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# Optimization of drafting zone variables in ring 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 a ring spinning system. The influence of fibre friction, front zone roller setting and front top roller pressure at speed frame and ring frame on yarn properties has been studied using the Box and Behnken design. The optimum conditions within the processing limits of the machines are established. It is observed that a higher fibre friction gives higher yarn tenacity and lower yarn unevenness, imperfection and hairiness. The roller setting and top roller pressure also influence the yarn properties at speed frame and ring frame. With the increase in roller setting the yarn tenacity increases initially and then decreases, while other yarn properties deteriorate at wider roller settings. The increase in top roller pressure leads to reduction in yarn unevenness, imperfection and hairiness due to better control of milkweed fibres in the drafting zone. In general, blends of cotton/alkali-treated milkweed fibres with moderate to lower roller setting and moderate to higher level of top roller pressure give better results.

**Keywords:** Box-Behnken design, Cotton/milkweed yarn, Fibre friction, Full factorial design, Ring spinning, Roller setting, Top roller pressure

## 1 Introduction

The roller drafting of fibre strands causes a tension to be generated in the fibres in the drafting zone. The force required to give the tension in moving fibre strand during drafting in the drafting zone is known as the drafting force[1]. The manner in which a fibre performs during drafting depends on the variation in frictional forces acting on it in the drafting zone. The static and dynamic force of friction and the coefficient of friction for cotton fibres increase with speed[2].

Many research works have been focused on different aspects of drafting force and its correlation with the material and machine parameters in ring spinning. Fibre crimp influences roller drafting process by influencing the comparative movement of fibres in the drafting zone[3,4]. The fibre friction is also considered to be an important property of textile fibres in view of their behavior during drafting. The behavior of the floating fibres in the drafting zone, in turn, depends on the frictional properties of the fibre and it influences the drafting force[5,6]. Drafting force and its variability are important characteristics that determine the irregularity added during drafting, the number of faults generated and the drafting failures[7]. The variability in drafting force appears to be more correlated with spinnability and yarn quality than to absolute value of drafting force. The drafting variables in the front zone are more crucial, as high draft is imparted in this zone. The number of fibres is relatively low, the velocity of fibres is higher and the chances of generation of irregularities in the fibre strand are more in this zone than in back zone[1-7].

Since the surface properties of milkweed fibres are quite different from cotton and have higher proportion of short fibre content, the process parameters and settings used for processing 100% cotton fibres are not suitable for cotton/milkweed (C/M) blended yarn production. The milkweed fibres are smoother compared to cotton fibres and hence the drafting force required for drafting the C/M blended slivers and roving are different as compared to 100% cotton. The present study is aimed at optimizing the process variables in speed frame and ring frame for improving the spinning performance and yarn quality of C/M blended yarns.

## 2 Materials and Methods

### 2.1 Materials

Medium grade cotton (S-4) and milkweed fibres were chosen for production of yarn. The static frictional coefficient (μ) of raw, dyed and alkali-treated milkweed fibres was 0.16, 0.22 and 0.28 respectively[8].

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### 2.2 Yarn Production

The spinning trials were conducted on a micro-spinning line (Trytex, India)[9,10]. The slivers were prepared for yarn production on a miniature model carding and draw frame machine. The slivers were then processed through speed frame (LF4200, Lakshmi Machine Works, Coimbatore, India) and ring frame (LR6, Lakshmi Machine Works, Coimbatore, India) to produce 29.5 tex yarn for producing a normal ring yarn.

### 2. 3 Testing of Yarn Properties

The yarn characteristics such as single yarn strength (ASTM D 2256-02), evenness, imperfections and hairiness index (ASTM D 1425-09) were tested as per standard method.

### 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 chosen for optimization. A three-variable and three-level factorial design technique proposed by Box & Behnken was used to investigate the influence of three process variables, viz. fibre friction, front zone roller setting and front roller top roller pressure, on C/M blended yarn characteristics.

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 process parameters were selected based on practical conditions in spinning mills. The other process parameters at different drafting stages were kept constant. While optimizing the speed frame process parameters, the ring frame process parameters were kept at ‘0’ coded levels and vice versa.

## 3 Results and Discussion

### 3.1 Optimization of Speed Frame and Ring Frame Drafting Parameters by Box-Behnken Design

In this section, the influence of front zone drafting variables such as front zone setting, front top roller pressure in speed frame and ring frame along with the fibre friction have been analysed using Box and Behnken design to improve the C/M (60/40) yarn characteristics[7,11]. These three parameters have been considered, as they are found to significantly influence the drafting behavior of fibres[12]. It has been reported earlier that the raw, dyed and alkali-treated milkweed fibre has relatively lower inter-fibre friction coefficient values of 0.16, 0.22 and 0.28 respectively as compared to cotton fibre (0.33). Though the alkali-treated yarns are found to produce better yarn characteristics with same settings as used for processing cotton fibre, the combined effect of fibre friction along with front zone variables needs to be further investigated.Keeping the ring frame parameters constant at ‘0’ coded level, yarns are spun by varying the speed frame parameters, and similarly maintaining the speed frame parameters constant at ‘0’ coded level, yarns are spun by varying the ring frame parameters. The resulting yarn properties are reported in Table 2. The regression equations in terms of coded factors after eliminating the insignificant factors are shown in the Table 3. The higher values of $R^2$ (Table 3) for all the yarn properties except breaking elongation show that the yarn properties are well correlated with all the chosen variables in speed frame and ring frame.

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

| Stages of drafting | Variables | Coded levels | | |
|---|---|---|---|---|
| | | -1 | 0 | +1 |
| Speed frame | Milkweed fibre friction ($S_1$), μ | 0.16 | 0.22 | 0.28 |
| | Roller setting ($S_2$), mm | 47 | 49 | 51 |
| | Top roller load ($S_3$), kgs | 20 | 25 | 30 |
| Ring frame | Milkweed fibre friction ($R_1$), μ | 0.16 | 0.22 | 0.28 |
| | Roller setting ($R_2$), mm | 40 | 42 | 44 |
| | Top roller load ($R_3$), kgs | 15 | 17.5 | 20 |

### 3.2 Effect of Speed Frame Parameters on Yarn Tenacity and Elongation

The influence of speed frame process parameters, namely roller setting and top roller pressure along with the fibre friction on C/M (60/40) ring yarn tenacity is shown in Fig. 1. From the contour plots (Figs 1a, b & c), it can be seen that the maximum yarn tenacity is obtained at fibre friction value of 0.27, a roller setting of 47.15 mm and top roller pressure of 23.53 kgf.

It is clear from the contour plots that an increase in fibre friction invariably increases the yarn tenacity. With the increase in fibre friction values, the inter-fibre friction between the fibres will be high and greater number of fibres ultimately contributes to the yarn strength. There seems to be an optimum point for top roller pressure at 23.53 kgf, before and after which the tenacity drops.

At lower top roller pressures, undrafted strands are observed which may be due to lesser influence of fibre friction field. The relatively lower friction values of milkweed fibres could have led to uncontrolled fibre movement in the drafting zone, resulting in lower tenacity. Similarly, at top roller loads over 23.53 kgf due to friction field overlap, uneven distribution of

Table 2 – Properties of ring yarn obtained by varying the speed frame process parameters

| Std. order | Fibre friction | Roller setting | Roller pressure | At speed frame A | B | C | D | E | At ring frame A | B | C | D | E |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -1 | -1 | 0 | 11.76 | 4.64 | 16.78 | 2290 | 13.37 | 10.93 | 4.78 | 16.75 | 2731 | 12.18 |
| 2 | +1 | -1 | 0 | 15.33 | 4.72 | 15.08 | 1240 | 10.12 | 15.67 | 4.91 | 15.57 | 1380 | 10.24 |
| 3 | -1 | +1 | 0 | 11.21 | 4.41 | 18.08 | 2889 | 14.27 | 10.29 | 4.09 | 18.79 | 3033 | 13.97 |
| 4 | +1 | +1 | 0 | 13.66 | 5.17 | 16.59 | 1665 | 12.06 | 13.52 | 4.59 | 16.98 | 1605 | 10.92 |
| 5 | -1 | 0 | -1 | 12.24 | 4.97 | 16.23 | 2031 | 13.96 | 11.78 | 5.16 | 17.16 | 2290 | 13.19 |
| 6 | +1 | 0 | -1 | 15.05 | 5.72 | 15.82 | 1123 | 10.24 | 14.95 | 5.77 | 15.94 | 721 | 9.48 |
| 7 | -1 | 0 | +1 | 11.42 | 4.94 | 17.45 | 2731 | 13.14 | 11.13 | 4.83 | 15.74 | 1918 | 12.09 |
| 8 | +1 | 0 | +1 | 14.15 | 4.89 | 15.60 | 1134 | 9.34 | 13.99 | 5.21 | 13.29 | 650 | 9.06 |
| 9 | 0 | -1 | -1 | 13.84 | 4.92 | 16.11 | 1309 | 11.41 | 13.21 | 4.21 | 16.66 | 1522 | 11.54 |
| 10 | 0 | +1 | -1 | 11.99 | 4.19 | 16.70 | 1818 | 12.87 | 12.13 | 4.33 | 17.17 | 2103 | 11.98 |
| 11 | 0 | -1 | +1 | 12.33 | 5.29 | 17.13 | 1929 | 10.77 | 12.01 | 4.81 | 15.34 | 1298 | 10.71 |
| 12 | 0 | +1 | +1 | 11.01 | 4.52 | 17.31 | 1985 | 12.23 | 11.69 | 4.59 | 16.03 | 1810 | 11.18 |
| 13 | 0 | 0 | 0 | 14.24 | 4.47 | 14.98 | 988 | 10.92 | 13.47 | 4.62 | 15.72 | 1093 | 10.73 |
| 14 | 0 | 0 | 0 | 13.99 | 4.51 | 14.31 | 978 | 11.01 | 13.75 | 5.3 | 15.41 | 1082 | 10.36 |
| 15 | 0 | 0 | 0 | 14.37 | 4.48 | 14.17 | 1097 | 10.78 | 13.25 | 5.63 | 15.92 | 1303 | 10.46 |

A – Tenacity (g/tex);B – Elongation; C –Unevenness (U%); D –Total imperfections; and E – Hairiness index.

Table 3 – Response surface equations for various yarn properties at speed frame and ring frame

| Drafting stage | Yarn characteristics | Response surface equations | p-value | Coefficient of determination ($R^2$) |
|---|---|---|---|---|
| Speed frame | Tenacity, g/tex | $14.2 + 1.44S_1 - 0.674S_2 - 0.526S_3 - 1.066 S_2^2 - 0.841S_3^2$ | 0.0018 | 0.9902 |
| | Elongation, % | * | 0.4169 | 0.6953 |
| | Unevenness, % | $15.153 - 0.881S_1 + 0.5975S_2 - 0.2787S_3 + 0.57S_1^2 + 0.908S_2^2 + 0.451S_3^2$ | 0.0006 | 0.9833 |
| | Imperfections/km | $1297.667 - 647.375S_1 + 186.125S_2 + 149.75S_3 + 346.41S_1^2 + 376.91S_2^2$ | 0.0102 | 0.9477 |
| | Hairiness (H) | $10.903 - 1.622S_1 + 0.72S_2 - 0.375S_3 + 0.701S_1^2 + 0.85S_2^2$ | 0.0004 | 0.9814 |
| Ring frame | Tenacity, g/tex | $13.49 + 1.75R_1 - 0.523R_2 - 0.406R_3 - 0.795R_2^2$ | 0.0019 | 0.9741 |
| | Elongation, % | * | 0.4272 | 0.6906 |
| | Unevenness, % | $15.683 - 0.883 R_1 + 0.581R_2 - 0.816R_3 - 1.053R_2^2$ | 0.0119 | 0.9441 |
| | Imperfections/km | $1159.33 - 702R_1 + 202.5R_2 - 120R_3 + 369.708 R_1^2 + 658.208R_2^2$ | 0.0002 | 0.9891 |
| | Hairiness (H) | $10.51 - 1.466R_1 + 0.422R_2 - 0.393R_3 + 0.854R_2^2$ | 0.0030 | 0.9687 |

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

fibres could have reduced the yarn strength. The increase in roller setting increases the yarn tenacity up to certain level and then decreases. At narrow roller setting, the greater frictional field causes the floating fibres to move in a controlled manner, resulting in higher tenacity. But at wider roll settings, the frictional field sharply decreases, resulting in irregular fibre movement leading to reduced yarn tenacity.

### 3.3 Effect of Speed Frame Parameters on Yarn Evenness

The influence of speed frame process parameters on yarn evenness is shown in Fig. 2.

By analyzing the contour diagram and point prediction tool from the software, it can be shown that the minimum yarn U% is obtained at fibre friction of 0.24, roller setting of 48.64 mm and top roller pressure of 24.49 kgf. The yarn U% decreases with the increase in fibre friction as it helps to realize a controlled fibre movement. Similarly, the yarn U% also decreases with an increase in the top roller load up to certain level and then increases, irrespective of roller setting. The initial increase in top roller load reduces the gap between the pressure fields of middle and front rollers. This provides a better control over the fibres, reducing the yarn unevenness. In addition, an increase in top roller load enables better gripping of low cohesive milkweed fibres at roller nip which avoids fibre slippage during roller drafting, thereby improving the yarn evenness. At higher top roller loads, there could be overlapping of friction fields in the main drafting zone, obstructing the smooth and proper flow of fibres, leading to higher yarn unevenness. The finding is in agreement with that reported by Das *et al.*[12].

With reference to roller setting, the yarn U% reduces as the roller setting increases up to 48.64 mm and then increases at wider roller settings. The initial decrease in yarn U% with roller setting may be due to controlled movement of shorter, less cohesive milkweed fibres in the main drafting zone. Further increase in yarn unevenness at wider roller setting could be due to higher floating distance of fibres between middle and front roller nip.

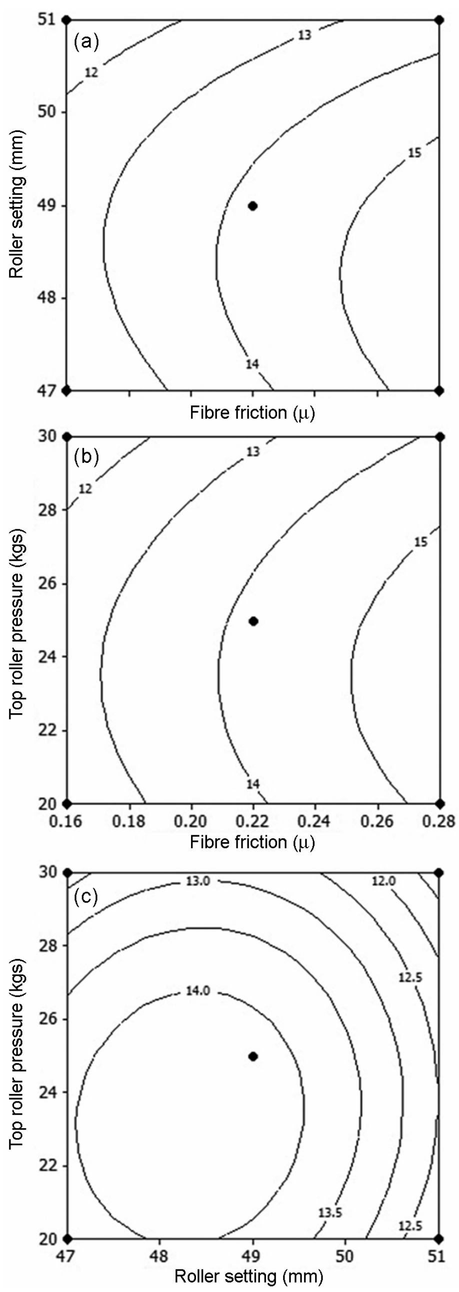


Fig. 1– Effects of (a) fibre friction with roller setting, (b) fibre friction with top roller load, and (c) roller setting with top roller load on yarn tenacity

### 3.4 Effect of Speed Frame Parameters on Yarn Imperfection

Figure 3 illustrates the influence of speed frame process parameters on yarn imperfection level.

By analyzing the contour plot and point prediction tool from the software, it can be shown that the minimum yarn imperfection value is obtained at fibre friction of 0.24, roller setting of 48.56 mm and top roller pressure of 25.07 kgf. With an increase in the fibre

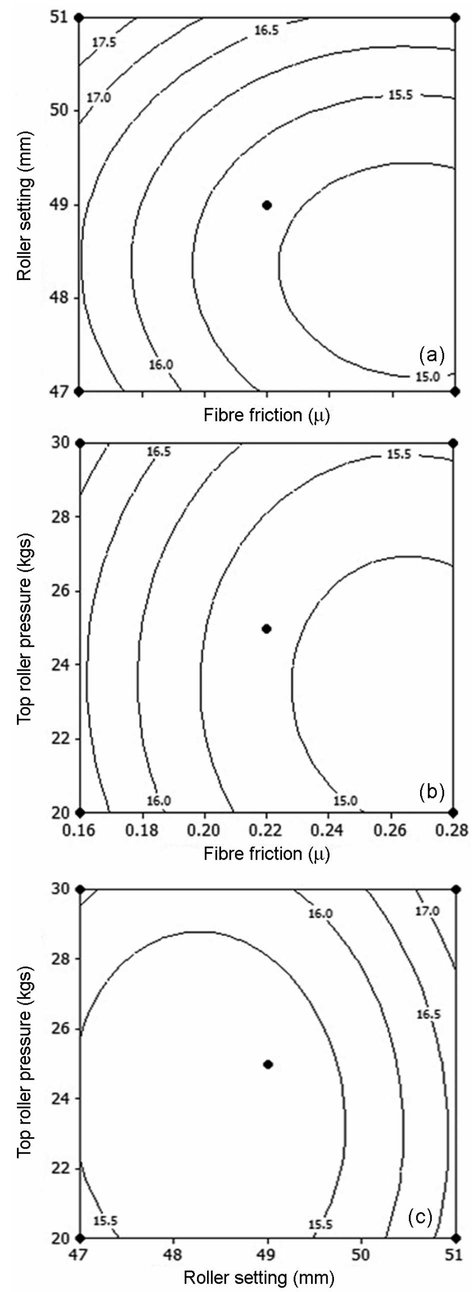


Fig. 2 –Effects of (a) fibre friction with roller setting, (b) fibre friction with top roller load, and (c) roller setting with top roller load on yarn evenness

friction values, the number of imperfection gradually decreases due to controlled movement of fibres during drafting and reduces the incidence of drafting waves.

As far as top roller load is concerned, the yarn imperfection decreases up to a certain level and then increases as top roller loads are increased. At lower top roller load, undrafted fibre strand from the drafting zone increases the yarn imperfections. At high top roller loads, the premature acceleration of shorter fibres during drafting causes the fibre to move in groups, resulting in greater numbers of thick and thin places in yarn. Changes in the friction field could be a reason for change in imperfection with respect to roller setting, the optimum being around 48.5 mm.

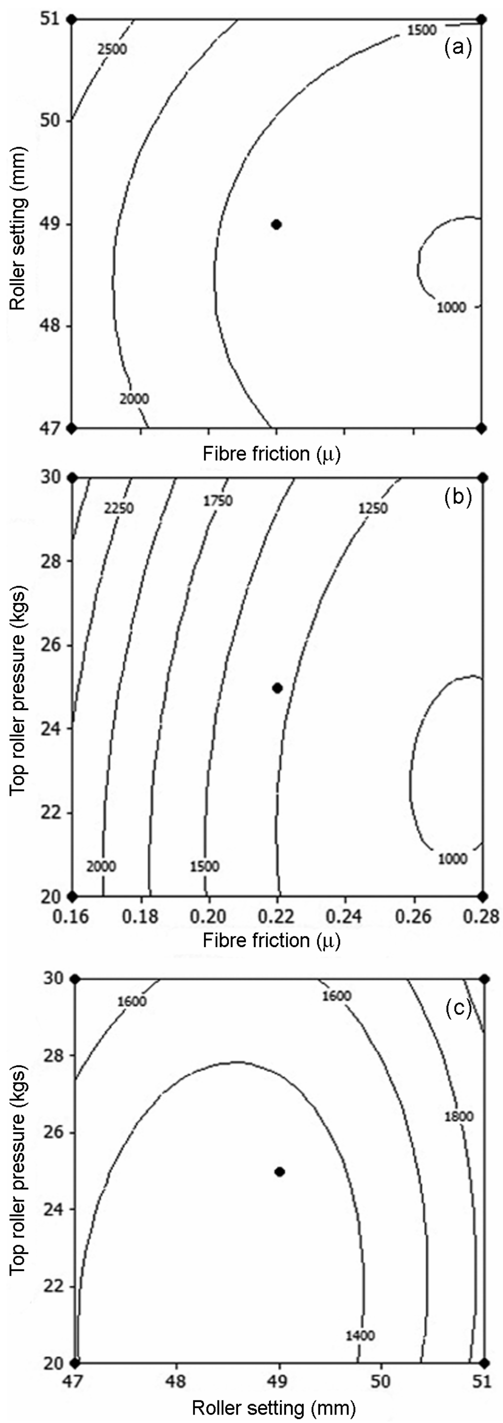


Fig. 3 –Effects of (a) fibre friction with roller setting, (b) fibre friction with top roller load, and (c) roller setting with top roller load on yarn imperfections

### 3.5 Effect of Speed Frame Parameters on Yarn Hairiness

The influence of speed frame process parameters on hairiness value is shown in Fig. 4. By analyzing the contour plot and point prediction tools from the software, it can be shown that the minimum yarn hairiness value is obtained at fibre friction of 0.28, roller setting of 47.8 mm and top roller pressure of 30 kgf. From the contour plots, it is observed that with the increase in fibre friction and top roller load, the yarn hairiness value shows a decreasing trend. The increase in fibre friction reduces the fibre spread during drafting and reduces yarn hairiness. At higher top roller load, the extended fibre friction field in the main draft zone leads to better control of shorter fibres, resulting in lesser yarn hairiness. With increase in roller setting, yarn hairiness increases due to less control on the fibres during drafting.

### 3.6 Effect of Ring Frame 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 friction, roller setting and top roller load. By analyzing the contour plot and point prediction tools from the software, it can be shown that the maximum yarn tenacity is obtained at fibre friction of 0.28, roller setting of 40.84 mm and top roller pressure of 17.65 kgf. The increase in fibre friction invariably increases the yarn tenacity. The trend obtained is similar to that of a speed frame and similar reasons as discussed for speed frame holds good here as well. The chosen variables have no significant effect on the yarn elongation.

### 3.7 Effect of Ring Frame Parameters on Yarn Evenness

The influence of ring frame process parameters on yarn unevenness is shown in Fig. 5. By analyzing the contour plot and point prediction tool from the software, it can be shown that the minimum yarn U% value is obtained at fibre friction of 0.28, roller setting of 41.51 mm and top roller pressure of 20 kgf.

From the contour plots, it is observed that the yarn U% decreases gradually with increase in fibre friction and top roller load, irrespective of roller setting due to better fibre control in drafting. With the increase in roller setting, the yarn U% decreases up to certain level and then increases, a trend exhibited with speed frame variables.

### 3.8 Effect of Ring Frame Parameters on Yarn Imperfection

By analyzing the contour plot and point prediction tools from the software, it can be shown that the

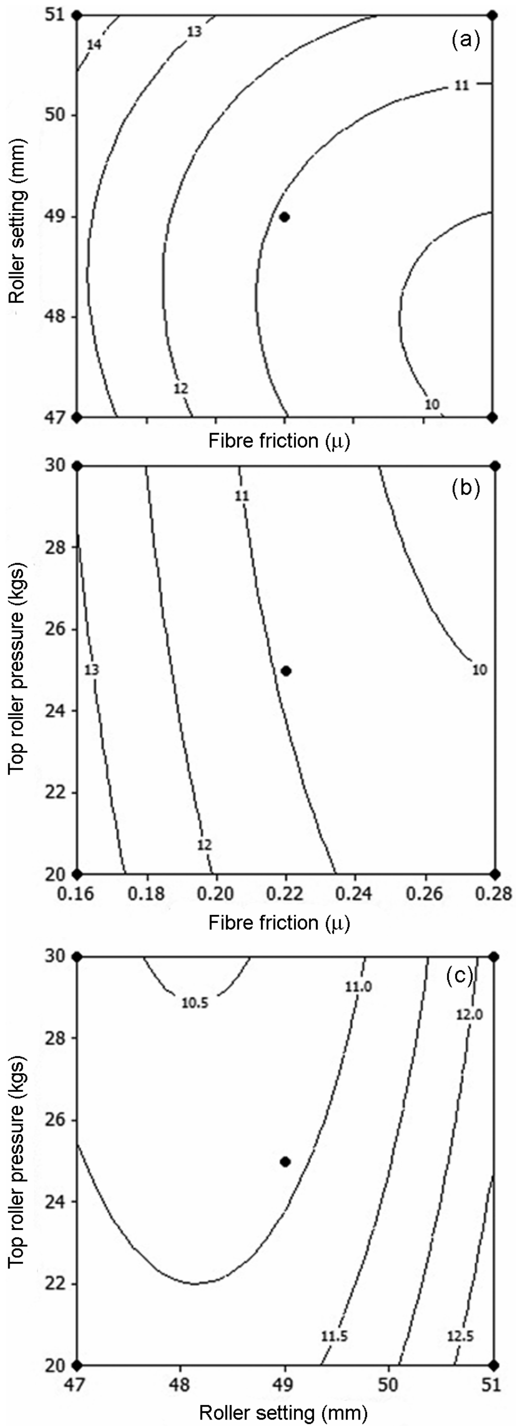


Fig. 4 –Effects of (a) fibre friction with roller setting, (b) fibre friction with top roller load, and (c) roller setting with top roller load on yarn hairiness (H)

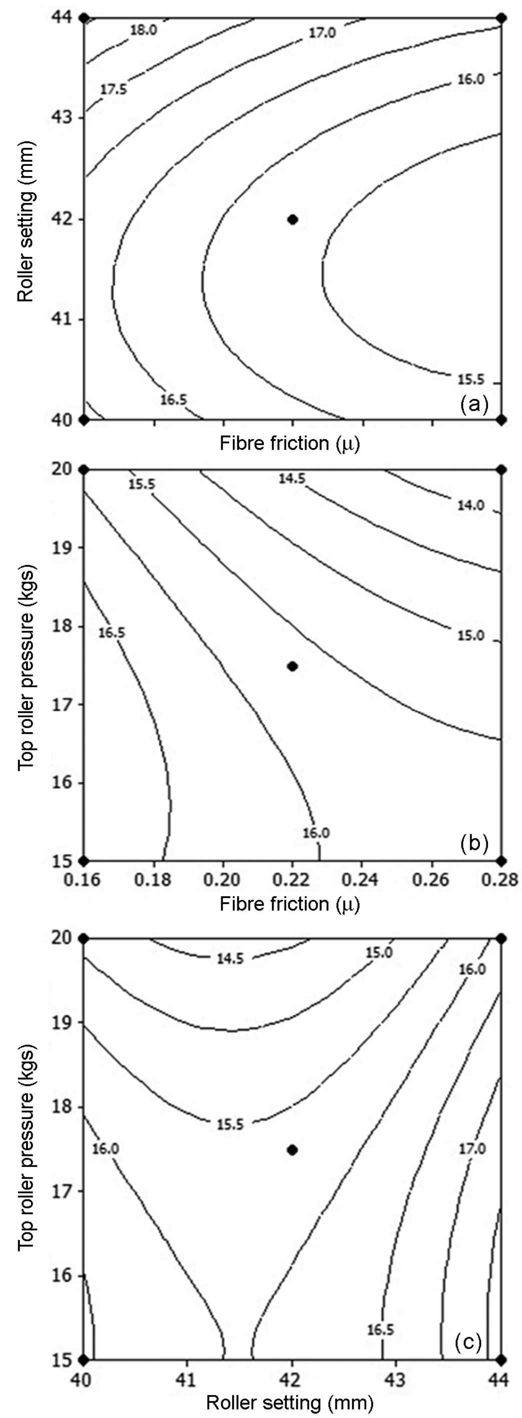


Fig. 5 –Effects of (a) fibre friction with roller setting, (b) fibre friction with top roller load, and (c) roller setting with top roller load on yarn unevenness

minimum yarn imperfection value is obtained at fibre friction of 0.27, roller setting of 41.53 mm and top roller pressure of 19.5 kgf.

From the contour plots shown in Fig. 6, it is apparent that imperfections decrease with increase in fibre friction. The top roller load does not show any significant influence on yarn imperfections.

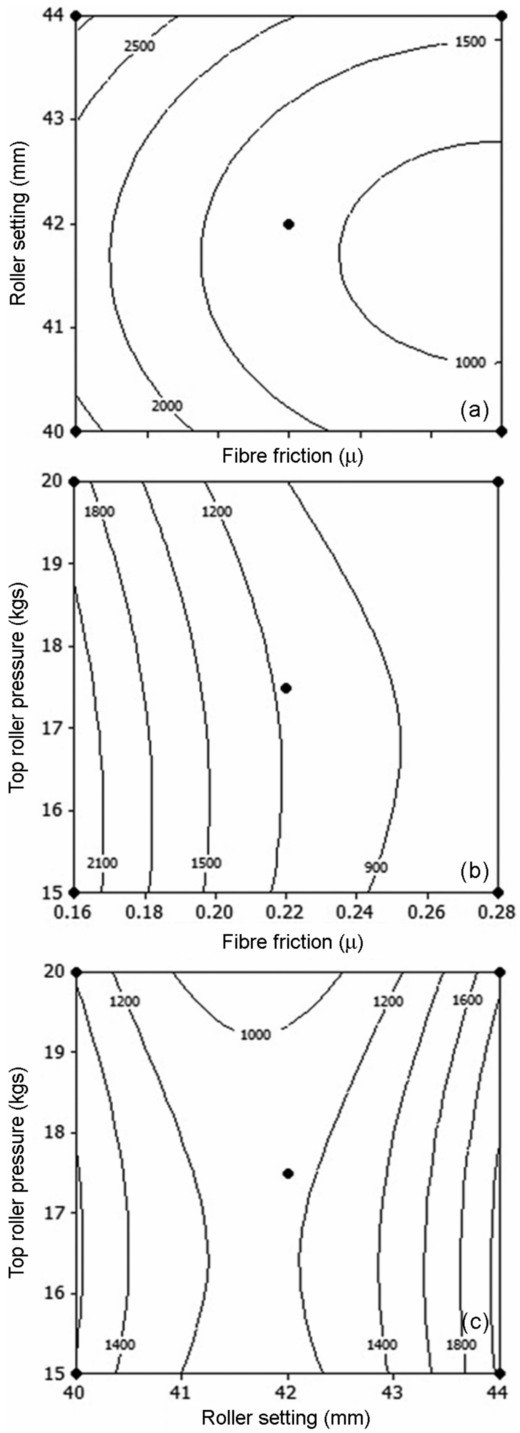


Fig. 6 –Effects of (a) fibre friction with roller setting, (b) fibre friction with top roller load, and (c) roller setting with top roller load on yarn imperfection

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

| Yarn characteristics | 100% Cotton | | C/M (60/40) | |
|---|---|---|---|---|
| | Ring | Compact | Ring | Compact |
| Tenacity, cN/tex | 15.32 | 16.98 | 14.63 | 16.05 |
| Elongation, % | 6.12 | 6.22 | 5.56 | 5.83 |
| U, % | 13.72 | 13.16 | 14.12 | 13.97 |
| Imperfections, IPV/km | 520.4 | 540.1 | 790 | 728 |
| Hairiness (H) | 6.63 | 4.75 | 9.42 | 7.64 |

### 3.9 Effect of Ring Frame Parameters on Yarn Hairiness

By analyzing the contour plot of yarn hairiness index, it can be shown that the minimum yarn hairiness value is obtained at fibre friction of 0.28, roller setting of 41 mm and top roller pressure of 20 kgf. The yarn hairiness decreases with increase in fibre friction and top roller pressure and increases with roller setting, the trend similar to speed frame.

### 3.10 Production of Yarn with Optimized Drafting Parameters

The numerical optimization tool of the software was used to determine the optimum values of the factors for spinning better ring yarns. The optimum values found from the software are obtained using the fibre friction value of 0.28, top roller pressure of 25 kgs in speed frame and 20 kgs in ring frame, and roller setting of 48.5 mm in speed frame and 41.5 mm in ring frame respectively. The comparison of 100% cotton yarns along with yarn characteristics of ring, and compact yarns produced with optimized parameters are given in Table 4. The data reveals that the yarn characteristics are found to be superior than those reported earlier and comparable to that of 100% cotton yarn.

## 4 Conclusion

**4.1** In speed frame, the optimum values for fibre friction, front zone roller setting and front top roller pressure are found to be 0.28, 48.5 mm and 25 kgf respectively for spinning the best C/M (60/40) yarns using the software output. In ring frame, fibre friction of 0.28, front zone roller setting of 41.5 mm and front top roller pressure of 20 kgf are found to be the optimum values.

**4.2** In general, the increase in fibre friction is found to increase all the observed yarn characteristics. With regard to top roller load and roller setting, moderate values are found to produce desirable yarn characteristics due to the role played by those parameters in friction field of drafting line.

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