(REFEREED RESEARCH)

A STUDY FOR THE MODIFICATION OF A YARN TWISTING MACHINE WITH AN AIR NOZZLE

İPLİK KATLAMA MAKİNESİNİN BİR HAVA DÜZESİ İLE MODİFİYE EDİLMESİ ÜZERİNE BİR ÇALIŞMA

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ABSTRACT

Single yarns are plied to improve some of the yarn and fabric properties such as hairiness, strength, elongation, evenness and abrasion resistance. Present work proposed a new method for the reduction of the plied yarn hairiness. The modified plying method employs an air nozzle and compressed air on a classical twisting machine. The air was fed into an air nozzle and single yarns were passed into the air nozzle. In the work, single yarns having S- and Z-twist direction were plied with classical and modified plying methods at different ply twist levels and airflow properties. The results indicated that presented method may open a new avenue to achieve an extra reduction in yarn hairiness and also an increase in productivity during the plying process. In literature, there were not any trials to incorporate the air nozzle and plying process in this manner. Therefore, modified method can be considered as an innovative plying process regarding with the improvement in yarn hairiness.

Keywords: Plying, yarn hairiness, air nozzle, plied yarn, compressed air.

ÖZET

Tek katlı iplikler, tüylülük, mukavemet, kopma uzaması, aşınma direnci gibi bazı iplik ve kumaş özelliklerini iyileştirmek için katlanmaktadır. Bu çalışmada, katlı ipliklerin iplik tüylülüğünü azaltmak için yeni bir metot önerilmektedir. Modifiye katlama metodu, klasik büküm makinesinde bir hava düzesi ve basınçlı havanın kullanılmasından oluşmaktadır. Basınçlı hava bir hava düzesine verilmekte ve tek katlı iplikler düze içerisinden geçirilmektedir. Çalışmada, S- ve Z- bükümlü tek katlı iplikler farklı katlama büküm değerlerinde ve basınçlı hava özelliklerinde klasik ve modifiye katlama metodu ile katlanmışlardır. Elde edilen sonuçlar, sunulan metodun katlama prosesi sırasında iplik tüylülüğünde ekstra bir iyileşme elde edilmesi ve aynı zamanda verimlilikte artış sağlanması konularında yeni bir kapı açacağını göstermiştir. Literatürde, hava düzesi ile katlama prosesinin bu tarzda birleştirilmesine yönelik herhangi bir deneme bulunmamaktadır. Bu nedenle, modifiye katlama metodu iplik tüylülüğündeki iyileşme açısından yenilikçi bir katlama prosesi olarak değerlendirilebilir.

Anahtar Kelimeler: Katlama, iplik tüylülüğü, hava düzesi, katlı iplik, basınçlı hava.

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1. INTRODUCTION

Single yarns are used in the majority of fabrics for normal textile and clothing applications. Sometimes, single yarns produced from staple fibrous strands are not capable to fulfill the particular physical characteristics for some downstream processes such as weaving and knitting processes. Also, special yarn features, particularly high strength and modulus are required for technical and industrial applications. Therefore ply yarns are often needed, and two or more single yarns are twisted together. In plying, the yarn strands consisting of fibres bundle wrap around each other and surface fibres of component single yarns are bound more effectively, which in turn, facilitate better utilization of fibre properties. Therefore, plying improves the yarn properties such as strength, elongation, evenness, hairiness, abrasion resistance, twist liveness, pilling formation etc. [1-11].

Plying process and the structure of plied yarns were interested by many researchers and series of papers were reported in the textile literature. Bennett and Postle (1979), worked on the torque generated in a single and plied yarn, and determined that a ratio of ply twist to single-yarn twist exists for the plied yarns. Palaniswamy and Mohamed (2005a; 2005b; 2006), in many their works, studied the effect of single yarn twist and ply to single yarn twist ratio on evenness, hairiness, abrasion resistance, strength and elongation properties of two-ply cotton yarn. In the studies, it was determined that single yarn twist has more effect on the improvement in tensile strength and hairiness of two-ply yarn than the ply twist. Ömeroğlu (2013), contrary to the results of Palaniswamy and Mohamed, showed that single yarn and ply twists have similar effect on yarn strength and abrasion resistant while ply twist was more effective on hairiness properties than single yarn twist. The differences in the findings were explained by different applied ratio of ply to single yarn twist.

Fraser and Stump (1998a) used the theory for the bending and twisting of thin elastic rods of uniform circular cross-section to derive a formula for the relationship between the initial single twist and the final ply twist. Fraser and Stump (1998b), in another their work, reported that the applied tensions and torques were required to hold the plied strands together. Philips et al. (2010), worked on a mathematical analysis of the torsional behaviour of n-plied yarns under tension. Chattopadhyay (1998) and Tyagi et al. (2002) determined that an optimum level of ply twist in the opposite direction to the direction of wrapping of the surface fibres lead to an increase in the strength and reduce the hard feel of air-jet-spun yarns. Tyagi and Dhamija (2000) found that the tenacity, breaking extension and unevenness of the air-jet yarns substantially improve after plying depending upon feed ratio, second jet pressure, level and direction of ply twist. They observed that Z-ply yarns are more rigid than S-ply twist and the flexural rigidity of Z-ply yarns decreases as the ply twist factor increases.

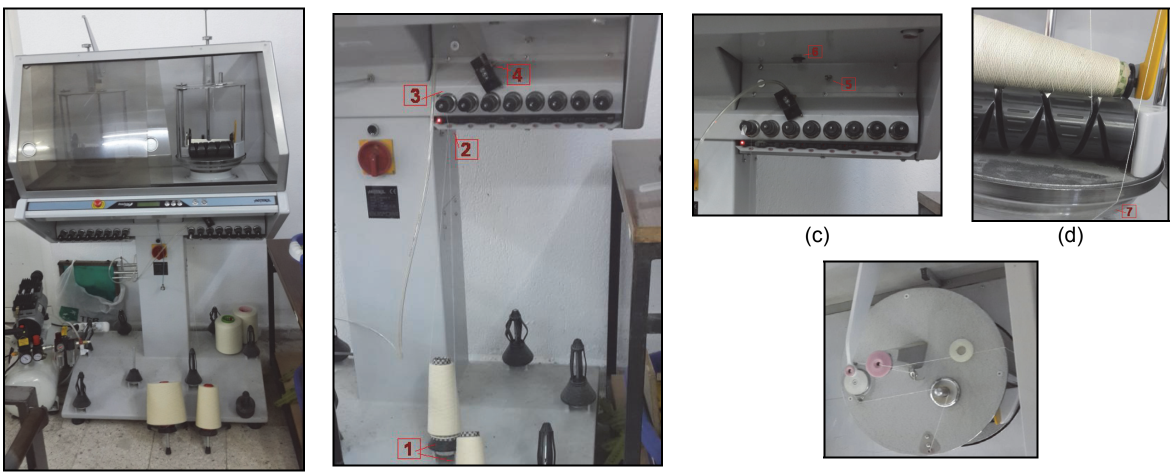
Lin et al. (1998) studied the influence of the twist direction on the physical properties of a plied yarn. They indicated that a Z-twist-direction plied yarn made from Z-twist single yarns has 24-61% higher strength, 42-88% more elongation, 5-60% higher twisting tension and a lower twist CV% of twisted yarn than an S-twist direction plied yarn. However, it was indicated that Z/Z twist-direction causes twist contraction without twist elongation while S/Z twist-direction leads to the single yarn structure untied and loose form. Elkhamy (2007) worked the development of an alternate twist plying process for producing plied yarns in the carpet industry where the plied yarns are either looped or cut. Beceren and Nergis (2008) researched whether plying compact yarns would offer additional advantages over single and two-ply conventional ring yarns. They observed only an improvement in hairiness and hence pilling resistance with evenness properties while, contrary to their expectations, tenacity and extension at break of the yarns did not differ after plying of single ring spun and compact yarns. Ishtiaque et al. (2009) found that structural parameters like fibre extent, spinning-in coefficient, fibre pair overlap length and packing density increase and migration parameters decrease after plying of regular ring-spun and compact yarns. Kireçci et al. (2011) researched the quality parameters of knitted fabrics produced from siro-spun, single and two-ply yarns. It was determined that the spirality values of plied yarn fabrics are slightly lower than those of sirospun yarn fabrics at finer yarn count values. Özgen (2013) investigated various physical properties of Kevlar and Nomex plied yarns. According to the analyses, the effect of yarn type and twist level on yarn properties was found to be statistically significant.

In this study, it was attempted to apply an air nozzle to the plying process and researched the effect of air nozzle on hairiness of plied yarns. Many researchers have been done some efforts to improve the yarn hairiness by using an air nozzle on to the various spinning systems and also winding machines. It was determined that nozzle usage in various spinning systems provides to produce considerably less hairy yarns compared to that of the conventional ring, compact or sirospun yarns [23-33]. Similar to the spinning process, it was shown that yarn hairiness decreases significantly after winding [34-35]. Considering the contributions of air nozzle on yarn features, in present work, a method was proposed to improve the hairiness of plied yarns in terms of the air nozzle usage. There were not any efforts to incorporate the air nozzle and plying process in this manner. As mentioned above, plying process is usually applied in short staple spinning and essentially required for long staple fibres such as wool to improve the strength, hairiness and irregularity properties of the yarns [21]. Therefore, we placed the air nozzle to the twisting machine and tried to figure out the advantages of the air nozzle on plied yarn hairiness.

2. MATERIAL AND METHOD

2.1. Material

In this work, we show a novel route for the plied yarn production consisting of an air nozzle and pressurized air. Our objective in this investigation is to produce, analyze and compare the properties of the yarns produced by classical and modified plying processes. In order to investigate the effect of the air nozzle on yarn hairiness, wool single yarns were plied by the Direct Twist 2A machine (Ağteks, Turkey) (Figure 1). S-twist of Nm 27.5/1 and Z-twist of Nm 48/1 wool yarns were used.



(a) (b) (c) (d) (e)

Figure 1. Direct Twist 2A machine

2.2. Method

In twisting (Direct Twist 2A) machine, it is possible to twist the single yarns without any need of extra machines such as doubling or winding machines [36]. During the plying process, two bobbins were located on the cone holders (1) for the twisting (Figure 1a-c). Both yarns were guided (2) through the yarn tensioning disk (3) and located on the twisting bowl (7). They were passed through the yarn guide shaft (5) and pigtail (6). Lastly, the yarns were guided from the bottom of the drum to the top of the cone and lower the cone onto the drum (Figure 1b-c). In modified plying process, an air nozzle (4) was placed on twisting machine. In previous studies, the nozzle was used on various yarn spinning machines [28-32]. In this study, this experimental apparatus was applied to the twisting machine and it was attempted to combine the nozzle and twisting machine. The pressurized air was fed from the compressor and transferred into the nozzle in terms of the hose. Two yarns coming from yarn tensioning disk were passed through the air nozzle before the twisting bowl (Figure 1b-c). In the study, different air pressure and mass flow values were used. A mass flow meter of Alicat Scientific firm was used and placed between the compressor and nozzle opening. Before the plying, air pressure and hence mass flow values of pressurized air was set in terms of the manometer of the compressor. In literature, air pressure was measured by only manometer regarding the air nozzle usage in various processes. There was not any trial to set the air pressure surely and to take definite data about compressed air.

Mass flow rate is the mass of an air which passes per unit of time and mass flow values were changed from 6.5 to 10.5 L/min (standard litre per minute-SLPM) in the study (Table 1). As seen, the mass flow of the compressed air is increased when air pressure values rise. In present study, the ply twist levels of 60 T/m and 45 T/m were chosen to investigate the effect of degree of twist on yarn hairiness. Number of twists per minute was set as 1500 T/min for all experiments. Therefore, production speed was 25 m/min for 60 T/m and 33.3 m/min for 45 T/m.

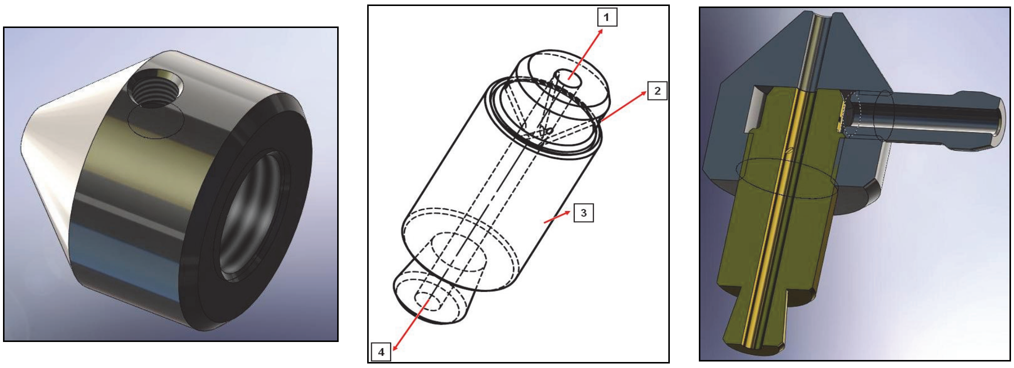
The nozzle, used in plied yarn production, consists of two parts and they are nozzle head and nozzle body (Figure 2). Nozzle body has a cylindrical cross section comprising of main hole (1), injectors (2), twisting chamber (3) and nozzle outlet (4) (Figure 4b). Main hole lies starting from the nozzle inlet to nozzle outlet and the nozzle has a constant diameter. Injectors are positioned at certain angle with respect to the nozzle axis and so they lie tangentially to the twisting chamber. Nozzle head transfers the pressurized air coming from the compressor into the nozzle body by means of the injectors. In this study, we used the angles of 15° due to its better hairiness results determined in the previous studies regarding with Jetring, Compact-jet and siro-jet spinning systems [28-32]. Air entered at the angle of 15º to the main hole. The nozzle has the diameters of 3.0 mm main hole and 0.5 mm injectors.

Physical character of plied yarns changes with the direction and the amount of the twist. In the following part of the study, S- and Z-twisted single yarns were plied at Z-direction with both plying methods. Two twist levels were used. In literature, S/Z plying process is called as twist-against-twist when the twist direction of single yarns is different from ply twist direction. In most cases, the single yarns have Z-twist direction and hence plying with S-direction is a common practice. On other hand, for special applications, ply twist direction is chosen as the same with the twist direction of single yarns and Z-on-Z is called as twist-on-twist [3].

Five bobbins of each yarn type were manufactured for the experiments in the same twisting unit. Hairiness and twist values of the plied yarns were measured on Zweigle G566 hairiness tester and Brustio Antonio twist tester, respectively. Ten measurements were done for each type of the experiments and test length was 100 m for the hairiness test. For the yarn twist, test length as 50 cm and twenty measurements were done for each bobbin. Test results were analysed statistically using the analysis of variance (One-Way ANOVA) and LSD post hoc test at the 95% level of confidence in SPSS 16.0 to determine any significant differences.

Table 1. Compressed air properties measured at Alicat mass flow meter

Mass flow values		Pressure (Pa)		
SLPM (Standard Litre Per Minute)	Kg/s ($x10^{-5}$)	Mean value	Upper value	Lower value
6.5	13	110129	108620	112069
7.0	14	112172	110069	113862
7.5	15	114705	112137	115793
8.0	16	117564	115172	119517
8.5	17	120238	117586	122137
9.0	18	123780	121310	125793
9.5	19	127103	124758	129310
10.0	20	129655	126000	132965
10.5	21	133492	130413	135034



(a) (b) (c)

Figure 2. Nozzle head (a), nozzle body (b) and the nozzle (c) [32] (1: Main hole, 2: Injectors, 3: Twisting chamber, 4: Nozzle outlet)

3. RESULTS AND DISCUSSION

3.1. Effect of twist amount on yarn hairiness

In this part of the study, it was studied the effect of an air nozzle on the plied yarn hairiness and determined the changes in hairiness of the yarns produced by classical and modified plying processes. In this experiment, ply twist levels were altered and two different twist amounts (60 T/m and 45 T/m) were used. S-twisted yarn bobbins were placed onto the Direct twist 2A machine and passed from the air nozzle. Type of twist direction was selected as Z and hence twisting bowl gave the twist with Z-direction to the yarns. Consequently, S-twisted single yarns were plied with Z direction (S/Z). Zweigle s3 hairiness results of the yarns were shown in Figure 3. In the figure, straight lines indicate the results of the plied yarns produced by classical plying process without the air nozzle and compressed air.

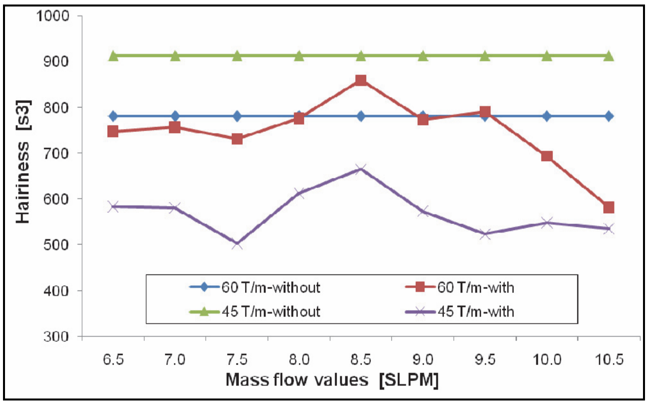


Figure 3. Zweigle s3 hairiness results of the S/Z plied yarns

As seen in Figure 3, hairiness of plied yarns produced with air nozzle changed with different mass flow and so air pressure values of the compressed air. When the hairiness of the yarns plied with modified and classical plying methods was compared, different cases were observed for 60 and 45 T/m. For 60 T/m, the yarns plied with the air nozzle had lower s3 values at certain mass flow ranges such as from 6.5 to 8.0 L/min and from 9.5 to 10.5 L/min in comparison to that of the yarns produced with classical plying process. However, the positive effect of air nozzle was mostly found statistically insignificant level and the yarns produced with both plying methods had statistically similar hairiness values (Table 2). Hairiness of the yarns produced at 10.5 L/min mass flow was the only significantly lowest.

However, for 45 T/m, there was another case and the yarns plied with air nozzle had considerable lower s3 hairiness values. In particular, at between 6.5 and 7.5 L/min, and 9.0 and 9.5 L/min mass flow values, the differences in the hairiness of the yarns were found statistically significant level (Table 2). Therefore, for 45 T/m, modified plying process provided a remarkable improvement on plied yarn hairiness. Moreover, the differences in s3 values of the yarns plied with classical and modified methods reached to about two times. On the other hand, mass flow level between 8.0 and 8.5 L/min lead to considerably higher hairy yarns while the lowest hairiness values were obtained at 7.0-7.5 L/min and 9.5-10.5 L/min mass flow values for both twist values. Consequently, lower ply twist levels at any mass flow values or higher air pressure values at higher ply twist levels enhanced less hairy plied yarn production.

Table 2. ANOVA test results for plied yarns

Plying parameters (L/min)		**S/Z**		**Z/Z**	
		60 T/m	**45 T/m**	**60 T/m**	**45 T/m**
Without nozzle	6.5	0.089	0.047*	0.002*	0.063
	7.0	0.749	0.045*	0.038*	0.135
	7.5	0.515	0.015*	0.016*	0.086
	8.0	0.947	0.068	0.013*	0.028*
	8.5	0.117	0.128	0.082	0.033*
	9.0	0.919	0.040*	0.036*	0.074
	9.5	0.895	0.020*	0.066	0.087
	10.0	0.211	0.070	0.027*	0.489
	10.5	0.013*	0.061	0.459	0.923

*. The mean difference is significant at the 0.05 level.

3.2. Effect of twist direction on yarn hairiness

In the study, following to S/Z plying, Z-twisted single yarns were plied with classical and modified plying methods to determine the effect of twist direction of the yarn hairiness. The hairiness results of the Z/Z plied yarns were given in Figure 4.

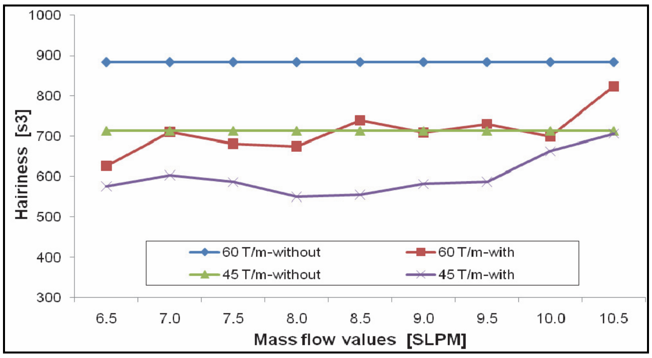


Figure 4. Zweigle s3 hairiness results of the Z/Z plied yarns

As seen in Figure 4, as similar to S/Z plying process, hairiness of plied yarns produced with air nozzle also changed in Z/Z plying when the mass flow and so air pressure values of the compressed air were increased. Contrary to S/Z plying, the yarns obtained at all mass flow values had considerable lower hairiness than the yarns produced without air nozzle. Particularly, for 60 T/m, the differences in s3 values of the yarns were found statistically significant at almost all mass flow values (Table 2). At 45 T/m, it was also produced less hairy yarns with air nozzle. However, hairiness of the yarns plied at 8.0 and 8.5 L/min mass flow values was significantly lower than that of the other mass flow values. Consequently, the yarns were considerably less hairy for 60 T/m and also 45 T/m twist levels.

On the other hand, similar to S/Z plying, mass flow levels of 7.5-8.0 L/min and 9.0-9.5 L/min gave the lowest hairiness values for both twist values. However, contrary to S/Z plying, the higher mass flow values such as 10.0/10.5 L/min lead to produce more hairy yarns in Z/Z plying.

The results of different twist directions and levels indicated that modified plying process comprising air nozzle and compressed air was capable to produce less hairy plied yarns. However, as similar to classical plying process, the improvement in hairiness changes depending on applied twist direction and twist amount. Lower twist levels or higher air pressure values should be used when the ply-twist direction was not the same with the single yarn twist (twist-against-twist). However, hairiness has been improving at any twist and air pressure levels when the ply and single yarn twist directions were the same. Therefore, twist-on-twist plying process had more positive effect on less hairy yarn production. Regardless of twist direction, air nozzle usage was more powerful at lower twist levels.

3.3. Effect of mass flow values on yarn hairiness

In this part, it was analysed the changes in yarn hairiness depending on compressed air properties, particularly mass flow values of the air. When s3 hairiness results were studied, any stable cases were not observed for both twist levels and directions (Figure 5).

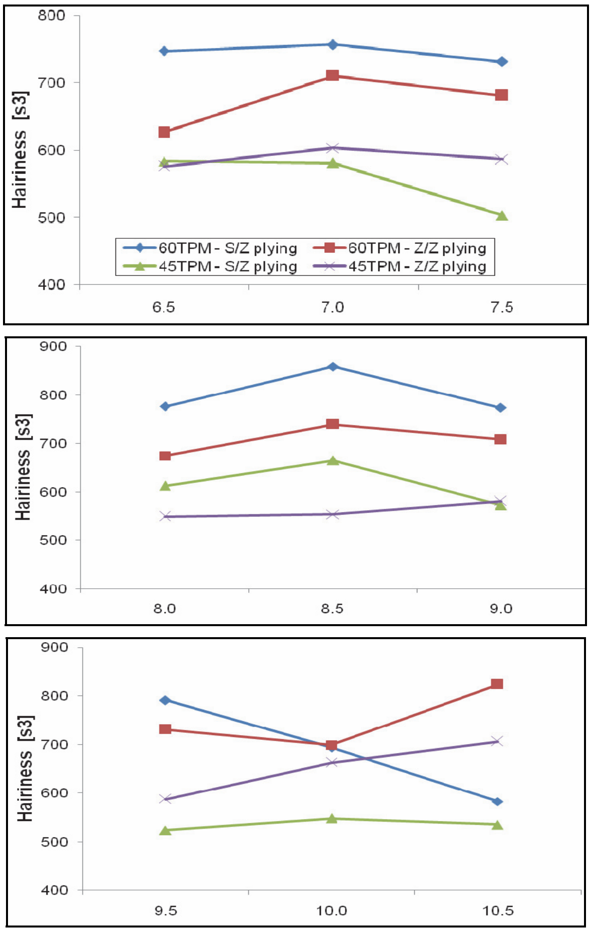


Figure 5. Detailed demonstration of Zweigle s3 hairiness results for different mass flow values

In most cases, s3 values increased insignificantly as the mass flow values of compressed air increased from 6.5 to 7.0 L/min (Table 3). At 7.5 L/min, hairiness of all the yarns decreased. And then, it was observed an increasing trend at between 7.5 and 8.5 L/min mass flow values. When the mass flow values were continued to rise from 8.5 to 9.5 L/min, except the yarns produced at 45 T/m with Z/Z plying, s3 values were roughly getting lower. There was not remarkable change of Z/Z yarns plied at 45 T/m. However, at the upper mass flow values than 9.5 L/min, the yarns displayed different character. Hairiness of the yarns plied with S/Z direction decreased while the yarns were getting more hairy in Z/Z plying. During the plying without air nozzle usage, the single yarns were getting together and plied at the yarn guide of the plying machine (Figure 6a). However, in modified plying method, it was observed that the yarns started to interlock and ply together before the yarn guide of the twist machine at the certain mass flow values (Figure 6b-c). A twist in small quantities was occurred and the amount of the twist increased with the higher mass flow rates. Even at the mass flow values up to 9.0 L/min, plying and binding case of the single yarns started when the single yarns were unwinding from the bobbin. Due to this wrapping case, the single yarns moved unstable and this case lead to different hairiness results at the higher mass flow levels. On the other hand, the differences in the s3 values of all mass flow values were mostly found statistically insignificant

(Table 3). Nevertheless, depending on the yarn twist direction, it was only observed statistically significant differences between the results of 8.0/8.5 L/min and 10.0/10.5 L/min mass flow values (Table 3).

Mass flow range from 7.5 to 8.0 L/min gave the least hairy yarns for almost all the yarns while the most hairy yarns were obtained at the range between 8.0 and 8.5 L/min. On the other hand, higher mass flow values enhanced less hairy yarn production in S/Z plying while hairiness of the yarns was getting worse in Z/Z plying. As a consequence, it might be better to work at lower mass flow values when the costs are taking into consideration.

(a) (b) (c)

Figure 6. Plying of the single yarns with classical and modified plying method

Table 3. ANOVA test results for different mass flow values

Plying parameters (L/min)		**60 T/m**		**45 T/m**	
		S/Z	**Z/Z**	**S/Z**	**Z/Z**
6.5	7.0	0.170	0.307	0.987	0.723
	7.5	0.308	0.506	0.614	0.891
	8.0	0.102	0.554	0.854	0.738
	8.5	0.004*	0.172	0.611	0.785
	9.0	0.110	0.320	0.946	0.944
	9.5	0.066	0.208	0.707	0.887
	10.0	0.596	0.378	0.856	0.267
	10.5	0.263	0.019*	0.804	0.076
7.0	7.5	0.739	0.719	0.625	0.828
	8.0	0.799	0.664	0.842	0.492
	8.5	0.070	0.728	0.600	0.531
	9.0	0.828	0.978	0.959	0.777
	9.5	0.652	0.811	0.718	0.832
	10.0	0.362	0.887	0.866	0.447
	10.5	0.027*	0.176	0.814	0.160
7.5	8.0	0.558	0.941	0.492	0.637
	8.5	0.039*	0.480	0.314	0.682
	9.0	0.582	0.740	0.662	0.947
	9.5	0.434	0.549	0.898	0.997
	10.0	0.582	0.828	0.818	0.330
	10.5	0.056	0.089	0.870	0.103
8.0	8.5	0.105	0.435	0.744	0.950
	9.0	0.971	0.684	0.802	0.685
	9.5	0.843	0.501	0.576	0.634
	10.0	0.237	0.771	0.740	0.151
	10.5	0.015*	0.076	0.690	0.035*
8.5	9.0	0.099	0.708	0.565	0.731
	9.5	0.142	0.914	0.378	0.679
	10.0	0.010*	0.624	0.551	0.169
	10.5	0.001*	0.312	0.507	0.040*
9.0	9.5	0.815	0.789	0.757	0.944
	10.0	0.253	0.908	0.899	0.298
	10.5	0.016*	0.168	0.847	0.089
9.5	10.0	0.164	0.702	0.900	0.332
	10.5	0.009*	0.264	0.953	0.104
10.0	10.5	0.115	0.136	0.954	0.546

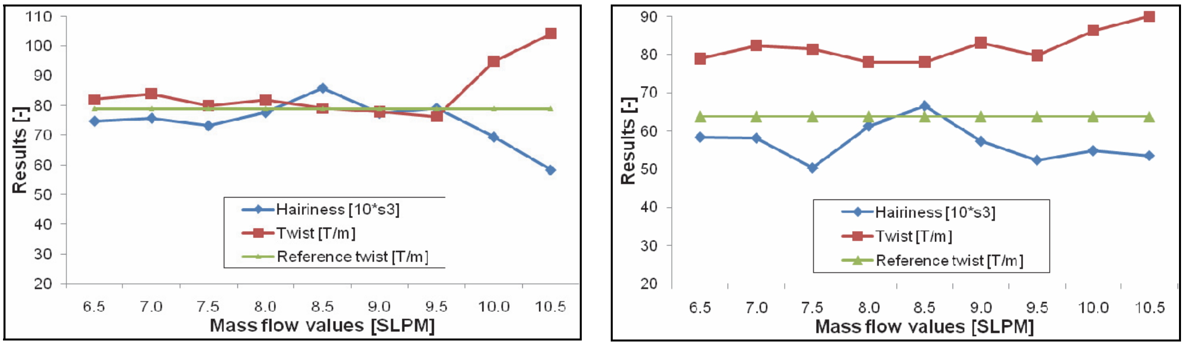
*. The mean difference is significant at the 0.05 level.

3.4. Yarn twist results

In this study, it was measured the twist values of the plied yarns produced by classical and modified plying methods, and analysed the relationship between yarn twist and hairiness properties. The results were shown in Figures 7-8. In the figures, straight lines which were called as reference twist indicated the twist results of the yarns plied without air nozzle. As seen in all figures, there was an increase or reduction in yarn twist values depending on applied mass flow and air pressure values. However, the changes were found statistically insignificant level (Table 4). Additionally, the yarns plied with classical and modified plying methods had also statistically similar ply twist values (Table 5).

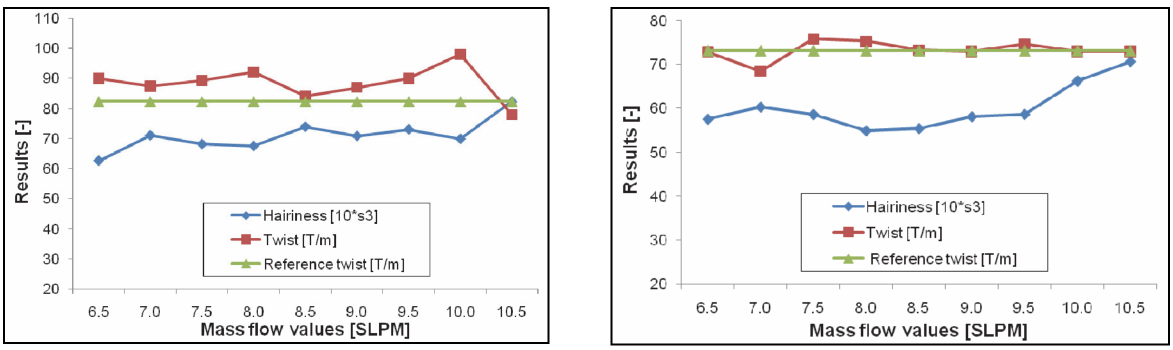
In S/Z plying, different from 60 T/m, the yarns plied with modified method at 45 T/m had higher yarn twist values than that of the yarns obtained with classical method and this case might be the main reason for higher improvement in hairiness of plied yarns at 45 T/m in comparison to 60 T/m. This result indicated that there was not a need of higher ply twist application for the improvement in yarn hairiness in the modified plying method. Working at lower ply twist levels has been providing an increase in production speed and productivity. Contrary to S/Z twisting, in Z/Z plying, twist values of plied at 60 T/m was slightly higher than that of the classical plied yarns and this might be one of the reason for higher improvement in yarn hairiness at this twist level.

When the trends in twist results of S/Z and Z/Z plying were analysed detailed, it was determined that the curves were not completely same. In S/Z plying, twist values increased and so yarn hairiness decreased at higher mass flow values than 8.5 L/min. There was not a relationship between yarn twist and hairiness results at lower mass flow values. The increase in yarn twist started at 9.5 L/min for 60 T/m while it was 8.5 L/min for 45 T/m. In Z/Z plying, yarn twist increased and so hairiness decreased from 7.5 to 8.5 L/min and from 8.5 to 9.5 L/min. Similar to S/Z plying, 8.5 L/min lead to a reduction in yarn twist. Contrary to S/Z plying, in Z/Z plying, higher mass flow values than 8.5 L/min, twist values decreased and so yarn hairiness increased. This case was observed at higher mass flow values such as 10.0 L/min for 60 T/m while it was 9.5 L/min for 45 T/m. On the other hand, for both twist directions and levels, the lowest twist and so higher yarn hairiness values were obtained at 8.5 L/min.



(a) (b)

Figure 7. The measured hairiness and twist values of the S/Z plied yarns at the 60 T/m (a) and 45 T/m (b)



(a) (b)

Figure 8. The measured hairiness and twist values of the Z/Z plied yarns at the 60 T/m (a) and 45 T/m (b)

Table 4. ANOVA test results for different mass flow values

Plying parameters (L/min)		60 T/m		45 T/m	
		S/Z	Z/Z	S/Z	Z/Z
6.5	7.0	0.849	0.702	0.875	0.849
	7.5	0.122	0.485	0.865	0.122
	8.0	0.211	0.685	0.990	0.211
	8.5	0.375	0.405	0.772	0.375
	9.0	0.730	0.684	0.734	0.730
	9.5	0.549	0.982	0.634	0.549
	10.0	0.446	0.185	0.250	0.446
	10.5	0.265	0.097	0.083	0.265
7.0	7.5	0.101	0.760	0.765	0.101
	8.0	0.175	0.441	0.876	0.175
	8.5	0.308	0.649	0.683	0.308
	9.0	0.612	0.966	0.650	0.612
	9.5	0.454	0.709	0.564	0.454
	10.0	0.371	0.108	0.376	0.371
	10.5	0.217	0.195	0.141	0.217
7.5	8.0	0.920	0.279	0.885	0.920
	8.5	0.554	0.869	0.912	0.554
	9.0	0.259	0.803	0.876	0.259
	9.5	0.379	0.507	0.779	0.379
	10.0	0.550	0.062	0.233	0.550
	10.5	0.718	0.303	0.084	0.718
8.0	8.5	0.670	0.231	0.800	0.670
	9.0	0.367	0.438	0.765	0.367
	9.5	0.497	0.728	0.672	0.497
	10.0	0.656	0.324	0.296	0.656
	10.5	0.825	0.047*	0.108	0.825
8.5	9.0	0.604	0.692	0.964	0.604
	9.5	0.782	0.428	0.865	0.782
	10.0	0.959	0.053	0.193	0.959
	10.5	0.825	0.399	0.069	0.825
9.0	9.5	0.808	0.690	0.900	0.808
	10.0	0.668	0.113	0.179	0.668
	10.5	0.461	0.226	0.064	0.461
9.5	10.0	0.838	0.222	0.143	0.838
	10.5	0.620	0.115	0.051	0.620
10.0	10.5	0.798	0.010*	0.435	0.798

*. The mean difference is significant at the 0.05 level.

Table 5. ANOVA test results for plied yarns

Plying parameters (L/min)		S/Z		Z/Z	
		60 T/m	45 T/m	60 T/m	45 T/m
Without nozzle	6.5	0.354	0.800	0.259	0.354
	7.0	0.288	0.708	0.456	0.288
	7.5	0.522	0.940	0.648	0.522
	8.0	0.649	0.826	0.136	0.649
	8.5	0.991	0.973	0.780	0.991
	9.0	0.593	0.937	0.500	0.593
	9.5	0.780	0.838	0.286	0.780
	10.0	0.966	0.205	0.029*	0.966
	10.5	0.807	0.074	0.560	0.807

*. The mean difference is significant at the 0.05 level.

3.5. Yarn appearances

In final part of the study, plied yarns were analysed under microscopy and the typical views are shown in Figures 9-12. In the figures, it was given the images of the Z-twisted single yarns at 45 T/min, as an imaginative.

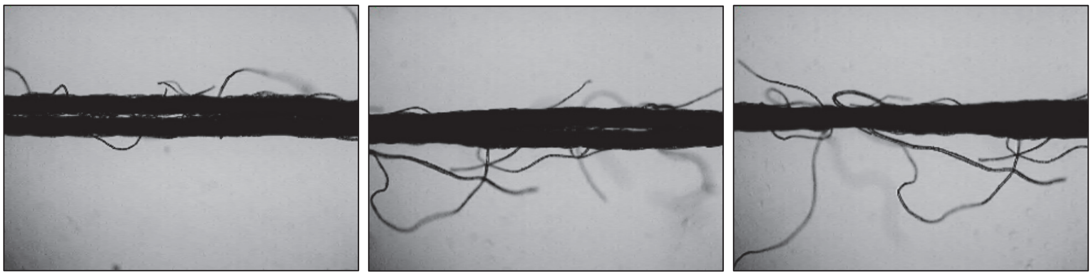
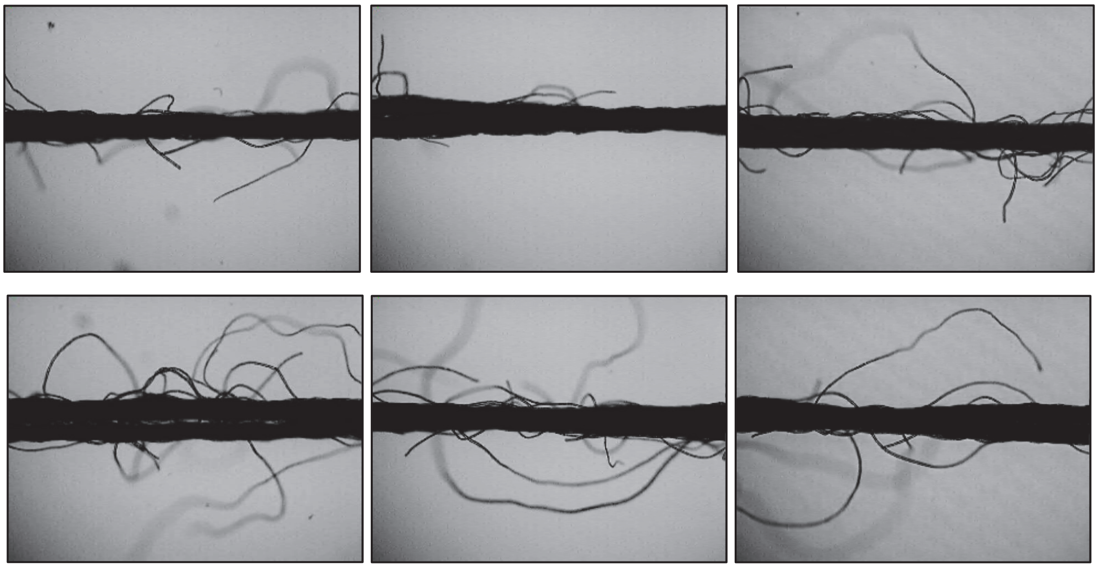
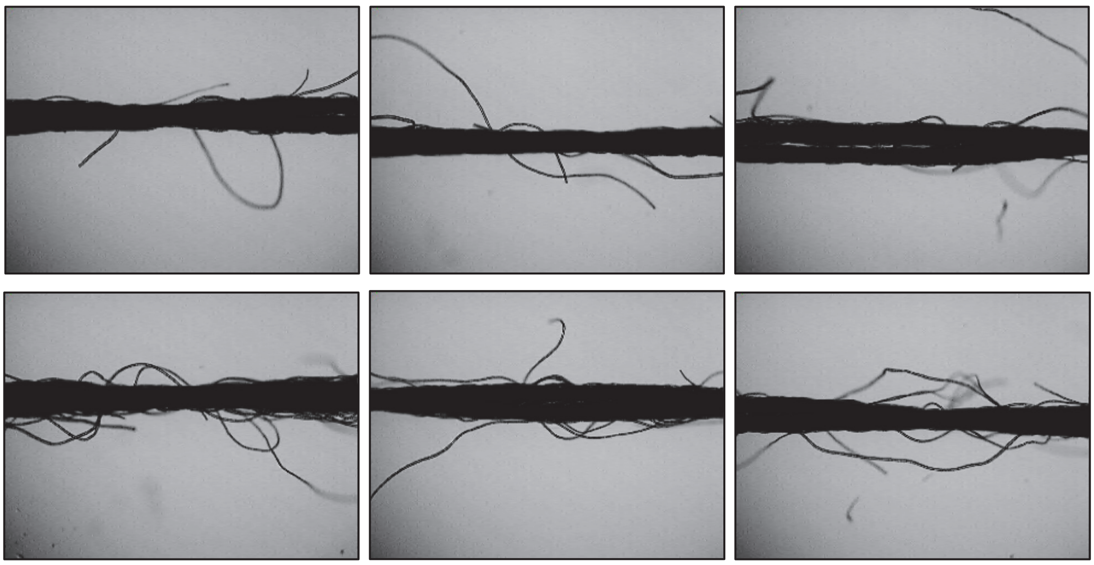


Figure 9. Typical views of the yarns produced with classical plying method (4x)



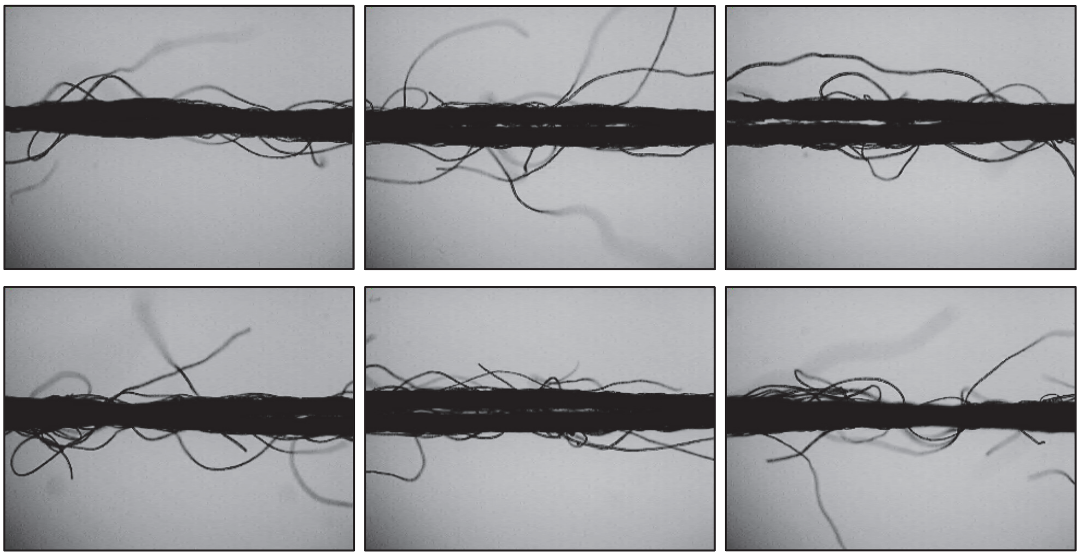
(a) (b) (c)

Figure 10. Typical views of the yarns produced with modified plying method at different mass flow values (4x) (a: 6.5 L/min, b: 7.0 L/min, c: 7.5 L/min)



(a) (b) (c)

Figure 11. Typical views of the yarns produced with modified plying method at different mass flow values (4x) (a: 8.0 L/min, b: 8.5 L/min, c: 9.0 L/min)



(a) (b) (c)

Figure 12. Typical views of the yarns produced with modified plying method at different mass flow values (4x) (a: 9.5 L/min, b: 10.0 L/min, c: 10.5 L/min)

As seen, the yarns plied with classical and modified twisting methods had similar yarn appearances. In both yarns, there were nodes along the yarn length due to the ply twist. At higher ply twist values such as 60 T/m, knotty appearances were getting more visible. Ply twist may help to hold the fibre strands together into one yarn structure. However, there were still many fibres projecting from the plied yarn bodies. When the structures of the plied yarns were compared, it was observed that the yarns produced by classical plying seem more bulky. There was some space between the single yarn components. As to the yarns plied with modified twisting method, yarn structure changed depending on mass flow values. At lower mass flow values, nodes were not as apparent as classical plied yarns and the yarns seemed more even in comparison to classical plied yarns. In addition to projected fibres, it was observed that some of the fibres wrapped onto the yarn body. However, the distribution of these fibres was not regular. Up to 9.0 L/min, structures of the yarns became tighter (Figures 10-11). When the mass flow values were increased from 9.0 L/min to 10.5 L/min, the space between the single yarn components was increased and the yarn diameter was getting bigger (Figure 12). Moreover, wrapping cases of the fibres were also increased. However, in some section of the yarns, the wrapping fibres were entangled to each other and untidy appearances were occurred. In addition to bulky structure, this case may lead to hairy structure.

In modified plying method, pressurized air swirls along the nozzle and an air vortex is occurred in the nozzle [25-26; 28-33]. Air nozzle produces some twist depending on air pressure. In sirospun spinning, strand twist is occurred up to 60 to 100 T/m and higher strand twist reduces the fibres projected from yarn body [3]. As in sirospun spinning, the twist obtained by the usage air nozzle and compressed air might help to trap the fibres on to the yarn. It is necessary to note that the amount of twist acquired in terms of the nature of the method is lower comparing with that of the sirospun. In particular, this case might be so effective at lower ply twist levels during the twist-against-twist plying. However, at higher mass flow and ply twist values, irregular airflow and hence yarn movements might damage the positive effect of twist and wrapping cases, and so hairiness of the yarns slightly increase.

4. CONCLUSIONS

In recent years, plying especially become important for wool raw materials and even new spinning systems such as solo and sirospun spinning systems were essentially designed for the less hairy wool yarn production. In this work, it was shown a novel method to improve the hairiness of plied yarns. The proposed method was based on the usage an air nozzle and compressed air different from classical plying method. As mentioned before, the nozzle and compressed air was applied to various spinning machines and indicated the improvement in hairiness of the yarns. From these experiences, it was strived to associate the experimental device and twisting machine. In the study, it was compared the hairiness of the yarns produced by classical and new/modified plying methods and figured out the advantages of the air nozzle application regarding yarn hairiness property. Following results were obtained:

- When the hairiness results of the yarns plied with both methods were compared, it was determined that proposed plying process gave lower s3 hairiness values than classical plying. Therefore, the method provided an opportunity to decrease the hairiness of plied yarns.
- The improvement in hairiness has been depending on compressed airflow properties such as mass flow/air pressure values and also plying parameters such as direction and number of ply twist.

- When the S-twisted single yarns were plied with Z-twist direction, significantly lower hairiness values were obtained at lower ply twist levels. This result indicated that working at lower ply twist levels enhanced to reduce the yarn hairiness together with an increase in production speed and productivity.
- As the ply twist increased, degree of improvement in hairiness decreased. However, there was still an opportunity to produce significantly less hairy yarns by using higher mass flow values such as 10-10.5 L/min.
- On the other hand, when the Z-twisted single yarns were plied with Z-twist direction, considerably less hairy yarns could be produced at all ply twist amounts. If the plying was required for the improvement of the yarn hairiness, similar hairiness values that obtained in classical plying with the higher ply twist levels could be achieved at the lower ply twist ranges in terms of the modified plying method.
- Mass flow levels of 7.0-7.5 L/min in S/Z plying and 7.5-8.0 L/min in Z/Z plying gave the lowest hairiness values for both twist levels. Therefore, less hairy yarn production might be possible at even low mass flow and air pressure values.
- 8.0-8.5 L/min mass flow ranges lead to the highest hairy yarn production for almost all yarns. Contrary to S/Z plying, the highest mass flow values such as 10.5 L/min lead to produce more hairy yarns in Z/Z plying.
- On the other hand, the differences in the s3 values of all mass flow values were mostly found statistically insignificant. Therefore, higher mass flow values than optimum level seem meaningless when the production costs are taken into consideration.
- When the ply twist of the yarns were analysed, it was observed that twist of the yarns change statistically insignificant degree. Up to 8.5 L/min mass flow values, twist of the yarns changed slightly. However, higher mass flow values caused an increase in S/Z plying while a reduction occurs in Z/Z plying.
- The yarns obtained with both twisting methods had similar yarn appearances comprising the nodes along the yarn length due to the ply twist. However, the yarns plied with new method had tighter structure than that of the classical plied yarns.

In short, the presented setup may open a new avenue to provide an extra reduction in yarn hairiness during the plying process. Additionally, in literature, there was not any effort to incorporate the air nozzle and plying process in this manner. Therefore, this study offers a new process with simple structure which can improve the yarn hairiness and productivity compared to classical plying method. The method is independent of Direct Twist 2A machine and any twisting machine used in plied yarn production could be modified with an air nozzle according to the quality and productivity expectations. However, it is necessary to conduct more studies for the optimisation in order to achieve a usable system.

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