	–	–	–
DSR45	–	–	283	–	–	–	283	–

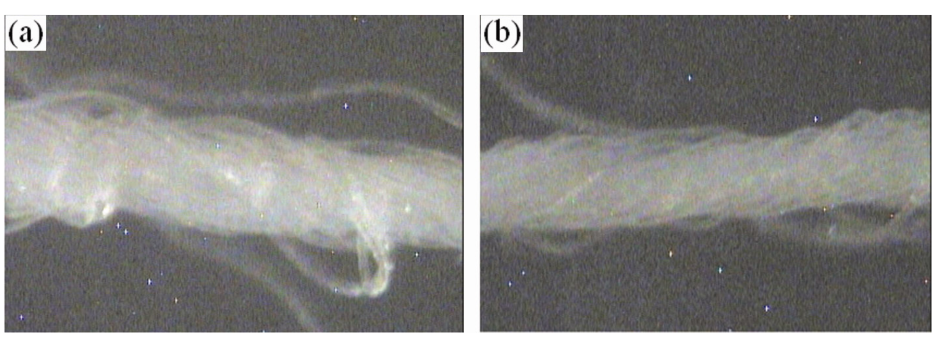

Fig. 5– Photograph of (a) ring and (b) DSR30 yarns

that if the angle of slots on the DSR roller be equal to the gradient of triangle side, the fibres may lie in the slots perfectly, otherwise they may cross several slots and their ends escape from the strand surface. Therefore, the slot angle should be determined in regard with spinning triangle dimension. Obviously, the dimension of spinning triangle depends on spinning parameters such as spinning speed, yarn tension, yarn twist, etc[15]. In this research, the least hairiness is obtained with DSR roller of 30°, which is suggested as the optimum slot angle for the yarns of count 20 tex and twist 650 t.p.m produced in our experiments.

We also tested the tensile properties of the yarns produced by various spinning methodologies on the Instron instrument at a speed of 240 mm/min. The average tenacity results of conventional ring-spun yarns, Solospun yarns and DSRspun yarns are 12.71 (ring), 13.62 (Solo), and 13.69 (DSR15), 14.26 (DSR30) and 13.94 (DSR45) cN/tex respectively. The tenacity of DSRspun yarns are found higher than those of Solospun and conventional ring-spun yarns. Among the DSRspun yarns, the DSR30 yarn is found stronger than those of other DSR yarns produced with 15° and 45° slot angles of DSR roller. The tenacity of DSR30 spun yarns is approximately 12% higher than that of conventional ring-spun yarns, while the tenacity of Solospun yarns is approximately 7% higher than that of conventional ring-spun yarns. The higher tenacity of Solo and DSR yarns is due to the fact that the structure of these yarns is tighter than that of ring-spun yarns. These results mean that the improvement in ring-spun yarn tenacity is much larger for newly developed DSR spinning processes in comparison with Solo spinning processes.

The results of statistical analyses show that the differences in the tenacity of the DSR30 spun yarns and the conventional ring-spun yarn are statistically significant at the 10% level of significance, while the differences between the tenacity of the Solospun yarns and conventional ring-spun yarn are same as between the tenacity of the Solospun yarns and the DSRspun yarn; these are not statistically significant even at 10% level of significance. The differences in tenacity of DSRspun yarn of various slot angles are not statistically significant even at the 10% level despite of significant difference in their hairiness. Consequently, the results indicate that the DSR rollers of optimized slot angle (30°) improve the ring-spun yarn tenacity, while Solo rollers do not show statistically significant influence on yarn tenacity.

The average elongation results of conventional ring-spun yarns, Solospun yarns and DSRspun yarns are 20.96 (ring), 21.36 (Solo), and 21.04 (DSR15), 22.24 (DSR30) and 21.1(DSR45) percent respectively. The elongation of DSR30 yarn is higher than those of Solospun yarn, conventional ring-spun yarn and other DSR yarns produced with 15° and 45° slot angles of DSR roller. The elongation of DSR30 spun yarns is approximately 6% and 4% higher than that of conventional ring-spun yarns and Solospun yarns respectively, while the Solospun yarns show a meaningless 2% higher elongation to that of conventional ring-spun yarns. These results mean that the improvement in conventional ring-spun yarn elongation is much larger for newly developed DSR30 spinning processes in comparison with Solo spinning processes.

Statistical analyses show that the differences between elongation of the DSR30 spun yarns and conventional ring-spun yarn and that between elongation of DSR30 spun yarns and Solospun yarn are statistically significant at the 10% level of significance. The differences in the elongation of the Solospun yarns and conventional ring-spun yarn are not statistically significant even at the 10% level of significance. This indicates that the DSR rollers of optimized slot angle (30°) improve the ring-spun yarn elongation.

The higher tenacity and elongation of DSR30 yarns may be explained by better association of fibre in the yarn structure which is due to their lower hairiness. The slots of appropriate angle leads the fibres end to lie on the yarn surface and entangle with the yarn structure, thus decreasing the yarn hairiness and increasing the yarn tenacity and elongation.

From the above discussed results, it is concluded that the DSR spinning methodology using DSR rollers of proper designed slot angles improves the hairiness and mechanical properties of ring-spun yarns. Although the improvement of the hairiness of ring-spun yarns by the DSR spinning method is same as that of Solo spinning method, the growth of the DSRspun yarn tenacity and elongation is much larger than those of Solopun yarns. Therefore, this newly developed spinning methodology can improve the ring-spun yarn and provide much more advantages in yarn properties in comparison with Solo spinning methodology.

4 Conclusion

The experimental results show that the yarns produced with DSR roller of 30° slot angle (DSR30) have less S3 value of hairiness and a cleaner appearance than conventional ring-spun yarns. The hairiness of the yarns of DSR30 and Solo spinning processes do not have a statistically significant difference. Also, the improvement in ring-spun yarn tenacity and elongation is much larger for newly developed DSR spinning processes in comparison with that of Solo spinning processes. Consequently, it is concluded that the DSR spinning methodology improves the hairiness and mechanical properties of ring-spun yarns even more successfully in comparison with the Solo spinning method.

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