Effect of Spindle Speed on the Properties of Ring Spun Acrylic Yarn

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This paper deals with the effect of twist multiplier and spindle speed on the properties of Ring spun acrylic yarn. The results show that at 20 tpi the 18.5 tex yarn gives highest tenacity and lowest total imperfection. Increase of spindle speed results the increase ion yarn tenacity, initial modulus, work of rupture, packing coefficient and total imperfections upto spindle speed 18 000 rpm whereas mass irregularity remains unchanged. Hairiness Index does not follow any relationship with the increase in spindle speed.

Keywords: Acrylic yarn; Imperfections; Mass irregularity; Packing coefficient; Spindle speed; Work of rupture

NOTATION

d : yarn diameter, cm

d_b : bulk density, gm/cc

d_y : yarn linear density, tex

ϕ : packing coefficient

ρ : fibre density, gm/cc

INTRODUCTION

With the advent of modern high speed ring frames, spindle speed has increased phenomenally in recent years. An early study of SITRA has shown that increase in spindle speed from 10 000 rpm to 13 000 rpm does not affect yarn evenness, thick and thin places and neps but there is an increasing trend in occurrence of thin places. Yarn irregularity shows a trend of variation with increases in spindle speed. Yarn hairiness also increases with the increase in spindle speed but it decreases if a heavier traveller is used for the same spindle speed. So spindle speed is one of the important factors which affects the yarn properties, *ie,* tensile strength, mass irregularity, imperfections and yarn hairiness.

The article is the outcome of a study on the effect of spindle speed at a range of 10 000 rpm to 18 000 rpm on the aforesaid yarn properties having 100% non-shrinkable acrylic yarn of 1.5 denier fibre fineness and 51 mm staple length.

Thick and thin places in the yarn can never be completely eliminated even with optimum machinery conditions. These imperfections as measured by Uster Irregularity Tester (UT-3) are known to fairly responsible, though they possess large variability. Against this background, the main objective of the study was to investigate the effect of spindle speeds on various physical properties of the yarn with optimum twist level at 20.3 tpi.

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LITERATURE REVIEW

Effect of spindle speed on yarn irregularity is observed by many workers. Audivert, *et al*[1] observed that for an increase in spindle speed range of 6 000 rpm to 12 000 rpm, there is a reduction in cotton yarn irregularity due to shuffling and randomisation of fibres within the drafting field. This conclusion is based on their argument on the increase in the ratio of dynamic and static friction with increase in drafting speed. Their report, however, did not include the results on irregularity obtained with different spindle speeds.

Dutta, *et al*[2] observed that for acrylic spun yarn the irregularity generally decreases with increase of spindle speed, but after a certain spindle speed the irregularity of the yarn gradually increases. In their study, it is pointed out that the increase in spindle speed from 10 000 rpm to 14 000 rpm results the decrease in yarn irregularity but beyond 15 000 rpm or above irregularity increases.

Shanklin[3] noticed a linear increase in irregularity with increase in drafting speeds. He, however, does not offer any reason for this behaviour.

Sengupta, *et al*[4] observed that with the polyester fibres, an increase in drafting speeds in terms of spindle speeds, brings about a corresponding increase in Uster (U_m %) value. With viscose fibres, however, increase in drafting speed brings about a progressive decrease in Uster (U_m %) value. The explanation given by them is that the extensibility of viscose fibres is much lower than that of the polyester fibres. With the low extensibility showed the improvement in regularity due to the increase in the ratio of dynamic to static friction brought about by increase in drafting speed. That means fibres or cluster of same fibres, seem to behave independently.

Sengupta and Kapoor[5] showed that in case of cotton yarn, both for single and double apron system of drafting, the Uster irregularity decreases with the increase in spindle speed.

Many workers noticed that the effect of spindle speed on yarn imperfections. Ratnam, *et al*[6] also observed that yarn imperfections do not show any appreciable differences in their three levels of speeds (low, high and medium).

Govindarajulu, *et al*[7] have remarked that with the increase in spindle speed (from 10 000 to 13 000), thick places in yarn have increased in 40 s and above count of yarn, but have shown a decrease in 20 s count of yarn. The thick places, however, have not shown any definite trend, whilst the neps in yarn are not altered by the increase in spindle speed. The highest the spinning tension at higher spindle speed resulting thin places in the yarn.

Yagyu and Kuroda[8], in their work on acrylic spun yarn observed that the thick places reduce slowly with the increase in spindle speed upto about 15 000 rpm but beyond this the thick places gradually increase. It is also followed for the thin places in the yarn. But their observation on neps noticed that neps are gradually increasing with the increase of spindle speed.

Gubler, *et al*[9] have remarked that in favour of individual drive it is possible to quote that the lower incidence of thread breaks, reduce thick and thin places, less harmonic tension variation due to improved spindle centring, smooth power transmissions, maintenance and servicing are reduced.

Dutta, *et al*[10] have observed the effect of spindle speed on yarn imperfections and power consumption by the developed ring traveller.

Gupta, *et al*[11] prepared a set of equations which has been derived in order to estimate minimum possible end breakage rate on ring frame. Yarn test data normally available in mills are used in the equations, including yarn count, CSP, lea count CV, uniformity and frequency of thin and thick places. The equations gave estimates very close to the observed end breakage rate over a wide range of count, yarn quality and spindle speed.

Sala, *et al*[12] made a statistical and mathematical analysis of spinning acrylic fibres in a woollen system comprising two passages on intersecting gill boxes, rubbing — apron drafting and high draft spinning. The analytical method facilities optimisation of the whole process by simultaneously varying four parameters and minimising three types of count irregularity. Minimum conditions are varied according to the type of irregularity, the optimum cycle is calculated from an average of such conditions.

Kleinhansl, *et al*[13] have investigated on a ring frame with spinning rings on air bearing and balloon limit rings with low rates lubrication have shown that yarn quality is not significantly impaired by raising the spinning speed to 18 000 rpm (47 m/sec) for polyester/cotton (50:50 and 67:33) yarn but observed decreasing trend with the increasing spindle speed.

The increase (2% to 3%) of hairiness observed with every 1% increase in spindle speed by Ratnam, *et al*[6] for 34 s and 35 s carded yarn but for combed yarn no such effect was prominent. In case of polyester-cotton blend, there is a marked increase (3 times to 4 times) in hairiness observed.

Govindarjulu, *et al*[7] observed that yarn hairiness increases with the increase in spindle speed, but it decreases if a heavy traveller is used for the same spindle speed.

Krishnaswamy, *et al*[14] have explained and examined the reasons for generation of hairiness in polyester, acrylic and polyester blended yarns with the increase in spindle speed. This included spindle misalignment and traveller wear during ring spinning. The use of a ring cleaner/lubricant helps to reduce hairiness by 50%.

Purandre, *et al*[15] have found that the increase in spindle speed from 8 000 rpm to 13 000 rpm did not cause any significant change in the level of hairiness of polyester-cotton yarns.

Viswanathan, *et al*[16] have examined the effect of various yarn characteristics on hairiness. Yarns with a wider variations of a linear density are selected for a study of the effect of the physical properties on hairiness of cotton yarn. It is concluded that the yarn diameter, single yarn strength and evenness are related independently to the hairiness indices.

Werkstatter[17] observed in his detailed study on hairiness on yarn. Theoretical relationships between handle, softness, bulk and gloss with hairiness, method of spinning, fibre type and mechanical processing condition influence the yarn structure. Ring spinning parameter (crown) and twisting parameters cause more or less hairy yarns.

Barella and Manich[18] studied the influence of the spinning process, yarn linear density and fibre properties on the hairiness of ring spun yarn and rotor spun yarns.

Hattemschwiter, *et al*[19] give general comments on the subjects of yarn hairiness are made and study examples of what influences this hairiness are provided from research work and industry.

The increase in skein strength of cotton yarn with the increase in drafting speed in terms of spindle speed in the range of 6 000 rpm to 12 000 rpm was observed by Audivert, *et al*[1].

Sengupta and Kapoor[5] observed the increase in breaking strength of yarn with the increase in spindle speed.

Ratnam, *et al*[6] remarked that single yarn strength and elongation do not show any greater differences in low, medium and high speed levels studied for different counts of carded, combed, hosiery cotton yarn and polyester-cotton blended yarns.

Tagya and Karoda[8] observed the increased in yarn strength significantly with the increase of spindle speed from 10 000 rpm to 18 000 rpm of acrylic spun yarn.

Newton and Shanklin[20] observed a decrease in skein strength with increase in drafting speed. Shanklin later reported an increase in skein strength with spindle speed in the range of speed from 8 000 rpm to 14 000 rpm.

MATERIAL AND METHODS

1.5 Denier and 51 mm staple length non-shrinkable modacrylic fibres having 27 cN/tex average single fibre tenacity were used for the preparation of the samples.

Yarn Preparation

Shirley miniature laboratory model flat card, Platt-sacowell miniature draw-frame, LF 1400 speed frame and G5/1 ring frame were used sequentially for the preparation of the samples. Five different samples of yarn having nominal linear density of 20 tex with 20.3 tpi were prepared by varying spindle speed from 10 000 rpm to 18 000 rpm.

Tensile Testing

Zwick Universal Tensile Tester with a testing speed of 300 m/min with a test length 50 cm was used for the testing of tensile properties. Average of 25 tests for breaking load and elongation value were taken for the calculation of tenacity and breaking extension of the samples. Initial modulus value was calculated from the load value at 1% extension. Work of rupture was given by the tester at the end of the test.

Evenness, Imperfections and Hairiness Testing

Uster Evenness Tester (UT-3) was used for the testing the evenness, imperfections and hairiness index with a testing speed of 400 m/min for one minute. Average of three tests were taken for final results.

Packing Coefficient

The yarn diameter of each sample yarn was measured by using WILD-M3Z Kombistereo microscope with a magnification 10 X. Average of 100 observations were taken for the measurement of diameter of the yarn and packing coefficient of each samples was calculated from the following relation:

$$\phi = \frac{d_b}{\rho} = \frac{d_y \cdot 4.10^{-5} / \pi d^2}{\rho}$$

RESULTS AND DISCUSSION

Effect of Spindle Speed on Yarn Strength

With the increase in spindle speed there is an increasing trend of yarn tenacity as shown in the Table 1. As the spindle speed increases, the randomisation of the fibres in the yarn gradually increases which causes better parallelisation of fibres along the axis in the yarn and hence increases the load shearing capacity of the fibres. At higher spindle speed, packing coefficient is higher resulting higher compactness. Higher the compactness of the yarn structure better is the fibre migration within the yarn and hence higher is the interlocking structure of fibres within the yarn. As a result the yarn strength rises with the increase in spindle speed of the ring frame.

Effect of Spindle Speed on Initial Modulus, Work of Rupture and Packing Coefficient

The initial modulus gives a measure of force required to produce a small extension. A high inextensible yarn will have a low modulus. Table 1 shows that there is an increasing trend of initial modulus with the increase in spindle speed. Yarn produced at higher spindle speed yields higher tenacity and much compact causes low extensibility of the yarn. Work of Rupture (WOR) or toughness of the yarn gives an indication of energy requirement to break the specimen. Experimental result shows that the gradual increase in spindle speed results

Table 1 Effect of spindle speed on the physical properties of ring spun yarn

Spindle speed, rpm	10 000	12 000	14 000	16 000	18 000
Linear density, tex	17.94	18.86	18.84	17.52	18.84
Tenacity, cN/tex	13.69	14.69	14.97	15.18	15.91
Strength, CV%	7.67	10.37	9.54	11.61	10.39
Initial modulus, cN/tex	235	255	274	342	351
Specific work of	0.44	0.57	0.64	0.79	0.89
Rupture, mJ/tex-m					
packing coefficient	0.828	0.812	0.835	0.857	0.895
Mass irregularity, U_m %	12.09	12.00	11.18	12.17	12.39
Imperfections/km					
Thick places (+ 50%)	17	34	15	33	47
Thin places (– 50%)	28	29	25	38	57
Neps (+ 200%)	43	22	39	41	51
Total imperfections	88	85	69	112	115
Hairiness index	4.32	4.34	4.67	3.92	3.88

the gradual increase of WOR value. The WOR gives the combined effect of tenacity and breaking extension of the material. As the packing coefficient of the yarns increases with the increase in spindle speed, therefore it results the more compact structure of the yarn. So more compact structure requires more energy to break the specimen and for this reason the WOR value increases with the increase in the spindle speed as indicated in the Table 1. At higher spindle speed the better randomisation, regular straightening and best migration of fibres takes place. The migrating fibres create an interlocked structure of the fibre in the yarn resulting better compactness and hence, packing of the fibres in the yarn is better at high spindle speed.

Effect of Spindle Speed on Yarn Mass Irregularity

Table 1 shows that the yarn mass irregularity (U_m %) decreases with the increase of spindle speed from 10 000 rpm to 14 000 rpm. This is due to increase of the ratio of dynamic to static friction, causing the probability of a floating fibres moving at intermediate velocity increases. The effect of intermediate velocity of the fibres in the drafting zone is to suffle or randomise the fibres which would result in a decrease of irregularity of ingoing sliver. But it is also observed from the Table 1 that beyond 14 000 rpm of spindle speed the mass irregularity of the yarn is gradually increases. At the higher spindle speed, the drafting force becomes higher. So, at the higher drafting force the average fibre tension at the front roller will cause an increase in the dragging out of the sliver into the front roller-nip. This dragging out of undrafted sliver into the nip of the front roller and if subsequent retreat under the action of internal elastic force would cause an increase in the irregularity that would offset the randomisation effect of the speed.

Effect of Spindle Speed on Yarn Imperfections

It is observed from the Table 1 that the total imperfections is minimum at 14 000 rpm of the ring frame spindle and beyond this speed the total imperfections increases gradually with the increase in spindle speed. At 14 000 rpm even drafting takes place, because of randomisation or resulting of fibres due to increase of the ratio of dynamic to static friction which is discussed earlier. At the high spindle speed, even drafting take place due to dragging out of sliver at the front roller-nip, resulting higher imperfections.

Effect of Spindle Speed on Yarn Hairiness Index

There is no appreciable change in hairiness index value of the yarns. Table 1 shows that there is small change of hairiness index with the change of spindle speed though the difference of increasing hairiness index is marginal which is not established appreciably the reason may be due to high centrifugal force acted on the yarn which gives more outward force of the tail end of the fibre causes formation of more protruding ends on the yarn surface.

CONCLUSIONS

1. The yarn tenacity, initial modulus, WOR and packing coefficient of the yarn gradually rises with the increase in spindle speed from 10 000 rpm to 18 000 rpm.

2. Yarn mass irregularity and total imperfections decrease spindle speed from 10 000 rpm to 14 000 rpm beyond this mass irregularity increases.

3. Hairiness index of the yarn does not follow any appreciable change with the increase in spindle speed.

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