

Optimization of process variables in rotor spinning for the production of cotton/milkweed blended yarns

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Cotton/milkweed (60/40) blended yarn of 29.5 tex has been produced on rotor spinning system. The influence of fibre friction, opening roller speed and sliver linear density on rotor yarn properties has been studied using Box and Behnken factorial design and the optimum conditions within the processing limits of the machines are established. The results show that fibre friction is the dominant factor in determining the tensile properties and other properties of rotor-spun yarn. It is observed that a higher fibre friction gives higher yarn tenacity, and lower yarn unevenness, imperfection and hairiness. The opening roller speed also has a greater influence on rotor yarn properties. With an increase in opening roller speed, the number of points per fibre increases, which results in better fibre separation and improvement in yarn properties. But very high opening roller speed deteriorates the yarn properties and increases the end breakage rate mainly due to fibre breakage and low fibre straightness. Generally, heavier sliver weight leads to higher spinning draft which deteriorates the yarn properties.

Keywords: Cotton/milkweed yarn, Fibre friction, Opening roller speed, Rotor spinning, Sliver linear density

1 Introduction

Open-end rotor spinning has emerged as a successful technology for spinning of short staple yarns due to its high productivity, lower man-power requirements and the elimination of speed frame and winding. Spinning parameters may be categorized into three major groups, viz based on the machine and speeds of opening roller, rotor and take-up¹; geometry of opening roller, fibre transportation zone, rotor and yarn withdrawal tube²; and pneumatic parameters like air speed, volume and suction pressures at the transportation tube³.

The opening roller system in rotor spinning gives a high degree of separation, but it is achieved at the expense of fibre breakage^{4,5}. The fibre breakage effects can be minimized by using low sliver linear density, a high speed of sliver input, a slow opening roller speed and a combing roller with a low wire point density⁶. New spinning technologies such as rotor, air-jet and friction spinning lack the traditional mechanical control inherent in ring spinning⁷. One common feature of these new systems is the existence of a gap in which fibres are flowing in an air stream,

the only mechanism of control being a combination of fibre-to-fibre, fibre-to-metal and fibre-to-air friction. The performance of fibres in such a gap depends largely on their frictional characteristics⁸.

Since the milkweed fibres are smooth, of low density, and have low elongation-at-break and more short fibres⁹⁻¹², their behaviour during spinning have to be analysed while blending it with the cotton fibre. The effect of process variables in speed frame and ring frame on ring yarn characteristics has been presented in the earlier study¹³. The effect of opening roller speed in rotor spinning varies from one fibre material to another; the fibres respond in different ways and with different results. The present study is therefore aimed at investigating the combined effect of fibre friction, opening roller speed and sliver linear density and then optimizing the above-mentioned parameters for better spinning performance and quality of cotton/milkweed blended rotor yarns.

2 Materials and Methods

2.1 Materials

Medium grade cotton (S-4) and milkweed fibres were chosen for the production of yarn. The chemical treatment of milkweed fibres, namely delignification by alkali treatment and the dyeing of fibres were carried out to modify the surface properties and to

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improve its spinnability. The fibre-to-fibre frictional coefficients of cotton and raw, dyed and alkali treated milkweed fibres were 0.33, 0.16, 0.22 and 0.28 respectively.

2.2 Yarn Production

The spinning trials were conducted on a micro-spinning line (Trytex, India)¹¹. The slivers were prepared for yarn production on a miniature model carding and draw frame machine. After the second draw frame passage, the sliver is processed on a miniature rotor spinning machine to produce 29.5 tex rotor yarn. The saw tooth type opening roller OS21 with wire angle of 12° was used for opening the C/M slivers in rotor spinning machine as the conventional wire angle of 18° (OK40) used for cotton fibres leads to more number of breakages.

2.3 Testing of Yarn Properties

The yarn characteristics, such as single yarn strength (ASTM D 2256-02); yarn evenness, imperfections and hairiness index (ASTM D 1425-09); and hairiness frequency (Zweigle hairiness- ASTM D 5647-07) were tested as per standard method. All the tests were carried out after conditioning the samples at the standard temperature and relative humidity (21.0 ± 0.1°C and 65 ± 2%).

2.4 Experimental Design

Based on the preliminary trials conducted on different cotton/milkweed blend proportions and

chemical treatment of milkweed fibres, the cotton/alkali treated milkweed 60/40 blend was used for the study. A three-variable factorial design proposed by Box & Behnken was used to investigate the combined influence of process and material variables in rotor spinning. The coded levels and corresponding actual values of the three variables in speed frame and ring frame drafting stages are given in Table 1. The other process parameters in rotor spinning were kept constant (rotor speed – 60,000 rpm, opening roller wire – OS21, TM – 4.4, rotor diameter – 43 mm).

3 Results and Discussion

Based on the Box & Behnken experimental design, the yarn properties were obtained and are shown in Table 2. The regression equation of models in terms of coded factors after eliminating the insignificant factors is shown in the Table 3. The yarn properties were found to be well correlated ($R^2 > 0.8$) with all chosen variables except breaking elongation.

3.1 Effect of Process Parameters on Yarn Tenacity and Elongation

The higher R^2 value in case of yarn tenacity (Table 3) shows that it is better correlated with fibre

Table 1—Coded levels and actual values for processing C/M 60/40 yarns in speed frame and ring frame

Variables	Coded levels		
	-1	0	+1
Milkweed fibre friction, μ , (X_1)	0.16	0.22	0.28
Opening roller speed, rpm, (X_2)	5000	6000	7000
Sliver linear density, g/m, (X_3)	3.3	3.9	4.5

Table 2—Properties of rotor yarn obtained by varying the rotor frame process parameters

Experiment no.	Fibre friction (X_1)	Opening roller speed (X_2)	Sliver linear density (X_3)	Tenacity cN/tex	Elongation %	U%	Total imperfections/km	Hairiness index (H)	End breakage rate breaks/rotor/h
1	0.16	5000	3.9	8.957	5.83	14.21	465	7.21	0.32
2	0.28	5000	3.9	10.49	6.58	13.9	442	6.52	0.35
3	0.16	7000	3.9	9.59	6.65	13.73	434	7.92	2.71
4	0.28	7000	3.9	10.76	6.70	13.55	418	7.08	2.12
5	0.16	6000	3.3	10.36	6.68	13.12	402	7.53	0.42
6	0.28	6000	3.3	11.47	6.24	12.73	391	7.04	0.46
7	0.16	6000	4.5	9.99	6.49	13.36	438	7.93	2.25
8	0.28	6000	4.5	10.6	6.42	13.03	407	7.42	2.19
9	0.22	5000	3.3	9.92	6.74	13.73	477	8.64	0.16
10	0.22	7000	3.3	10.97	6.95	13.38	437	7.64	1.49
11	0.22	5000	4.5	9.01	6.21	13.9	492	8.86	1.93
12	0.22	7000	4.5	10.13	6.28	13.97	438	8.13	4.23
13	0.22	6000	3.9	10.61	6.87	13.18	396	6.43	1.12
14	0.22	6000	3.9	10.73	6.01	13.23	392	6.74	1.45
15	0.22	6000	3.9	10.75	6.12	13.19	402	6.37	1.31

Table 3—Response surface equations for various yarn properties

Yarn characteristics	Response surface equations	p-value	Coefficient of determination(R ²)
Tenacity, g/tex	$10.697 + 0.5531X_1 + 0.384X_2 - 0.374X_3 - 0.672X_2^2$	0.0106	0.9469
Elongation, %	*	0.3422	0.2526
Unevenness, U %	$13.2 - 0.151X_1 - 0.139X_2 - 0.163X_3 + 0.666 X_2^2$	0.0012	0.9785
Imperfections/km	$396.667 - 10.125X_1 - 18.625X_2 + 8.5X_3 + 47.292X_2^2 + 17.042X_3^2$	0.0025	0.9710
Hairiness index (H)	$6.513 - 0.766X_1 + 1.203X_2^2$	0.0682	0.8799
End-breakage rate	$1.293 + 0.973X_2 + 1.01 X_3 + 0.3521 X_2^2 + 0.307 X_3^2$	0.0004	0.9863

* Response surface equation could not be obtained due to insignificant regression coefficient.

friction, opening roller speed and sliver linear density. The influence of process parameters on yarn tenacity is shown in Fig. 1. By analyzing the contour diagram and point prediction tools from the software, it can be shown that the maximum yarn tenacity is obtained at a fibre friction of 0.27, an opening roller speed of 6285.32 rpm and a sliver linear density of 3.31 g/m. It is apparent from the contour that an increase in fibre friction invariably increases the yarn tenacity as in case of ring yarns. But with an increase in opening roller speed, tenacity increases up to an optimum opening roller speed but decreases with the further increase in speed.

Initial increase in yarn tenacity with opening roller speed could be due to increased points per fibre (ppf), which leads to improved fibre separation and trash removal from the sliver. As the opening roller speed increases, the carrying factor increases, which, in turn, increases the opening intensity of the opening roller. Owing to the better opening of fibres, it can be anticipated that the fibre tufts of smaller and uniform size are fed into the rotor groove via transport tube¹⁴. But, beyond optimum opening roller speed, the yarn tenacity deteriorates because of two reasons, namely (i) the higher opening roller speed causes excessive fibre breakage, resulting in decreased mean fibre length of fibres^{15,16}; and (ii) the fibre straightness and degree of alignment is lost due to throwing away of fibre into the transport tube caused by the higher opening roller speed¹⁷.

With the increase in sliver linear density, the yarn tenacity decreases invariably. This decrease can be attributed to the increase in spinning draft (between feed and opening roller) for a particular count to be spun causing more fibre damage and frequent end-breaks resulting in weaker yarn^{18,19}. It is found that no significant change in yarn elongation is caused by changes in the chosen variables.

3.2 Effect of Process Parameters on Yarn Unevenness

The influence of process parameters on yarn unevenness is shown in Fig. 2. By analyzing the contour plot and point prediction tools from the software, it can be observed that the minimum yarn U% is obtained at a fibre friction of 0.28, an opening roller speed of 6192.41 rpm and a sliver linear density of 3.31 g/m.

The increase in fibre friction reduces the yarn U% due to better inter-fibre friction. An increase in opening roller speed results in an initial decrease in yarn unevenness up to a certain point and then the unevenness increases at higher opening roller speed. The inadequate opening of fibres at lower opening roller speeds leads to increase in yarn unevenness²⁰. On the other hand, excessive action of the opening roller (higher ppf) on fibres at higher speeds will not continue to improve the yarn evenness, but it leads to the deterioration of yarn evenness due to fibre breakage. Further, a greater centrifugal force on fibres, caused by higher opening roller speed, will clump them within the inlet of the transport tube at a speed close to, or even higher than the speed generated by aerodynamic forces. This increases the probability of fibre accumulation at the inlet of the transport tube. The low density and finer milkweed fibres could travel at a different speed compared to the cotton fibres, leading to uneven deposition on rotor groove and hence higher yarn unevenness.

With an increase in sliver linear density, the yarn U% increases linearly. At higher sliver linear density, the feed rate becomes less, presenting more number of fibres per unit time to the opening roller. This results in inadequate opening of fibres, leading to increased yarn U%.

3.3 Effect of Process Parameters on Yarn Imperfections

The influence of process parameters on yarn imperfections is shown in Fig. 3. By analyzing the contour plot and point prediction tools from the

software, it is observed that the minimum yarn imperfections is obtained at a fibre friction of 0.27, an opening roller speed of 5842.59 rpm and a sliver linear

density of 3.92 g/m. It is evident from the contour that an increase in fibre friction decreases the yarn imperfections due to controlled flow of fibres in the transport channel and deposition of more or less equal number of fibres in the rotor groove.

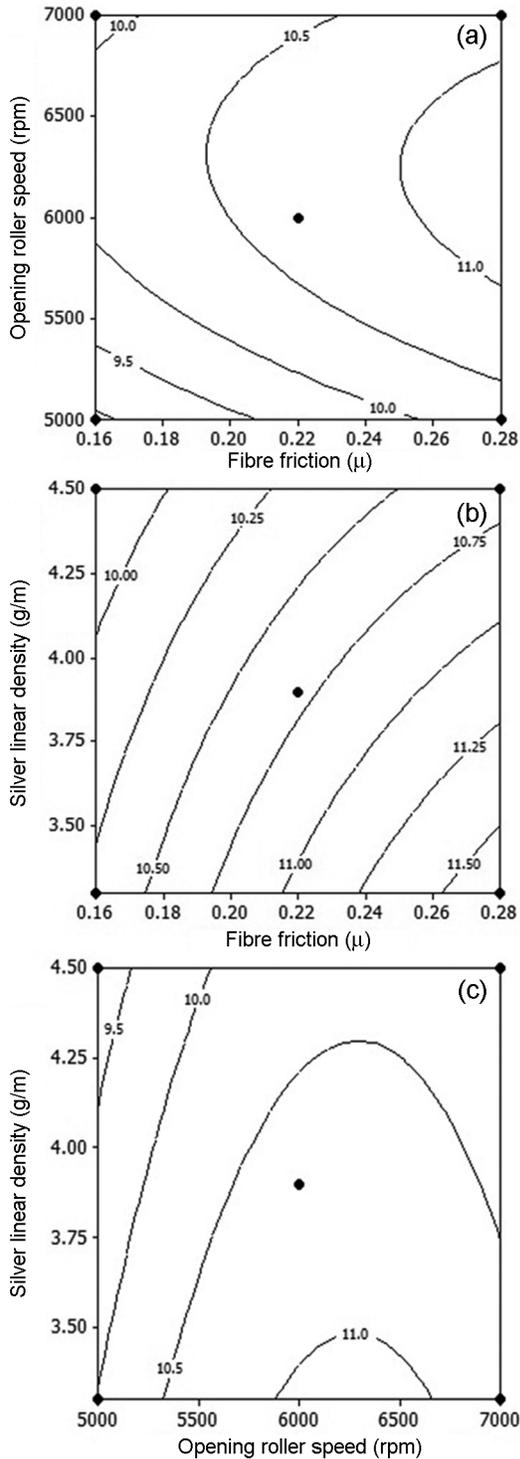


Fig. 1—Effects of (a) fibre friction with opening roller speed, (b) fibre friction with sliver linear density and (c) opening roller speed with sliver linear density on yarn tenacity

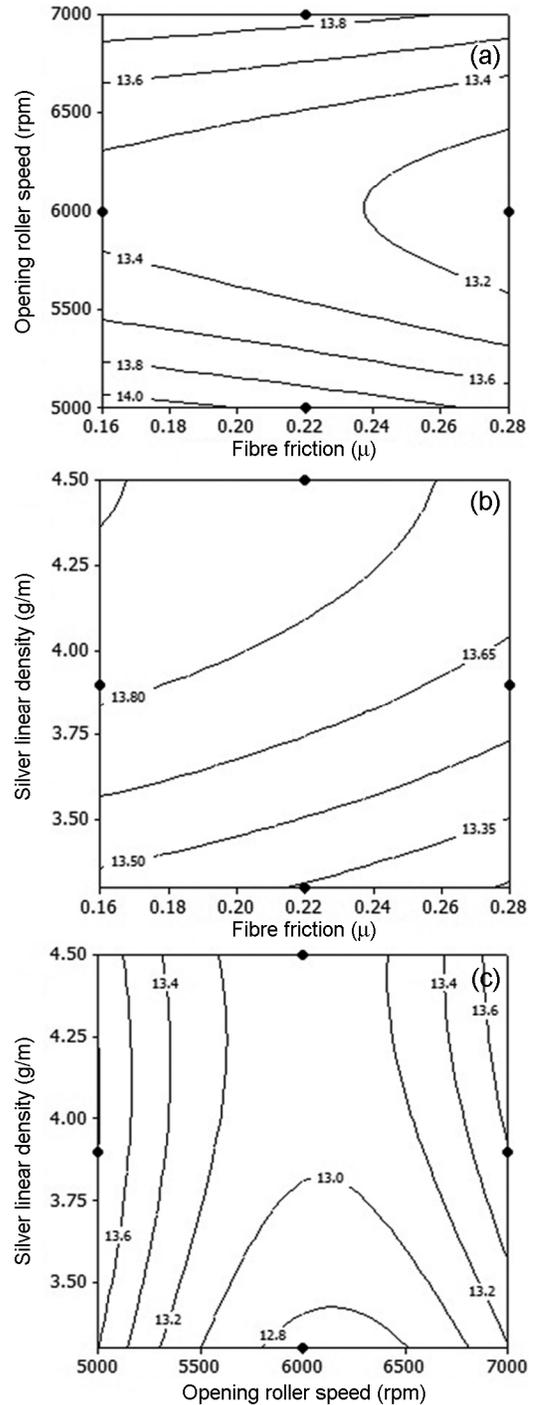


Fig. 2—Effects of (a) fibre friction with opening roller speed, (b) fibre friction with sliver linear density and (c) opening roller speed with sliver linear density on yarn unevenness

An increase in opening roller speed results in initial decrease in yarn imperfections upto a certain level followed by the increase in imperfections with the

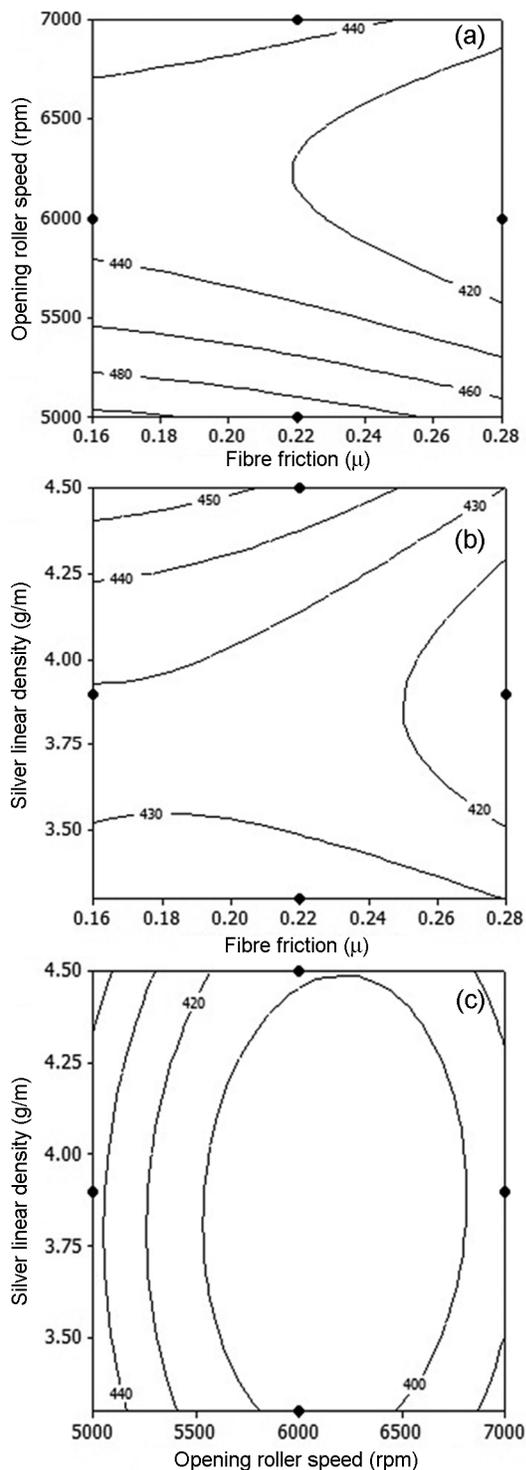


Fig. 3—Effects of (a) fibre friction with opening roller speed, (b) fibre friction with sliver linear density and (c) opening roller speed with sliver linear density on yarn imperfections

further increase in roller speed. The initial decrease in yarn imperfection with opening roller speed could be due to better opening of fibres. At lower opening roller speeds, inadequate opening of fibres leads to more amount of thick and nep faults in yarn. On the other hand, higher opening roller speed paves the way to premature acceleration of low density milkweed fibres, leading to irregular deposition in the rotor groove and hence a higher yarn imperfection level.

With the increase in sliver linear density, the yarn imperfections reduce slightly up to a certain level and then increase steeply thereafter. Higher yarn imperfections at lesser sliver linear density could be due to the excessive action of opening rollers on a lesser number of fibres presented in unit time. At a higher sliver linear density, the feed rate becomes less, presenting more number of fibres per unit time to the opening roller, resulting in insufficient opening of fibres which ultimately leads to more thick and nep faults in the yarn.

3.4 Effect of Process Parameters on Yarn Hairiness

The influence of process parameters on yarn hairiness index (H) is shown in Fig. 4. By analyzing the contour plot and point prediction tools from the software, it can be observed that the minimum yarn hairiness is obtained at a fibre friction of 0.28, an opening roller speed of 5805 rpm and a sliver linear density of 3.57 g/m. Increase in fibre friction keeps the fibres intact in the yarn strand and results in lower hairiness. But with higher opening roller speeds, fibre breaks occurs liberating short fibres and hence increased hairiness.

3.5 Effect of Process Parameters on End-breakage Rate

The influence of fibre friction, opening roller speed and sliver linear density on end breakage rate is shown in Fig. 5. By analyzing the contour plot and point prediction tools from the software, it can be observed that the minimum end-breaks are obtained at a fibre friction of 0.28, an opening roller speed of 5027 rpm and a sliver linear density of 3.48 g/m.

From the contour plots (Fig. 5) it is observed that the increase in opening roller speed increases the end breakage rate gradually. At higher speeds, fibre rupture of milkweed fibre leads to higher rotor deposition, disrupting the yarn formation process. As the sliver linear density increases, more number of fibres acts upon by the opening roller, leading to increased breaks.

3.6 Production of Yarn with Optimized Parameters

The numerical optimization tool of the software was used to determine the optimum values of the factors for the spinning of better ring and rotor yarns. The optimum values observed are 0.28 fibre friction

(alkali treated), 6010 rpm opening roller speed and 3.54 g/m sliver linear density. The comparison of 100% cotton yarns with yarn characteristics of C/M 60/40 rotor yarns produced with optimized parameters are shown in Table 4. The data reveal that the yarn

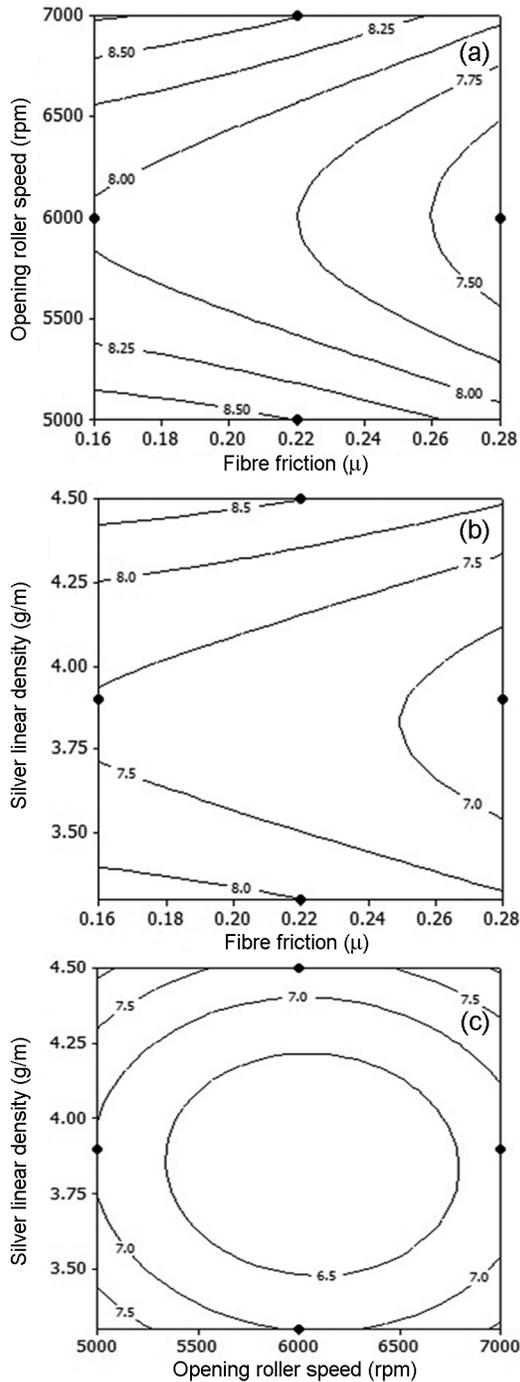


Fig. 4—Effects of (a) fibre friction with opening roller speed, (b) fibre friction with sliver linear density and (c) opening roller speed with sliver linear on yarn hairiness index (H)

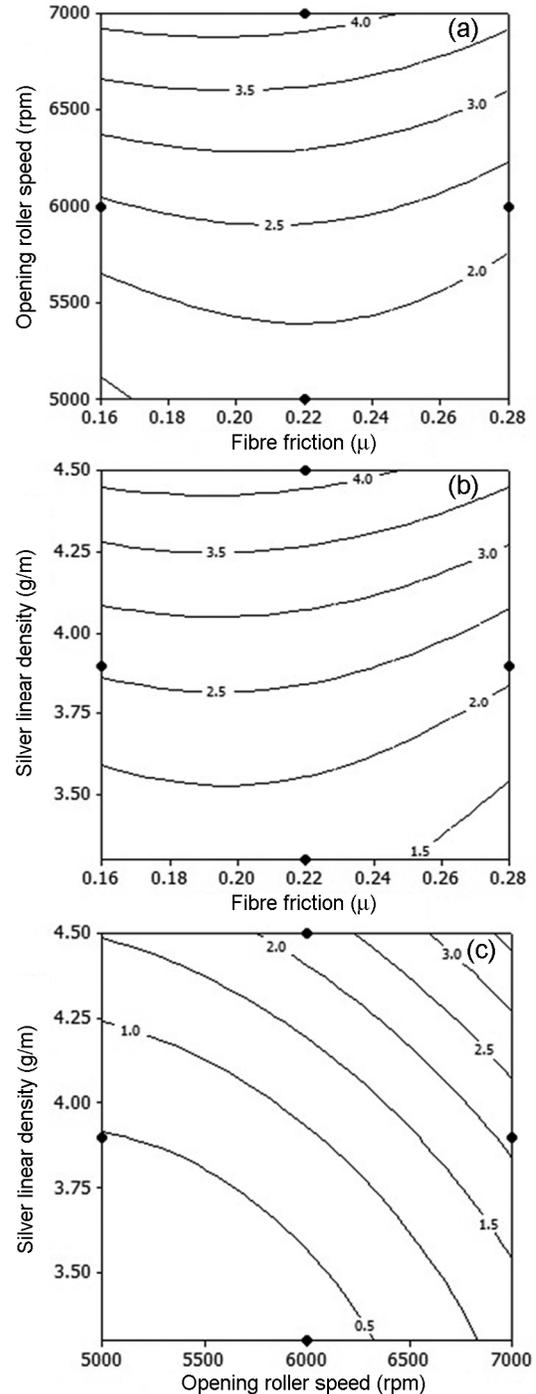


Fig. 5—Effects of (a) fibre friction with opening roller speed, (b) fibre friction with sliver linear density and (c) opening roller speed with sliver linear on end breakage rate

Table 4—Comparison of C/M 60/40 yarn properties obtained with optimized process parameters with 100% cotton yarns

Yarn	Tenacity, cN/tex	Elongation, %	U %	Imperfections/km	Hairiness (H)	Hairiness (S ₃)
100% Cotton	12.4	6.25	12.5	540.1	4.69	132
C/M 60/40	11.85	6.43	10.4	382	6.21	199

characteristics are comparable to that of 100% cotton yarn.

4 Conclusion

4.1 It is inferred that a higher level of fibre friction, a moderate level of opening roller speed and a moderate to lower level of sliver linear density lead to better yarn characteristics.

4.2 For better running performance and quality of cotton/milkweed blended yarns in rotor spinning, the opening roller speed could be reduced to around 25% and the sliver linear density could be kept slightly on the finer side compared to those used for 100% cotton respectively.

4.3 The fibre friction has a significant influence on all the yarn properties tested. At a higher fibre friction, there is more inter-fibre cohesion and a greater number of fibres ultimately contribute to the yarn strength, which causes an increase in the yarn tenacity.

4.4 The opening roller in a rotor spinning system causes fibre damage of varying degrees, which differs from one material to another. As the speed of the opening roller increases, fibre breakage becomes higher. The choice of the opening roller speed can therefore significantly influence the yarn properties. Drastic deterioration in all the yarn characteristics has been noticed at high opening roller speeds due to high fibre breakage and low fibre straightness. Extensive deterioration in yarn evenness and imperfections occurs at low opening roller speeds due to the low degree of fibre opening.

4.5 Heavier sliver weight leads to higher spinning draft, which deteriorates the yarn properties. Finally, the optimum process conditions for cotton/milkweed 60/40 blends have been achieved at a fibre friction of 0.28, an opening roller speed of 6010 rpm and at a sliver linear density of 3.54 g/m.

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