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Tensile failure of blended spun yarns under dynamic condition: Part I –Yarn failure during warping

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The failure behaviour of polyester/viscose blended ring, rotor and air-jet spun yarns has been studied on the basis of fibre failure coefficient, yarn broken end configuration and failure zone length. The failure behaviour of spun yarns under warping process is simulated in the dynamic tensile tester. The tensile failure behaviour of ring, rotor and air-jet yarns are found to be different owing to their difference in fibre consolidation mechanism. The yarn failure is observed to be more and more dominated by fibre slippage once moving from ring to rotor and finally to air-jet yarns. The study also reports mathematical modeling of spun yarn failure behaviour during warping process. The mathematical model indicates that the spun yarn failure is non-linearly related to yarn structural parameters.

Keywords: Blended spun yarn, Fibre failure coefficient, Tensile failure, Warping failure

1 Introduction

The spun yarn failure behaviour under static condition explains the tensile failure behaviour of yarns sequentially connected with certain distance gap for a longer length. This failure behaviour possesses a close resemblance with the failure behaviour of yarns inside fabric during its tensile failure. This is mainly due to the similarity in the method of assessment of tensile failure under static condition and that occurred during the fabric end uses. The yarns are transported in a continuous manner during the post spinning process like winding, warping and weaving. Hence, it is expected that the failure behaviour of yarns under static condition and during continuous running will differ due to different conditions during yarn failure. Further, static tensile failure is being assessed over a short gauge length. Hence, the behaviour of yarn failure under such condition could not be exactly replicated for spun yarn failure behaviour during its running condition in subsequent machines, because the occurrence and nature of weakest places measured under static and dynamic conditions are quite different and therefore, their failure behaviour is also going to be different.

Spun yarn failure under dynamic conditions such as winding, warping, weaving and knitting decides the efficiency of these processes and subsequently, the quality of output product. The study of yarn failure behaviour under such dynamic conditions imposes several constraints and challenges. Slodowy and Rutkowska[1] developed the method to differentiate the behaviour of continuity loss under dynamic conditions of the longitudinal loading of a loose linear fibre product (load-elongation behaviour), which occurs by means of fibre breakage and fibre slippage. They claimed that the twist of product has an essential influence on the products strength under dynamic loading. Ishtiaque *et al.*[2] studied the dynamic failure behaviour of carded and combed cotton yarns of various counts with three levels of twist multiplier made from cotton. The spun yarn failure was studied in terms of the broken end configuration. However, the real behaviour of spun yarn failure under dynamic conditions is unexplored.

There are many reported literature on warp breaks and the warp yarn behaviour in weaving process[3-6], but the warping preparation, which is a major contributor towards the ends breakage rate in weaving is rarely discovered. The latest reported literature on yarn break in warping process has explored the effect of blend ratio, fibre type, yarn twist and yarn count on it[7]. However, mechanism of yarn failure in warping is never explored. Therefore, in this study, an attempt has been made to investigate the warping failure behaviour of blended yarns. The overall objective of this reported work is to characterize the failure behaviour of spun yarns under simulated conditions of warping made on different technologies.

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2 Materials and Methods

Viscose and polyester fibres were used and their detailed specifications are mentioned in Table 1.

2.1 Preparation of Samples

Viscose and polyester fibres were spun to produce polyester/viscose blended yarns of different fibre proportions (0/100, 33/67, 50/50, 67/33, 100/0) on ring, rotor and air-jet spinning systems. The nominal counts of yarns was 22^s Ne. The spinning parameters used were those considered by commercial spinners, based on their experience with each of the spinning systems. The twist multipliers (TM in cotton system) for ring, rotor and air-jet spun yarns were 2.8, 4.2, and 4.2 respectively. The tracer fibers were mixed before opening in the blow-room in such a proportion, to have an average of 6 tracers of different colours in a given yarn cross-section. The six different colours selected for tracer fibre preparation were red, green, orange, violet, black and blue with shades well visible when the yarn was observed under a projection microscope by immersing it in benzyl alcohol solution. The mix ratio of polyester- and viscose-tracer fibres was as per the blend ratio of blended yarns, e.g. 4:2 ratio was maintained for the 67/33 polyester/viscose yarns[8].

2.2 Measurement of Yarn Structural Parameters

The yarn structural parameters were measured utilizing the tracer fibre technique. The representative image of a tracer fibre in spun yarn is shown in Fig. 1.

The measurement of yarn structural parameters [helix angle, yarn diameter, fibre extent, fibre overlap index(FOI), migration parameters] and fibre properties (tenacity, elongation and cohesiveness) have already been reported in our earlier papers[8-10].

Table 1— Fibre properties

Fibre parameter	Test method	Polyester	Viscose
Fibre denier	ASTM D-1577: 1996	1.40 (8.5)	1.52 (12.2)
Breaking strength, cN	ASTM D-3822: 2001	8.30 (9.0)	3.10 (12.1)
Tenacity cN/tex	ASTM D-3822: 2001	53.46 (8.3)	18.45 (8.3)
Breaking elongation, %	ASTM D-3822: 2001	19.8 (27.5)	20.1(12.6)
Fibre modulus cN/tex	ASTM D-3822: 2001	338.4 (28.9)	291.6 (24.8)
Crimps, % (grey)	Vibrotex	13.69 (36.83)	9.67 (32.22)
Crimps, % (dyed)	Vibrotex	2.61 (59.86)	9.60 (42.98)

Values in parentheses indicate CV%.

The consolidated structural parameters of ring, rotor and air-jet spun blended yarns are presented in Table 2.

2.3 Measurement of Yarn Failure Parameters

The broken ends were tried to collect by running the warping machine. However, some practical limitations are encountered in collecting the undistorted broken ends. The disposition of fibres gets disturbed when the end is wrapped around the beam or abraded against the floor. The inertia effect of motion forces the yarns to move to some distances after the yarn breaks. This movement of yarn either wraps the yarn into the warper beam or abrades it into the floor, and in both the cases the exact disposition of fibre during break was altered. Hence, the failure studied was carried out under simulated conditions in CTT instrument (Dynamic Tensile Tester, Lawson-Hemphill).

The detailed process for the evaluation of dynamic load in CTT instrument is reported in our earlier publication[4]. For the study of spun yarn failure under simulated warping condition, the spun yarns were transported under constant tension (5 cN higher than dynamic load) at the standard testing speed of 40 m/min and the broken ends were collected. Forty (40) numbers of broken ends for each yarn were collected for this specific study.

The method of estimating percentage of broken and slipped fibres is reported by Ghosh *et al.*[11]. The representative image of yarn broken ends for explaining the failure mechanism is shown in Fig. 2. The classification of yarn broken ends into sharp, tapered and slipped was carried out using the procedure as mentioned by Ishtiaque *et al.*[2] (Fig. 3).

The fibre failure coefficient (C_f) is defined as the ratio of proportion of fibre slip to proportion of fibre break in the yarn, calculated using the following equation:

$$\text{Fibre failure coefficient } (C_f) = \frac{\text{Proportion of fibre slip}}{\text{Proportion of fibre break}} = \frac{n_2}{n_1} = \frac{n - n_1}{n_1}$$

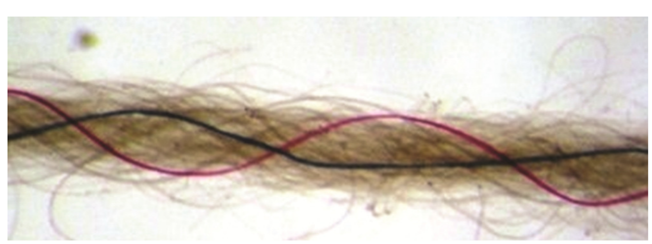

Fig. 1 — Tracer fibres in spun yarn

Table 2 — Structural parameters of ring, rotor and air-jet yarns

Blend	SIC	FOI	MFP	RMSD	MMI	HA	YD	NOF
Ring yarn								
Polyester	0.708	0.54	0.433	0.227	0.610	14.21	266.14	177.98
67/33 P/V	0.689	0.53	0.452	0.245	0.605	15.80	255.01	168.83
50/50 P/V	0.686	0.52	0.461	0.251	0.608	15.53	247.04	163.00
33/67 P/V	0.703	0.53	0.469	0.275	0.609	14.49	236.73	169.09
Viscose	0.686	0.50	0.485	0.264	0.587	15.30	229.88	155.09
Rotor yarn								
Polyester	0.465	0.44	0.321	0.218	0.883	24.51	304.42	162.96
67/33 P/V	0.445	0.38	0.343	0.245	0.853	28.55	297.52	174.66
50/50 P/V	0.451	0.42	0.355	0.252	0.868	27.32	271.07	171.00
33/67 P/V	0.454	0.41	0.350	0.258	0.8730	26.63	254.19	176.42
Viscose	0.450	0.40	0.379	0.224	0.776	27.67	244.34	162.66
Air-jet yarn								
100Polyester	0.778	0.65	0.389	0.252	1.142	8.50	244.91	163.22
67/33 P/V	0.767	0.59	0.397	0.288	1.129	11.93	236.14	175.88
50/50 P/V	0.770	0.60	0.403	0.298	1.135	11.38	212.69	171.68
33/67 P/V	0.778	0.62	0.413	0.302	1.139	9.65	206.79	176.67
Viscose	0.776	0.63	0.426	0.279	1.117	9.81	196.44	159.24

SIC—spinning-in-coefficient, FOI—fibre overlap index, MFP—mean fibre position, RMSD—root mean square deviation, MMI—mean migration intensity, HA—helix angle, YD—yarn diameter, NOF—number of fibres in yarn cross-section, P—polyester and V—viscose.

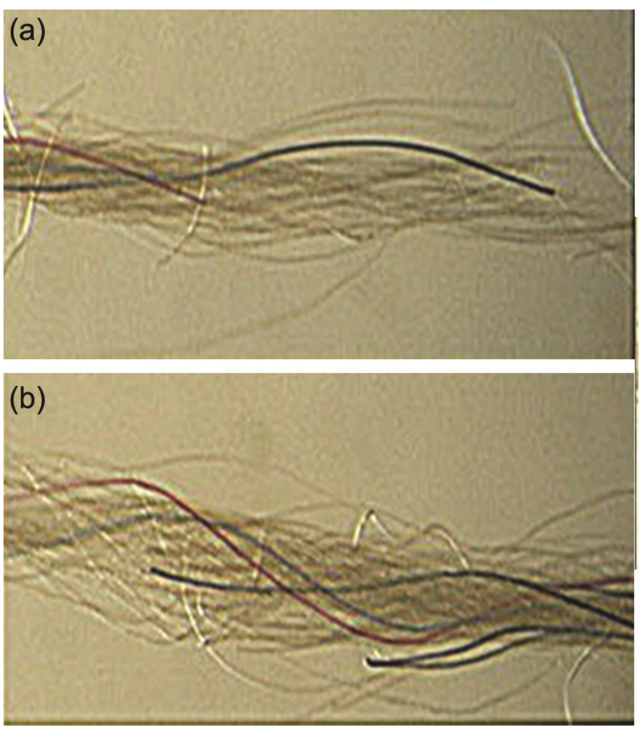

Fig. 2 —Yarn broken ends carrying tracer tracer fibres (a) left posotion of broken end, and (b) right position of broken end

where n is the total number of fibres in the yarn failure zone; n_1, the number of broken fibres in the failure zone; and n_2, the number of slipped fibres in the failure zone. If the value of C_f is higher than one, it indicates that fibre slippage dominates over fibre break, and if the value of ratio is less than one, then fibre breakage dominates over fibre slip. Further, if the value of fibre failure coefficient decreases; it indicates that the influence of fibre breakages is dominating over fibre slip, and increasing trend of fibre failure coefficient influences domination of fibre slippage over fibre breakages.

3 Results and Discussion

3.1 Fibre Failure Coefficient

The results of fibre failure coefficient (C_f) clearly indicate that the value of C_f decreases for ring yarns with the decrease in polyester content in the blended yarns (Table 3). But the fibre failure coefficient value is found always higher than one, indicating that the polyester component is contributing more towards fibre slippage. Further, it is observed that the value of fibre failure coefficient for viscose component decreases with the increase in viscose content in yarn; however, the value of fibre failure coefficient is always lesser than one, indicating that the viscose fibre is contributing more towards fibre breakage. The results of the average value of both the components clearly show that the value of fibre failure coefficient decreases with the increase of viscose content in the blended yarns; but the value of fibre failure coefficient is found more than one up to

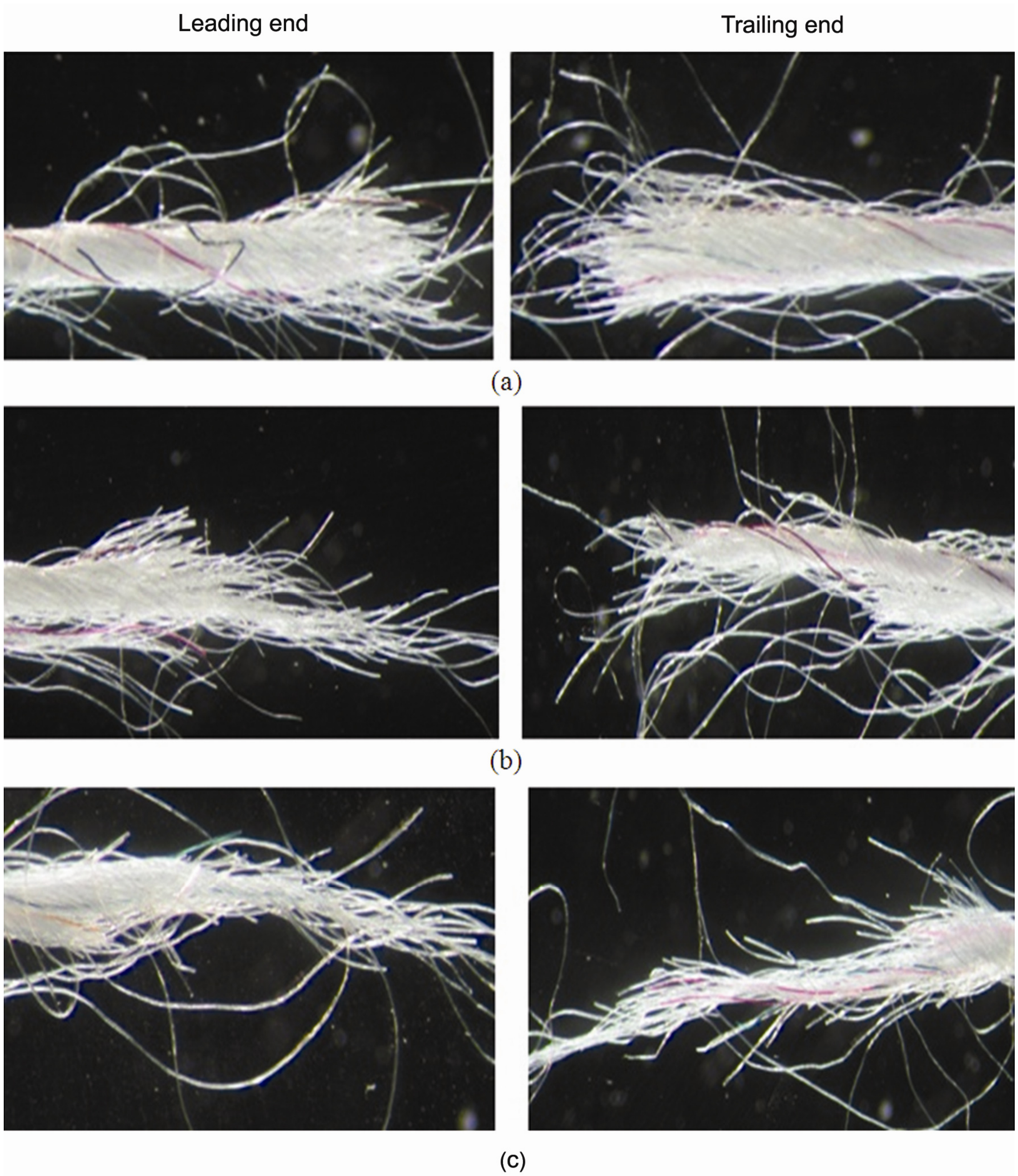

Fig. 3— Representative images of configuration of yarn broken ends (a) sharp broken end, (b) tapered broken end, and (c) slipped broken end

67/33 P/V yarn and lesser than one for the rest of three blended yarns. This further confirms that initial high percentage of polyester component in the yarn contributes more towards fibre slippage but with the increase of viscose component in the yarn, it contribute more towards fibre breakage.

It is observed from Table 3 that the average values of fibre failure coefficient for rotor yarns and for both the fibre components decrease with the increase in viscose content in yarns. It is also noticed that the value of fibre failure coefficient is more than one for all the cases, except for viscose component of 33/67 P/V yarn. But the value of fibre failure coefficient for all considered cases is more than ring yarns, which implies further that the failure behaviour of rotor yarns during warping is dominated by fibre slippage.

The results of fibre failure coefficient for polyester fibre component as well as resultant air-jet yarn decrease (except of 50/50 P/V yarn) with the increase in viscose content in yarn. But the viscose component does not follow any specific trend. It is further noticed that the value of fibre failure coefficient is always more than one and highest among all the considered spinning technologies, which implies that the failure behaviour of air-jet yarn is highly dominated by fibre slippage. The above-mentioned observations can be explained by considering three factors, (i) like other spinning systems, the presence of strong polyester fibre in yarn is transferring its maximum load to weaker fibre and therefore, contributing more towards fibre slippage; (ii) the typical core-sheath structure of air-jet yarn behaves quite differently during tensile loading in comparison to ring and rotor yarns, early failure of viscose fibre as sheath component will loosen the yarn structure and will enhance the slippage of entire core component of yarn; and (iii) under these circumstances, the contribution of individual component does not show any specific trend with the increase in viscose content in the yarn.

3.2 Configuration of Yarn Broken Ends

The results of configuration of yarn broken ends (sharp, tapered and slipped) of ring, rotor and air-jet blended yarns are shown in Table 4. In the case of P/V blended ring yarns, the percentage of tapered broken ends are found to be the highest followed by sharp and slipped broken ends; except for 100% viscose yarn, where the percentage of sharp broken ends are higher than the tapered broken ends. The percentage of sharp broken ends is increased with the increase in viscose content, which is due to the decrease in fibre failure coefficient. The percentage of tapered broken ends decreases and increases alternatively from 100% polyester yarn to 100% viscose yarn. It is evident from Table 3 that the contribution of viscose fibres towards proportion of fibre break increases with the increase in viscose content. This implies that there are chances of translation of tapered to sharp and slipped to tapered broken ends with the increase in viscose content. The result of this translation process decides the trend of percentage of tapered broken ends with the increase in viscose content. Further, the percentage of slipped broken ends decreases and increases alternatively from 100% polyester yarn to 100% viscose yarn. It is obvious that the translation of slipped broken ends to tapered broken ends leads to decrease in the percentage of slipped broken ends with the increase in viscose content. During the yarn extension, the tension generated by the applied strain continues to increase. The increase in generated tension is limited by the tensile strength of fibres. Initially, as the extension increases, few weaker fibres with low

Table 3 — Fibre failure coefficient of ring, rotor and air-jet yarns

Material	Proportion of fibre break (FB)			Proportion of fibre slip (FS)			Fibre failure coefficient (FS/FB)		
	Ring	Rotor	Air-jet	Ring	Rotor	Air-jet	Ring	Rotor	Air-jet
Polyester	0.44	0.31	0.29	0.56	0.69	0.71	1.27	2.23	2.45
67/33 P/V	P(0.46)	P(0.32)	P(0.30)	P(0.54)	P(0.68)	P(0.70)	P(1.17)	P(2.12)	P(2.33)
	V(0.53)	V(0.44)	V(0.44)	V(0.47)	V(0.56)	V(0.56)	V(0.89)	V(1.27)	V(1.27)
	A(0.49)	A(0.36)	A(0.35)	A(0.51)	A(0.64)	A(0.65)	A(1.04)	A(1.78)	A(1.86)
50/50 P/V	P(0.45)	P(0.34)	P(0.28)	P(0.55)	P(0.66)	P(0.72)	P(1.22)	P(1.94)	P(2.57)
	V(0.61)	V(0.48)	V(0.39)	V(0.39)	V(0.52)	V(0.61)	V(0.64)	V(1.08)	V(1.56)
	A(0.53)	A(0.41)	A(0.32)	A(0.47)	A(0.59)	A(0.68)	A(0.89)	A(1.44)	A(2.12)
33/67 P/V	P(0.47)	P(0.35)	P(0.32)	P(0.53)	P(0.65)	P(0.68)	P(1.13)	P(1.86)	P(2.12)
	V(0.66)	V(0.52)	V(0.44)	V(0.34)	V(0.48)	V(0.56)	V(0.51)	V(0.92)	V(1.27)
	A(0.57)	A(0.46)	A(0.38)	A(0.43)	A(0.54)	A(0.62)	A(0.75)	A(1.17)	A(1.63)
Viscose	0.62	0.50	0.40	0.38	0.50	0.60	0.61	1.00	1.50

P—Polyester, V— Viscose, and A—Average value.

Table 4 — Configuration of yarn broken ends of ring, rotor and air-jet yarns

Material	Sharp broken ends, %			Tapered broken ends, %			Slipped broken ends, %		
	Ring	Rotor	Air-jet	Ring	Rotor	Air-jet	Ring	Rotor	Air-jet
Polyester	32.5	20.0	15.0	50.0	52.5	50.0	17.5	27.5	35.0
67/33 P/V	35.0	22.5	22.5	52.5	52.5	47.5	12.5	25.0	30.0
50/50 P/V	40.0	27.5	17.5	45.0	45.0	50.0	15.0	27.5	32.5
33/67 P/V	42.5	32.5	25.0	50.0	47.5	45.0	7.5	20.0	30.0
Viscose	45.0	35.0	20.0	42.5	42.5	47.5	12.5	22.5	32.5

strength may break. The load will continue to increase depending upon the load bearing capacity of surviving fibres. Before yarn breakage, few fibres are gripped and rest of them slip. Due to more extension, yarn breakage of gripped fibres starts at the place of weakest zone and causes rupture of gripped fibres to propagate faster across the cross-section. Finally, the yarn failure takes place in a mixed mode of fibre breakage and slippage. Keeping the above explanation into consideration, one should read the trend from Table 4 of sharp broken end and combination of tapered and slipped broken ends with the increase of viscose content in the blended yarn. The results clearly indicate that the percentage of sharp broken ends increases and sum of percentage of tapered and slipped broken ends decreases with the increase in viscose content in the ring yarns.

It is depicted from Table 4 that the percentage of tapered broken ends is highest for rotor yarn than the other two kinds of yarn broken ends. But the percentage of slipped broken ends is higher than that of sharp broken ends up to 50/50 P/V blend, and after that the results show reverse trend. The percentage of sharp broken ends increases with the increase in viscose content. In general, the percentage of tapered broken ends decreases with the increase in the viscose content. The reasoning of said trend is similar to that explained for ring yarns. The sum of percentage of tapered and slipped yarn broken ends also decreases with the increase in viscose content in rotor yarns.

Table 4 shows that the percentage of tapered broken ends is highest for P/V blended air-jet yarns followed by slipped and sharp broken ends. Unlike other two technology yarns, sum of percentage of tapered and slipped broken ends does not show any specific trend with the increase in viscose content, but results clearly indicate that air-jet yarns give the least percentage of sharp yarn broken ends in comparison to other two technology yarns. Peculiar structure of air-jet yarn is responsible for observed trend during warping operation.

3.3 Failure Zone Length

The values of failure zone length of ring, rotor and air-jet spun blended yarns are shown in Table 5. The failure zone length decreases with the increase in viscose content in P/V blended ring yarns. It is now an established fact that the failure zone length is dependent on the fibre failure coefficient and configuration of yarn broken ends. The results clearly indicate that there is a decrease in fibre failure coefficient, increase in percentage of sharp broken ends and decrease in sum of the percentage of tapered and slipped broken ends with the increase in viscose content; this creates fare chances to decrease the failure zone length with the increase in viscose content. The results show that the values of fibre failure coefficient and length of failure zone both decrease with the increase in viscose content in the yarns. This clearly implies that the decrease in the value of fibre failure coefficient with the increase in viscose content causes the fibres in the yarn to move from highly slipping mode to highly breakage mode and this supports the reduction in failure zone lengths.

The failure zone length for rotor yarn also decreases with the increase in the viscose content. It is also noticed from Table 3 that the value of fibre failure coefficient of rotor yarn is always higher than that of ring yarns. Hence, it justifies the higher failure zone length of rotor yarn.

The failure zone length of P/V blended air-jet yarns does not follow the trend shown by other two technology yarns with the increase in viscose content of the blends, but it gives the highest value. The air-jet yarn failure is highly dominated by fibre slippage mechanism and hence gives the highest value of failure zone length. This observed trend can also be supported while considering the fibre failure coefficient value. The combination of fibre failure coefficient along with the fibre consolidation mechanism in air-jet spinning is responsible for this observed trend.

Table 5 — Failure zone length and fibre failure coefficient of yarns

Material	Failure zone length, mm			Fibre failure coefficient (C_f)		
	Ring	Rotor	Air-jet	Ring	Rotor	Air-jet
Polyester	4.26 (16.76)	6.17 (20.25)	7.33 (17.54)	-5.41	-10.63	-7.87
67/33 P/V	3.95 (21.85)	5.64 (18.58)	6.71 (27.65)	-1.20	-4.68	9.63
50/50 P/V	3.47 (24.54)	5.25 (17.68)	8.58 (25.67)	11.80	3.33	-14.47
33/67 P/V	3.11 (27.61)	4.79 (19.65)	6.19 (21.29)	-5.37	12.33	-0.58
viscose	2.75 (23.69)	4.37 (21.42)	7.96 (29.63)	-10.39	-4.87	-4.30

Values in parentheses indicate the CV%.

3.4 Prediction of Fibre Failure Coefficient under Simulated Warping Process

The detailed matrix reduction technique utilized for developing the mathematical models is explained in our earlier reported work[12]. The similar technique is adopted for deriving the under mentioned models. The mathematical models for prediction of fibre failure coefficient of ring, rotor and air-jet yarns observed during spun yarn failure under simulated warping process are shown in following equations:

$$\text{Fibre failure coefficient } (C_f)_{ring} = 0.92 \times \frac{MMI^{8.1000} \times AFS^{1.0411}}{PD^{0.0100} \times FOI^{9.1032} \times MFP^{1.0000}} \quad \ldots (1)$$

$$\text{Fibre failure coefficient } (C_f)_{roter} = 1.47 \times \frac{MMI^{1.5875} \times AFS^{0.2360}}{PD^{1.0390} \times FOI^{0.5434} \times MFP^{1.0000}} \quad \ldots (2)$$

$$\text{Fibre failure coefficient } (C_f)_{airjet} = 1.81 \times \frac{MMI^{1.004} \times AFS^{0.2548}}{PD^{0.3987} \times FOI^{0.3993} \times MFP^{1.0000}} \quad \ldots (3)$$

where MMI— mean migration intensity, ASF— average strength of fibre, PD—packing density, FOI— fibre overlap index, and MFP— mean fibre position

The percentage error of prediction of the mathematical models for fibre failure coefficients of ring, rotor and air-jet yarns under the warping process is presented in Table 5. The error is well within the tolerance limit and hence these models may be treated as suitable models for prediction of the spun yarn failure behaviour under warping process. The scale factor is found highest for air-jet yarn followed by ring and rotor yarns. This implies that the scale factor is also representing the governance of fibre break or slip during yarn failure.

3.5 Comparison of Failure Behaviour of Yarns made on different Spinning Systems

Among all the three yarns, ring yarn displays the lowest value of fibre failure coefficient followed by rotor and air-jet yarns. The polyester fibre component contributes more towards proportion of fibre slip than fibre break and this is applicable for all three yarns. The fibre failure coefficient decreases with the increase in viscose content, in case of ring and rotor yarns, but air-jet yarns do not follow any specific trend. The contribution of viscose fibres towards fibre break is higher than towards fibre slip for ring yarn, but for rotor and air-jet yarns viscose fibres contribute more towards fibre slip than towards fibre break. In ring spinning system, the fibres in the drafting zone are in the form of flat ribbon. Thus, two dimensional flat ribbons are converted into three dimensional roughly round shape interlocked helical structure. When yarn is subjected to extension, the tension is generated in the yarn, which is opposed by the resistance of material. As generated tension acts on the helical structure, the yarn is compressed radially and a force normal to the fibre axis is developed. An increment in the normal force between fibre surfaces in the yarn builds up resistance necessary to prevent fibre slippage. Therefore, ring yarn contributes highest value of proportion of fibre break and, in particular, due to the weaker fibre i.e. viscose fibre. With the increase in percentage of viscose fibre in blended yarn, chances of fibre break of viscose component further increases. In case of rotor yarn, triangular shape of fibre gets converted in to circular shape and during this transformation, the corner of triangle get wrapped on the core portion of fibre and hence produces a more open surface structure. When yarn is subjected to extension, due to open structure less tension is generated in the yarn and an increase in the normal force between the fibre surfaces in the yarn is not enough to avoid fibre slippage. Therefore, it generates more fibre slippage than fibre breakage in comparison of ring yarns. The air-jet yarn consists of a majority of fibres in an almost untwisted state in the core and surface layers of fibres wrapped around core. During yarn extension, the wrapper fibres start breaking first, it loosens the core portion of the yarn and therefore increases more chances of fibre slippage.

The percentages of sharp broken ends are found to be highest for ring yarns followed by rotor and air-jet yarns. The percentages of slipped broken ends are found to be highest for air-jet yarns followed by rotor and ring yarns. The spinning technologies do not show any specific trend for tapered broken ends.

Air-jet yarns display the highest value of failure zone length followed by rotor and ring spun yarns. The failure zone length decreases with the increase in viscose content for ring and rotor yarns. Failure zone length of air-jet yarns does not follow any specific trend with the increase in viscose content of yarns.

4 Conclusion

4.1 The fibre failure coefficient is higher than one for rotor and air-jet yarns, and failure during warping for these the yarns is predominately due to fibre slippage. The fibre failure coefficient values are higher and lower than one for ring spun blended yarns and the yarn failure is mixed mode of fibre break and slip.

4.2 The sharp broken ends increase with the increase in viscose content for ring and rotor yarns and there is no specific trend noticed with air-jet yarns. Highest sharp broken ends are observed with ring yarns followed by rotor and air-jet yarns. Lowest slipped broken ends are noticed with ring yarns followed by rotor and air-jet yarns.

4.3 The failure zone length is highest for air-jet yarns followed by rotor and ring yarns. The failure zone length decreases with the increase in viscose content for ring and rotor yarns and no specific trend is observed for air-jet yarns.

4.4 The developed mathematical models express a very low error% and this enables its potential application in predicting the spun yarn failure behaviour during warping process.

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