

Influence of fibre length and denier on properties of polyester ring and air-jet spun yarns

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The effect of polyester fibre length and denier on hairiness, abrasion resistance, flexural rigidity, co-efficient of friction and compressional energy of air-jet and ring-spun yarns has been studied. It is observed that the yarn hand in terms of flexural rigidity and compressional energy improves by using finer fibres in air-jet yarns. Increase in fibre length decreases the yarn hairiness, abrasion damage and yarn-to-metal friction in both air-jet and ring yarns. Finer fibres decrease the hairiness and abrasion damage and increase the yarn-to-metal friction in both air-jet and ring yarns.

Keywords: Abrasion resistance, Compressional energy, Flexural rigidity, Hairiness, Polyester fibre, Torsional rigidity

1 Introduction

With the advent of air-jet spinning, the ring spinning system is facing strong competition in the medium and fine count range. However, the yarns produced on air-jet spinning system have quality attributes quite different from those of the ring yarns. Hence, it is reasonable to expect that the air-jet yarns would be used to produce products different from that of ring yarns.

Most of the information available in the literature on air-jet spinning is related to the influence of fibre and process parameters on the structure and ultimate properties of air-jet spun yarns. Information on low-stress mechanical properties of air-jet yarns and the factors influencing these properties is less extensive. However, it is the low-stress mechanical properties, which determine the fabric handle to a great extent.

Kaushik *et al.*¹ observed that the flexural rigidity of 100% viscose air-jet yarns decreases with the fine denier fibres. Bhortakke *et al.*² found that the increase in polyester fibre length increases the yarn stiffness in air-jet spinning. Coarser polyester fibres and high delivery speeds lead to the formation of greater number of hairs (0.5 mm and 2.0 mm) in the yarn. Fabric abrasion resistance is generally higher for longer polyester fibres and low delivery speeds in air-jet spinning². Fibres that are likely to form better

wrappers impart higher abrasion resistance to yarns and fabrics. According to Krause and Soliman³, the longer fibres form better wrappers than the shorter ones and, therefore, exhibit higher abrasion resistance of yarns and fabrics. Compressional energy (energy required to compress the fabric till the pressure reaches to a pre-determined level) of polyester fabrics made out of air-jet yarns is generally higher for short fibres². Chattopadhyay and Banerjee⁴ observed that the yarn-to-metal friction increases with finer yarns due to the larger area of contact between yarn and metal which is attributed to the decrease in flexural rigidity of yarn. For yarn-to-metal friction, it is only the surface characteristics of yarn that determine the frictional behaviour⁴.

The present work was aimed at studying the effect of fibre denier and length on hairiness, abrasion resistance, flexural rigidity, co-efficient of friction and compressional energy of air-jet and ring yarns spun from 100% polyester.

2 Materials and Methods

Polyester yarns of 30s and 40s counts were spun on air-jet and ring spinning systems. Polyester fibres of 40 mm and 51 mm length and 1.0-1.4 denier were used for the study. The fibre properties, counts spun and spinning system adopted are given in Table 1.

All the 16 yarn samples were tested for hairiness (number of protruding hairs having length of 3 mm and above) using Zweigle Hairiness Tester G 565,

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Table 1—Fibre denier, fibre length, count spun and spinning system

Sample No.	Fibre denier	Fibre length mm	Yarn count Ne	Spinning system
S ₁	1.0	40	30s	Air-jet
S ₂	1.2	40	30s	Air-jet
S ₃	1.4	40	30s	Air-jet
S ₄	1.2	51	30s	Air-jet
S ₅	1.0	40	30s	Ring
S ₆	1.2	40	30s	Ring
S ₇	1.4	40	30s	Ring
S ₈	1.2	51	30s	Ring
S ₉	1.0	40	40s	Air-jet
S ₁₀	1.2	40	40s	Air-jet
S ₁₁	1.4	40	40s	Air-jet
S ₁₂	1.2	51	40s	Air-jet
S ₁₃	1.0	40	40s	Ring
S ₁₄	1.2	40	40s	Ring
S ₁₅	1.4	40	40s	Ring
S ₁₆	1.2	51	40s	Ring

abrasion resistance (number of abrasion cycles to break the specimen) using Zweigle Abrasion Tester G 551, flexural rigidity using ring loop method⁵, coefficient of friction (yarn-to-metal) using Schlafhorst Reibwertwaage⁶ and compressional energy using Universal Instron Tester⁷. The hairiness was measured for a yarn length of 1000 m/sample and expressed as No. of hairs/100 m. For abrasion resistance and flexural rigidity, 20 readings/sample and for coefficient of friction and compressional energy, 10 readings/sample were taken.

The process parameters used for air-jet spinning of both 30s and 40s count yarns were: spinning speed, 150 m/min; main draft ratio, 35.7; feed ratio, 0.98; first nozzle pressure, 2.5 kg/cm²; and second nozzle pressure, 3.5 kg/cm².

2.1 Measurement of Compressional Energy

Universal Instron Tester was used to measure the lateral compression of yarns. This tester is a micro-processor controlled and load cell based instrument for determining the stress-strain behaviour of yarns and fabrics under light loads, both tensile and compression. In the compression mode, the Instron consists of two units—the actual compression unit and a control console, which consists of a computer with a printer/plotter.

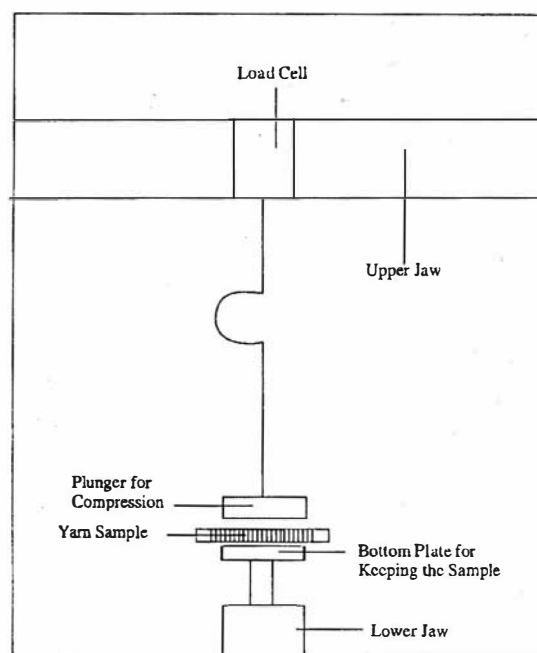


Fig. 1—Schematic diagram of Instron compression tester

In the compression unit (Fig. 1), a bottom plate of 75 mm diam. provides the space for keeping the specimen to be tested. The actual compression is done by a plunger that can move down to press the test sample. The distance between the plunger and the sample on the bottom plate is adjustable. The plunger is connected to the load cell. The plunger compresses the sample against the bottom plate. In such a test, the control circuit moves the plunger down till the load cell registers a load of 250 g (5.6 g/cm²) and then lifts the plunger up again. During the compression and decompression cycles, the load readings and the plunger position were accurately observed. An electronic integrator integrates the signals computing the work done during compression (area under the compression curve) and the work recovered during decompression (area under the decompression curve).

The initial gap T_1 between the plunger and bottom plate of the Instron is set. The plunger moves down from the set position and after compressing the sample and reaching the maximum pre-set pressure (250 g), it comes up to the initial set position. In the Instron tester, two integrators are used for the integration of W_c and W_c^1 . W_c is the area under the compression curve and W_c^1 , the area under the decompression curve. Compressional energy (W_c), energy spent during decompression (W_c^1) and

compressional resilience (R_c) were determined using the following relationships:

$$W_c = \int_{t_{\min}}^{t_{\max}} P dt$$

$$W_c^1 = \int_{t_{\max}}^{t_{\min}} P dt$$

$$R_c(\%) = \frac{W_c^1}{W_c} \times 100$$

where P is the pressure applied during compression and t , the original thickness of the specimen.

3 Results and Discussion

3.1 Effect of Fibre Properties on Hairiness and Abrasion Resistance

The effect of fibre properties on hairiness and abrasion resistance of air-jet and ring yarns is shown in Table 2.

3.1.1 Effect of Fibre Denier on Hairiness

It is observed from Table 2 that the finer polyester fibres produce yarns with less hairs for all the samples studied. Hair formation in air-jet spinning is

influenced by the number of fibre ends in unit length of yarn, the number of edge fibres being detached from the main strand and the number of detached edge fibres that fail to be properly caught by the yarn².

Fine denier polyester produces more fibre ends per unit length of the yarn but reduces protruding hairs. More fibres in the strand and the consequent greater surface contact between them may make it difficult for the edge fibres in air-jet yarns to detach from the main strand at the front roller. Moreover, due to the lower torsional rigidities of fine polyester fibres, whatever edge fibres do get detached are likely to provide a good wrapping for the core, thus binding many fibre ends which otherwise would have become protruding hairs². Hence, in air-jet spinning, the fine denier fibres produce less hairs. Between 1.4 and 1.0 denier polyester fibres, the yarn hairiness decreases by 75-80% in both 30s and 40s yarns. Between 1.4 and 1.2 denier fibres, the hairiness decrease is of the order of 50-70%. In both the cases, the decrease is significant at 99% level.

In ring yarns, as the fibre becomes finer, the hairiness decreases, the order of decrease being about 60% when the fibre denier changes from 1.4 to 1.0. In ring spinning, the fibre torsional rigidity⁸ is the most

Table 2—Hairiness, abrasion resistance, flexural rigidity, coefficient of friction and compressional energy of air-jet and ring-spun yarns

Sample No.	Fibre denier	Fibre length mm	Yarn type	Count Ne	Hairs ^a /100m	Abrasion resistance cycles	Flexural rigidity $\times 10^{-3}$ g.cm ²	Coefficient of friction (μ)	Compressional energy $\times 10^{-4}$ kg.cm
S ₁	1.0	40	Air-jet	30s	38	114.9	3.405	0.284	1.157
S ₂	1.2	40	Air-jet	30s	76	79.3	3.849	0.308	1.151
S ₃	1.4	40	Air-jet	30s	150	57.1	4.336	0.310	1.133
S ₄	1.2	51	Air-jet	30s	90	104.4	4.286	0.277	1.141
S ₅	1.0	40	Ring	30s	138	157.8	0.903	0.335	1.110
S ₆	1.2	40	Ring	30s	159	152.1	0.817	0.341	1.115
S ₇	1.4	40	Ring	30s	334	136.4	0.804	0.360	1.198
S ₈	1.2	51	Ring	30s	108	189.4	0.955	0.329	1.103
S ₉	1.0	40	Air-jet	40s	17	53.0	2.600	0.290	1.102
S ₁₀	1.2	40	Air-jet	40s	28	43.7	3.276	0.305	1.101
S ₁₁	1.4	40	Air-jet	40s	89	38.8	3.685	0.314	1.063
S ₁₂	1.2	51	Air-jet	40s	25	48.4	3.748	0.285	1.055
S ₁₃	1.0	40	Ring	40s	97	128.1	0.467	0.311	1.018
S ₁₄	1.2	40	Ring	40s	214	113.3	0.393	0.322	1.104
S ₁₅	1.4	40	Ring	40s	241	104.5	0.369	0.350	1.139
S ₁₆	1.2	51	Ring	40s	99	129.1	0.435	0.307	1.031

^aNo. of protruding fibres of 3 mm length and above

important single property contributing to yarn hairiness; fibre length and fibre fineness come next in the order of importance. When the other factors are kept constant, the fibre fineness may have a direct relationship with hairiness. For finer fibre means more fibres and hence more protruding ends in a unit length of yarn. However, coarser fibre has higher torsional rigidity and hence may cause higher number of protruding ends from the yarn structure. The actual yarn hairiness observed in this study is the result of these two opposing factors.

3.1.2 Effect of Fibre Length on Hairiness

Hairiness remains practically unaffected with the increase in fibre length from 40 mm to 51 mm in 30s and 40s air-jet yarns. In ring yarns, hairiness decreases with the increase in fibre length, the order of decrease being 30-55% in both 30s and 40s yarns. This is as per the expected lines, since the longer fibres decrease the number of fibre ends in a given length of yarn.

3.1.3 Effect of Fibre Denier and Length on Yarn Abrasion

In air-jet yarns, the abrasion resistance increases with the decrease in fibre denier and increase in fibre length. Fibres that are likely to form better wrappers in air-jet yarns generally lead to higher abrasion resistance². Longer and finer fibres^{3,9} form better wrappers and hence exhibit increased values of abrasion cycles in air-jet yarns.

The behaviour of ring yarns on abrasion is similar to that of the air-jet yarns. In ring yarns, the longer and finer fibres exhibit higher abrasion resistance, the increase is less pronounced in 40s yarns as compared to that in 30s yarns. While using longer fibres, there is a greater length of overlapping of fibres in yarns, leading to better consolidation and fibre cohesion which prevent the plucking action of the abradent on the surface fibres¹⁰. Higher abrasion resistance with finer fibres is due to the greater number of fibres in the yarn cross-section and consequently yarn uniformity¹⁰. The per cent improvement/deterioration in abrasion resistance with the corresponding change in fibre properties is shown in Table 3.

With the decrease in fibre denier from 1.4 to 1.0, there is an improvement in yarn abrasion resistance which is of the order of about 100% in 30s air-jet, 37% in 40s air-jet, 16% in 30s ring and 23% in 40s ring yarns. All these improvements are significant at 95% level. However, the influence of fibre length on abrasion is observed only in 30s air-jet and ring yarns

Table 3—Change in fibre properties and the corresponding change in yarn abrasion resistance

Spinning system	Count Ne	Change in fibre properties ^a	Corresponding change in abrasion resistance, %
Air-jet	30s	Fibre denier (-29%)	+100
		Fibre length (+27.5%)	+32
	40s	Fibre denier (-29%)	+37
		Fibre length (+27.5%)	+11
Ring	30s	Fibre denier (-29%)	+16
		Fibre length (+27.5%)	+24
	40s	Fibre denier (-29%)	+23
		Fibre length (+27.5%)	+14

for every 1% increase in length (between 40 mm and 51 mm) yarn abrasion improves by 1.2% and 0.9% in air-jet and ring yarns respectively. No significant influence of fibre length on yarn abrasion was observed in 40s air-jet and ring yarns.

3.2 Effect of Fibre Properties on Flexural Rigidity and Coefficient of Friction

The effect of fibre properties on flexural rigidity and coefficient of friction of air-jet and ring yarns is shown in Table 2.

3.2.1 Effect of Fibre Denier on Flexural Rigidity

Air-jet and ring yarns show different trends as far as flexural rigidity is concerned. In air-jet yarns, as the fibre denier decreases, the flexural rigidity decreases. On the other hand, in ring yarns, fibre denier does not have any significant influence on flexural rigidity.

In air-jet spinning, when the finer fibres are used, although the number of fibres per cross-section is increased (when spun under identical conditions), the number of wrappings remains the same i.e. the ratio of wrapping fibres to core fibres becomes lower¹¹ which could be expected to make the yarn less stiff and more flexible. In this study, for every 1% decrease in fibre denier, the flexural rigidity decreased by 0.7-1.0% in air-jet yarns.

In ring spinning, the flexural rigidity of yarn is the combined effect of the flexural rigidity of individual fibres and the total number of fibres in yarn cross-section⁵. With the increase in fibre denier from 1.0 to 1.4, one would expect an increase in fibre flexural rigidity. However, when the fibre denier increases from 1.0 to 1.4, the number of fibres in yarn cross-section gets reduced by about 30% in both 30s and 40s counts. The resultant flexural rigidity in ring yarns is due to the combined effect of these two opposing factors (increase in fibre flexural rigidity and decrease in number of fibres in yarn cross-section). Between 1.4 and 1.0 denier, the flexural rigidity remains statistically same in ring yarns.

3.2.2 Effect of Fibre Length on Flexural Rigidity

In air-jet yarns, when the fibre length is more, the yarn structure could be expected to become more compact due to the better wrappers and hence higher flexural rigidity is normally expected. In ring yarns, better consolidation of the yarn structure is expected with longer fibres due to the greater length of overlapping of fibres in the yarn. This, in turn, may result in higher values of flexural rigidity. However, flexural rigidity does not change significantly with the increase in fibre length from 40 mm to 51 mm in both air-jet and ring yarns. Studies with some more fibre lengths are required to arrive at the trend of change in flexural rigidity with fibre lengths.

3.2.3 Effect of Fibre Denier and Length on Yarn Friction

In ring yarns, the co-efficient of friction decreases with the decrease in fibre denier, the decrease being 7-10% with the change in denier from 1.4 to 1.0. This is fully explained by the corresponding increase in the flexural rigidity of the respective yarns.

In air-jet yarns, the co-efficient of friction is low for finer fibres (Table 2) in spite of the fact that lower fibre weight decreases the flexural rigidity of the yarn. Therefore, higher value of coefficient of friction could be expected. This anomaly could be due to the decrease in air-jet yarn hairiness when the fibre becomes finer. According to Chattopadhyay *et al.*⁴, surface hairiness is an important parameter influencing the yarn-to-metal friction. It appears that in air-jet yarns, while decreasing the denier of the fibre (within the range covered), the attendant decrease in yarn hairiness overrides the effect of reduced flexural rigidity and the ultimate yarn tends to have lower

coefficient of friction. However, this aspect needs further explanation using fibres of higher denier.

In both air-jet and ring yarns, the increase in fibre length from 40 mm to 51 mm decreases the yarn-to-metal friction, the order of decrease being 10% in air-jet and 5% in ring yarns. This is attributed to the increase in flexural rigidity. When the yarn is more stiff, one would expect a reduction in area of contact between yarn and guide which, in turn, will lower the friction coefficient⁴.

3.3 Effect of Fibre Properties on Compressional Energy

The effect of fibre properties on compressional energy (energy required to compress the yarn specimen till the pressure reaches to 2.5 g/cm²) of air-jet and ring yarns is shown in Table 2.

3.3.1 Effect of Fibre Denier on Compressional Energy

In air-jet spinning, when the finer fibres are used, the ratio of wrapper fibres to core fibres decreases which is expected to make the yarn relatively bulkier¹¹. The higher bulkiness of yarn from finer fibres may be expected to exhibit higher compressional energy. However, in this study, compressional energy is found statistically same for 1.4 and 1.0 denier fibres. Further studies with fibres of higher denier may be required to confirm the trend.

In ring spinning, with the decrease in fibre weight, the compressional energy tends to decrease in both the counts. This agrees well with the findings of Jayachandran¹² and Peer Mohamed¹³. Compressional energy in ring yarn mainly depends on yarn packing. If the fibres are closely packed in a yarn, further consolidation is hardly possible and compressional energy will be relatively low for these yarns as compared to that for the yarns with loose packing. When finer fibres are used, the yarns will have higher packing and that could be the reason for the decrease in yarn compressional energy with fine denier fibres. For every 10% decrease in fibre weight, the compressional energy gets reduced by 3-4%.

3.3.2 Effect of Fibre Length on Compressional Energy

In air-jet spinning, the longer fibres form better wrappers. This is expected to make the yarn less bulky and due to this, those yarns will have less scope for compression. In ring yarns, the longer fibres provide compact packing and, therefore, these yarns are also expected to show less compression under a given load.

In this study, for every 10% increase in fibre length, the compressional energy gets decreased by 1.5% and 2.5% in 40s air-jet and ring yarns respectively. This decrease is statistically significant even at 99% level. However, in 30s count, compressional energy does not vary with the variation in fibre length in both air-jet and ring yarns. It appears that the effect of fibre length on compressional energy is a function of yarn count and the studies with some more counts may be required to arrive at the minimum number of fibres in yarn above which the fibre length predominantly influences compressional energy.

4 Conclusions

4.1 In air-jet and ring-spun yarns, long hairs (≥ 3 mm) decrease with the decrease in fibre denier, the decrease being 75-80% in air-jet yarns and 60% in ring yarns with the change in fibre denier from 1.4 to 1.0. With the increase in fibre length from 40 mm to 51 mm, the hairiness remains unaffected in air-jet yarns but decreases by 30-55% in ring yarns.

4.2 Longer and finer fibres exhibit higher abrasion resistance in air-jet and ring yarns. With the decrease in fibre denier from 1.4 to 1.0, yarn abrasion improves by 40-100% in air-jet yarns and 15-25% in ring yarns. The yarn abrasion improves by 1.2% and 0.9% in air-jet and ring yarns respectively for every 1% increase in fibre length within the range of fibre length studied.

4.3 Air-jet and ring yarns show different trends for flexural rigidity. In air-jet yarns, decrease in fibre denier decreases the flexural rigidity, whereas in ring yarns, fibre denier does not have significant influence on flexural rigidity. Similarly, flexural rigidity does not get altered with the change in fibre length.

4.4 With the change in fibre denier from 1.4 to 1.0, the yarn-to-metal friction decreases by 8% and 7-10% in air-jet and ring yarns respectively. With the increase in fibre length from 40 mm to 51 mm, the

yarn-to-metal friction decreases by 10% and 5% in air-jet and ring yarns respectively.

4.5 Compressional energy remains statistically same for different deniers in air-jet yarns. In ring yarns, for every 10% decrease in fibre weight, the compressional energy decreases by 3-4%. For every 10% increase in fibre length, the compressional energy decreases by 1.5% and 2.5% in air-jet and ring yarns respectively.

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