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Properties of viscose air-jet spun plied yarns

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Effect of ply twist, its direction and number of plies on air-jet plied yarn properties has been studied. It is found that when air-jet yarns are plied in a direction which is similar to single yarn wrapper fibre twist direction, the yarn irregularity, imperfections and hairiness improve, while plying in the opposite direction of the single yarn wrapper fibres reduces twist liveliness and improves yarn tenacity. Regarding the effect of ply twist, by increasing ply twist, the yarn abrasion resistance and hairiness improve, while tenacity improves to an optimum level and then deteriorates. This optimum twist level varies according to ply yarn twist direction. Three plied yarns are better than two plied yarns in terms of tenacity and breaking elongation. This confirms that three plied yarn has better evenness than two plied yarn. Considering yarn tenacity, air-jet yarns should be twisted in opposite direction of their single yarn twist direction.

Keywords: Air-jet spinning, Plied yarn, Yarn twist, Viscose fibre

1 Introduction

Air-jet spun yarn consists of parallel core fibres enclosed by wrapper fibres and the main disadvantage of this yarn is its weakness comparatively with ring-spun yarn. This disadvantage arises from yarn structure, having some loose wrapper fibres and irregular wrappings, which, in turn, gives more chance of weak places incidence in the yarn. However, this property can be improved relatively by the yarn plying process.

Chattopadhyay[1] observed that the plying process enhances the air-jet yarn strength regardless the ply twist direction. Also, the breaking extension of polyester/viscose yarn improves while increasing plying twist and this improvement ratio is found higher when plying in Z-direction. Krthekeyan *et al.*[2] mentioned that the breaking strength deteriorates and breaking elongation improves while increasing the plying twist of Murata jet spun yarns. Tygai *et al.*[3] studied the structure and properties of polyester Murata jet spun plied yarns and they concluded that applying a ply twist factor in the opposite twist direction of wrapper fibres reduces the fibre helix angle and helix diameter and increases the fibre extent, consequently the plied yarn becomes stronger, high abrasion resistant, more even and less rigid. Oxenham[4], and Tyagi and Dhamija[5] studied the influence of ply twist and twist direction on the properties of viscose jet-spun yarns and they found that yarn tensile properties and evenness improve by plying.

Generally, when yarns are plied in a direction opposite to its single yarn twist direction, the resultant yarn loses a considerable amount of twist until it reaches the theoretical point of twist equilibrium[1-6]. This twist equilibrium point is variable and depends on material, yarn type and production parameters. This is well known for ring-spun yarns, while there is less information about air-jet spun yarns. Plied twist should be in correspondence with single yarn twist factor but the characterization of air-jet yarns single twist factor is still a problem. Basu[6] mentioned that the plying in S direction reduces the aggregation effect of core fibres as the wrapper fibres start to release their tight grip on core fibres. The latest method of air-jet yarn production is launched by Rieter and this research aims to study the effect of ply twist and its direction on the plied yarn properties in order to optimize and give better understanding of the influence of plying process on yarn properties produced by this new spinning technique.

2 Materials and Methods

Viscose fibres (Lenzing) (1.3 dtex/38 mm) were used to produce 23 tex air-jet yarn using Rieter J20 air-jet spinning machine. The spinning machine production parameters were kept under standard mill conditions, such as tube diameter 1.2 mm, nozzle pressure 5 bar and delivery speed 400 m/min. The

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single yarn having Z-wrapper fibre twist direction was plied and twisted using Galan ring twister unit in both Z and S directions using three levels of ply twist factor and two different numbers of plies according to the plan shown in Table 1.

The single yarn and the 12 plied yarn samples were kept in the lab for 24 h at 20±2°C and 65±2% relative humidity. Yarn hairiness, imperfections and irregularity were tested using Uster tester 4-SX with a testing speed of 200 m/min for 1 min taking 10 observations from each yarn sample. Yarn tensile properties were measured using Instron 4411 instrument with a 250 mm/min testing speed and 500 mm gauge length, taking 50 observations from each yarn sample. Also, yarn abrasion resistance was measured using Zweigle-G552 instrument and 30 g weight. Yarn snarling twist was measured manually: two ends of 1 m yarn length were held together so that the middle of the yarn was twisted freely and the amount of formed snarls were counted. Thirty (30) observations for each yarn were taken.

Table 1 — Plied yarn production parameters

Sample code	Number of plies	Ply twist direction	Turns per meter	Twist coefficient (α_e)
1	2	s	281	2.1
2	2	s	422	3.2
3	2	s	563	4.2
4	2	z	281	2.1
5	2	z	422	3.2
6	2	z	563	4.2
7	3	s	150	1.3
8	3	s	260	2.3
9	3	s	375	3.3
10	3	z	150	1.3
11	3	z	260	2.3
12	3	z	375	3.3

Table 2 — Effect of number of plies, ply twist and ply twist direction on yarn imperfections

Sample code	Thin -50% /km	Thick +50% /km	Neps +140% /km	Total imperfection/km
Single	3	7	202	212
2	0	2	66	68
3	0	2	109	121
4	0	3	5	8
5	0	1	1	2
6	0	2	4	6
7	0	3	184	186
8	0	0	58	58
9	0	1	19	20
10	0	0	3	3
11	0	1	2	3
12	0	0	0	0

Multi-way ANOVA was applied for both 2 and 3-plied yarns using SPSS software to analyse the significance of ply twist and ply twist direction on yarn properties at a confidence level of 95% (the difference between the groups is considered significant if p value is less than 0.05).

3 Results and Discussion

3.1 Yarn Irregularity and Imperfections

Figure 1 and Table 2 show the yarn mass irregularity and imperfections for the single and the 12 plied yarns. It is evident from results that there is a significant improvement in yarn evenness and reduction in imperfections incidence after plying process for both 2 and 3-plied yarns. This is believed to occur as a result of reducing the yarn variation while assembling a number of strands together. This improvement ranges approximately 16-41% and 22-99% for yarn evenness and total imperfections respectively. Statistical analysis (Table 3) shows that ply twist direction, ply twist value and their interaction effect have a significant effect on yarn mass irregularity, incidence of neps formation and yarn total imperfections at 95% confidence level (except for the interaction effect on 3-plied yarn irregularity), while they have insignificant effect on yarn thin and thick places.

By increasing ply twist, yarn irregularity changes slightly. The relatively biggest differences are recorded between mass irregularity (CV_m values) of two plied yarn of 281 tpm, 422 tpm and 563 tpm. Although these differences are statistically significant, from the technological point of view they are very

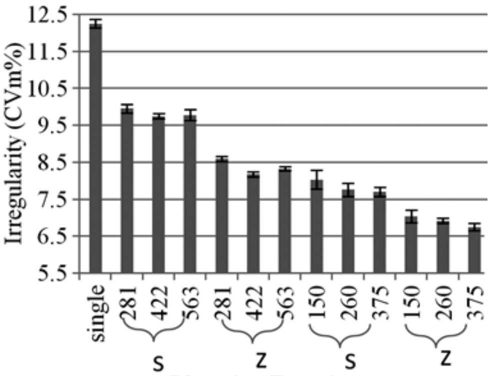

Fig. 1 — Relationship among ply twist, its direction and yarn irregularity (with confidence levels of 95%)

Table 3 — Statistical significance of independent factors (ply twist direction, ply twist value and their interaction effect) on 2 and 3-plied yarns properties at 95% confidence level

Dependent factor	2-Plied yarn			3-Plied yarn		
	Ply twist direction	Ply twist	Ply twist direction *ply twist	Ply twist direction	Ply twist	Ply twist direction *ply twist
Tenacity	s	s	s	ns	ns	s
Elongation	s	s	s	s	s	ns
Irregularity	s	s	s	s	s	ns
Thin places	ns	ns	ns	ns	ns	ns
Thick places	ns	ns	ns	ns	ns	ns
Neps	s	s	s	s	s	s
Total imperfections	s	s	s	s	s	s
Hairiness	s	s	s	s	s	s
Abrasion resistance	s	s	s	ns	s	ns
Snarling tendency	s	s	s	s	s	s

small and can be attributed to variation of mass irregularity of single yarns.

Any systematic changes in yarn neps with increasing ply twist are not recorded for 2-plied yarn, whereas number of neps decreases significantly with increasing ply twist in the case of 3-plied yarn. This result might be random because neps can be recorded as a place where wrapper fibres are more accumulated and randomly arranged around core. This explanation can also be supported by high variability of number of neps within samples (40–200%). This fact opens new research activities in the field of measuring and evaluating number of neps of air-jet yarns.

Regarding number of plies, 3-plied yarns are found regular than 2 plied yarns by about 18.3-19.2% and this is attributed to the increase in number of fibres in yarn cross section.

Results show that plied yarns (two-ply as well as three-ply) when twisted in the opposite direction of wrapper fibres have significantly higher CV_m values (both statistically and technologically) compared to plied yarns twisted in the direction of wrapper fibres. As it is known, air-jet yarn consists of a core (theoretically parallel oriented fibres) and wrapper fibres twisted approximately in a helical form around the core. During plying (whether in S or Z twist direction) mass irregularity of core does not change, but the wrapper layer changes its geometrical structure markedly due to fibre loosening in the case of plying in opposite direction of wrapper fibres. Thus, the random irregular geometrical structure is created. This effect is reflected in increasing mass unevenness of wrapper layer and in increasing total mass irregularity of plied yarn. Conversely, in the case of plying where yarns are twisted in the direction of wrapper fibres, the regular geometrical structure of fibres in the wrapper layer is maintained and supported by the same twist direction. This expresses itself as lower value of irregularity CV_m of resultant plied yarn compared to plied yarn twisted in the opposite direction of wrapper fibres.

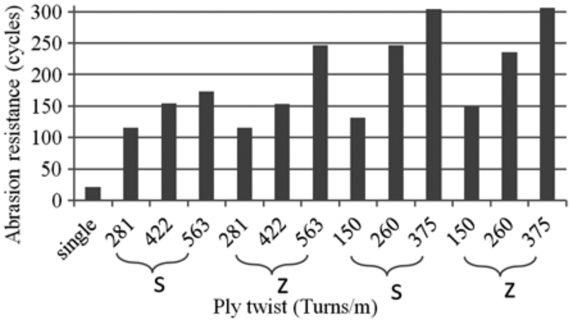

Fig. 2 — Single and plied yarns abrasion resistance

3.2 Yarn Abrasion Resistance

Figure 2 shows single and plied yarn abrasion resistance results. It is clear that plying process improves yarn abrasion resistance to a great extent, whereas irregular wraps, wild fibres and protruding fibres are embedded inside the plied yarn structure. Ply twist affects yarn abrasion resistance and differences are found statistically significant at 95% confidence level. By increasing ply twist, yarn abrasion resistance increases irrespective of ply twist direction by about 54-100% and 114-112% for 2 and 3-plied yarns respectively. This is due to the better yarn surface integrity at higher twist which reduces the number of lost fibres during abrasion cycles. Also 3-plied yarns show better abrasion resistance than 2-plied yarns due to the increase in number of fibres that contact the abrasive surface, and therefore the forces applied per each fibre are less.

3.3 Yarn Hairiness

For both 2 and 3-plied yarns, ply twist value, ply twist direction and their interaction affect the yarn hairiness and differences are found statistically significant. Figure 3 shows that after yarn plying process, the hairiness of the 2-plied yarn in z direction improves as compared to single yarn by about 2-9.3%, while the hairiness of the remaining samples is increased. It is evident that plying in Z direction which is in the same direction of the single yarn significantly improves yarn hairiness by about 15.7-27.8% and 11.9-21.9% in case of two and three plies respectively. This is attributed to hairs repression inside yarn body as more twist is added to the final plied yarn in this case.

Results also show that increasing ply twist in opposite direction of single yarn untwists some wrapper fibres in single yarn, and consequently the yarn hairiness deteriorates by about 5.9% and 8.5% for 2 and 3-plies respectively, while increasing ply twist in the same direction of single yarn twists the wrapper fibres more, and consequently the yarn hairiness improves by about 9.3% and 7.7% for 2 and 3-plies respectively.

3.4 Yarn Snarling Twist

Figure 4 shows snarling twist values for 2 and 3-plied yarns at different levels of ply twist. Results in Table 3 show that ply twist and its direction affect yarn snarling twist significantly where snarling twist increases by increasing ply twist for both 2 and 3-plied yarns. Also it is clear that plying in opposite direction of the single yarn reduces snarling twist by about 74% and 85.5% for 2 and 3-plied yarns respectively and these yarns are found almost balanced.

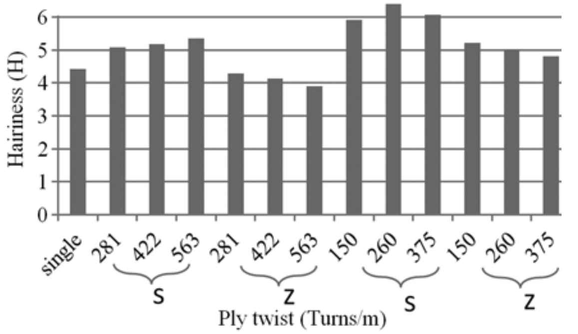

Fig. 3 — Effect of increasing ply twist value on yarn hairiness

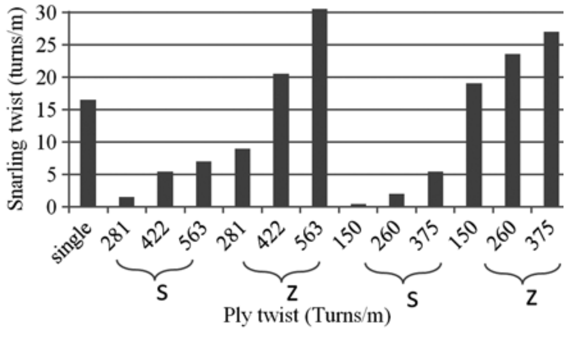

Fig. 4 — Snarling twist values for 2- and 3-plied yarns at different levels of ply twist

When ring-spun yarn is plied in opposite direction of its single end twist direction, a considerable amount of fibres in the single yarns is untwisted, causing yarn snarling twist to decrease. By increasing ply twist to a level where ply to single twist reaches a specific ratio, plied yarn becomes stable or balanced. Any further increase in ply twist results in increasing plied yarn snarling twist. For air-jet yarns, the first decrement trend is not observed as in ring yarns. Perhaps this is because, as shown in Fig. 5, the air-jet yarn twist consists of few amount of fibres (around 30%), in the form of regular and irregular wrapper having Z twist direction in addition to 70% of core parallel fibres having very few false twist or no twist in Z direction. Therefore, the core fibres have more influence than wrapper fibres and twisted quickly as ply twist factor increases.

3.5 Yarn Tensile Properties

Figure 6 shows that the plying generally improves yarn tenacity about 15.1% and this causes increase in number of fibres in yarn cross-section, which further increases the core fibres contact points and fibre-to-fibre cohesion, and reduces yarn imperfections, thin and weak places. Plying process also reduces the 2-plied yarn breaking elongation by about 8.7% and increases the 3-plied yarn breaking elongation by about 19%. The tenacity improvement (%) varies according to ply twist direction; Plying in S direction increases yarn tenacity by 21% approximately, whereas plying in Z direction increases yarn tenacity by about 9.9%. Differences in yarn tenacity and breaking elongation values due to change in ply twist, its direction and the their combined effect are statistically significant, while only ply twist and its direction effect for 3-plied yarn tenacity are insignificant.

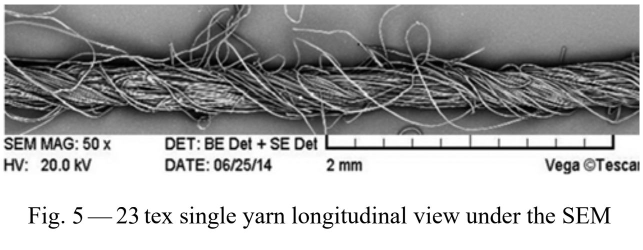

Fig. 5 — 23 tex single yarn longitudinal view under the SEM

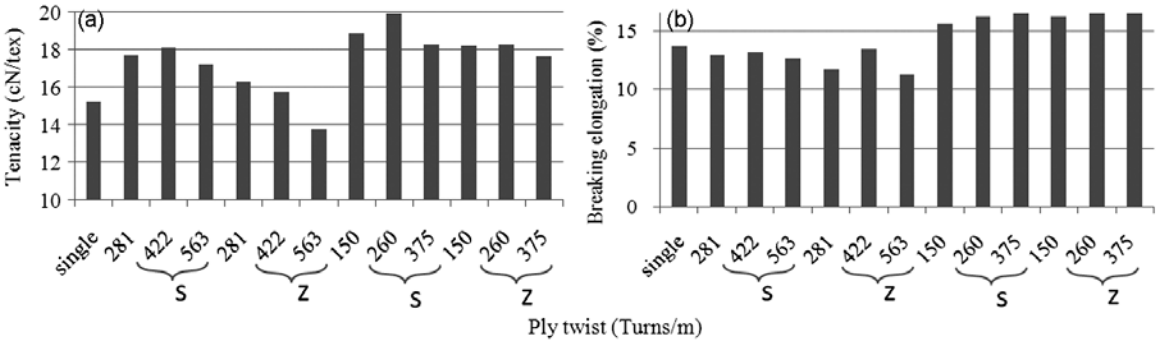

Fig. 6 — Tensile properties for 2-and 3-plied yarns at different levels of ply twist; (a) tenacity, and (b) breaking elongation

Plied yarns in S direction are stronger than corresponding plied yarns in Z direction by about 15.7% and 5% for 2- and 3-plied yarns respectively and this is because of the over twits in Z direction, which is verified by high snarling twist values that may affect the wrapping effect of the 2 and 3 strands negatively. When plying in S direction at 281 and 150 turns per meter, the wrapper fibres, which are in Z direction, start to untwist; hence they are not participating in load bearing and tenacity becomes low initially. At 422 and 260 turns per meter, they start to rotate in S direction and contribute along with core fibres in load bearing, therefore yarn tenacity is maximum. At 563 and 375 tpm the tenacity decreases because of the over-twisting and fibres obliquity increases.

On the other hand, when plying in Z direction, increasing ply twist results in excessive inserted twist, snarling twist increases, and hence yarn tenacity deteriorates particularly at higher twist levels (563 and 375 turns per meter).

4 Conclusion

In this study, the effect of plying process parameters on Rieter air-jet yarn properties is investigated. It is obvious that both ply twist value and twist direction influence plied air-jet yarn properties. Plying in the same direction of the single yarn wrapper fibres twist direction improves hairiness, while plying in the opposite direction of the single yarn wrapper fibres twist reduces snarling twist tendency and improves yarn tenacity. Results show that increasing ply twist improves yarn abrasion resistance and hairiness. This also improves yarn tenacity to an optimum level and after that the tenacity deteriorates. This optimum twist level is found at a low ply twist level for yarns plied in the same single yarn twist direction as compared to the yarns plied in the opposite direction. For seeking the best yarn tenacity, air-jet yarns should be twisted in opposite direction of their single yarn twist direction.

As the most important and unexpected finding is the significant effect of twist direction on yarn mass irregularity as well as number of neps. The reason of higher values of yarn mass irregularity and number of neps of plied yarns twisted in the opposite direction of single yarn wrapper fibres can be attributed to the remarked deterioration in geometrical structure of wrapper layers due to opening of wrapper fibres and creation of new random irregular structure. This is reflected in increasing mass unevenness of wrapper layer and in increasing total mass irregularity and neps of plied yarn when plying in the opposite direction of wrapper fibres twist.

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