AUTEX Research Journal, Vol. 5, No3, September 2005 © AUTEX

REDUCING YARN HAIRINESS IN WINDING BY MEANS OF JETS: OPTIMISATION OF JET PARAMETERS, YARN LINEAR DENSITY AND WINDING SPEED

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Abstract

Reducing yarn hairiness during yarn winding by the use of air jets is a new approach, since the production rate of winding is very high and the process itself increases yarn hairiness. The Box & Behnken factorial design approach has been used to optimise the jet angle, the jet diameter, yarn linear density and the winding speed in order to reduce the yarn hairiness. A jet angle of 45^0*, a jet diameter of 2.2 mm, 10 tex yarn and a winding speed of 800 m/min give the optimal results in terms of reducing the hairiness. A CFD (computational fluid dynamics) model has been developed to simulate the airflow pattern inside the jets with the use of Fluent 6.1 software. The air velocity around the core of the jet is the influencing factor in wrapping the hairs on the yarn body.*

Key words:

Factorial design, JetWind, S3 values, simulation, swirling

Introduction

Increase in yarn hairiness during winding is a well-known phenomenon [1-3]. Since commercial winding machines operate at high speeds, any method to reduce the yarn hairiness at the winding stage will not only reduce the processing cost in the downstream, but will also produce high quality fabrics. Few works have been published on reducing yarn hairiness in winding by using air-jets [4-5]. In these works, spun yarn is first converted into pirn, and this yarn is subjected to the action of a jet. The works published in this area do not contain any study on airflow simulation inside the jets, which plays a key role in describing the mechanism of hairiness reduction. We have developed a system of jets which acts on the principle of false twisting, to reduce the hairiness of yarns during the first winding operation. In the present work, the air-jets are situated so that the axial airflow direction is kept along the direction of yarn movement. A CFD (computational fluid dynamics) model has been developed to simulate the airflow pattern inside the jets using Fluent 6.1 software, to solve the three-dimensional flow field [6]. In the present work, an attempt has been made to optimise various jet parameters, namely jet angle and jet diameter, yarn linear density and winding speed, by using the Box & Behnken factorial design [7].

Experimental Work

To create a effect of swirling air inside the jet, four air holes of 0.4 mm diameter are made tangentially to the inner walls of the jet. The air pressure in the jets is maintained at 0.9 bar. The airflow in the jets is along the yarn movement, and is located at a distance of 10 cm above the balloon bracket in the winding machine. The jet is positioned in the jet housing. Compressed air is supplied to the jet through a pipe with a pressure regulator and an air filter. A frame to mount the jet was constructed. A front view of the jet is shown in Figure 1.

Figure 1. Front view of the jet along with housing

Z-twisted carded cotton yarns were used in the study. Two sets of experiments were performed. In the first set of experiments, jet angles of 40^0, 45^0 & 50^0 with a constant yarn channel diameter of 2.2 mm were used. In the second experiment, yarn channel diameters of 1.8, 2.2 & 2.6 mm with a constant jet angle of 40^0 were used. For both the experiments, ring-spun cotton yarns with linear densities of 10, 20 & 30 tex and winding speeds of 800, 1000 & 1200 m/min were employed. The coded three-levels of variables are given in Table 1.

Table 1. Coded levels corresponding to actual levels of variables

Variables	Coded levels		
	-1	0	+1
Linear density (b), tex	10	20	30
Winding speed (c), m/min	800	1000	1200
Jet angle (a), degree	40º	45º	50º
Jet diameter (a_1), mm	1.8	2.2	2.6

The hairiness of the yarns was tested on a Zweigle G 566 hairiness tester. For each sample, 800 m length of yarn was tested for hairiness at a speed of 50 m/min. The samples were maintained in standard testing conditions for 24 hours prior to testing.

Simulation Method

In the present study, the airflow inside the jets was simulated. We used a fluid flow analysis package, Fluent 6.1, which uses finite volume method for flow simulation. The flow in the jets is turbulent, and hence the standard k-ε model of turbulence was used along with standard wall functions.

We assumed that the flow inside the chamber affects the yarn, but the presence of yarn has no effect on the flow patterns, and hence the yarn has not been modelled. The high pressure and velocities of the air, coupled with the very low volume of the yarn compared to that of the jet chamber, justifies this assumption. In the present configuration, the air inlet boundaries are assumed to be of the "pressure inlet" type while outflow boundaries are assumed to be of the "pressure outlet" type. Although the high velocity of the air stream is a heat source that will increase the temperature in the jets, the jets are very short and the process occurs in a very short time. For simplification, we assume that the process is adiabatic, i.e. with no heat transfer through walls. The flow model used was viscous, compressible airflow.

Results and Discussion

The Box & Behnken design for three variables at three levels, along with the S3 values (i.e. the number of hairs whose lengths are 3 mm and above which protrude from the yarn) are given in Table 2. The response surface equation for S3 values is given in Table 3 along with the square of the correlation coefficients between the experimental and calculated values obtained from the response surface equations. We give some selective contours from the factorial design approach in the following sections.

Influence of jet angle, yarn linear density and winding speed on S3 values

Figure 2 shows the influence of yarn linear density and winding speed on S3 values for a jet at an angle of 45º. The S3 values increases with the increase in yarn linear density. This can be attributed to the fact that with the increase in yarn linear density, the number of fibres in the yarn cross-section increases, so a greater number of fibre ends are available, which in turn gives rise to a greater number of marginal fibres. These can be easily projected as hair, as they are not grasped by the yarn convergence point during ring spinning. With the increase in winding speed, the S3 values increase; this is because at the higher winding speed, the increased rubbing of the yarns by the machine parts and grooved drums gives rise to more hairiness. In addition, higher air-drag forces act on the yarn during high-speed winding compared to winding at low speed. The combined effect of yarn linear density and winding speed on the S3 values indicate that lowest yarn tex and lowest winding speed gives the optimum zone in terms of reducing the hairiness of yarns.

Table 2. Box & Behnken design for three variables and S3 values

Expt.no.	**Level of variables**			**S3 values**	
	a/a_1	b	c	Angle series	Diameter series
1	-1	-1	0	626	667
2	1	-1	0	653	688
3	-1	1	0	812	817
4	1	1	0	834	838
5	-1	0	-1	698	751
6	1	0	-1	713	768
7	-1	0	1	767	821
8	1	0	1	788	840
9	0	-1	-1	560	594
10	0	1	-1	750	780
11	0	-1	1	670	725
12	0	1	1	850	855
13	0	0	0	740	785
14	0	0	0	744	788
15	0	0	0	736	791

Table 3. Response surface equations for various parameters

Parameter	**Response surface equations**	**Coefficient of determination**
S3 (angle series)	$740 + 10.625 a + 92.125 b + 44.25 c + 12.625 a^2 - 21.375 b^2 - 11.125 c^2$	0.993
S3 (diameter series)	$785.846 + 9.75 a_1 + 77 b_1 + 43.5 c_1 + 10.769 a_1^2 - 21.375 b^2 - 11.125 c^2$	0.992

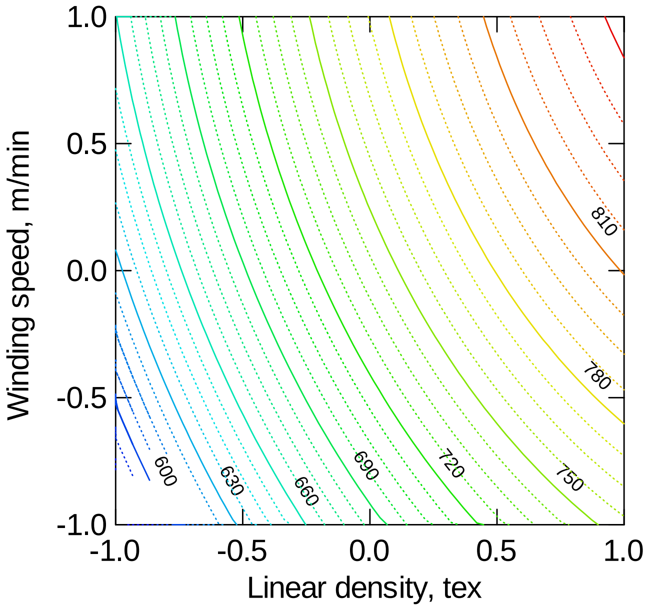


Figure 2. Influence of linear density and winding speed on S3 values for jet angle of 45º

The influence of jet angle and yarn linear density on the S3 values for a winding speed of 1000 m/min is shown in Figure 3. From the above contours, the best result is found between -0.5 to 0.0 level of angle (approx. 44º), followed by -1.0 level (jet 40º), and the worst result for 1.0 level (jet 50º). We used CFD modelling in describing the results. We have compared the axial air velocities of the jet at 45º with the second best performing jet at 40º.

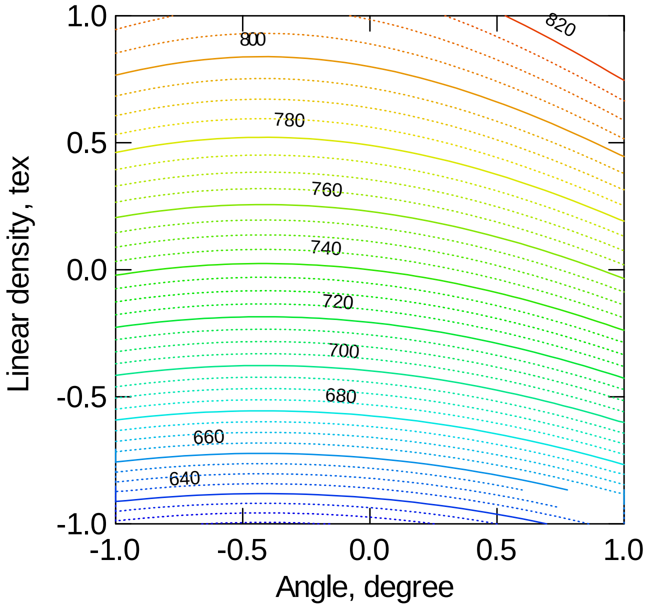
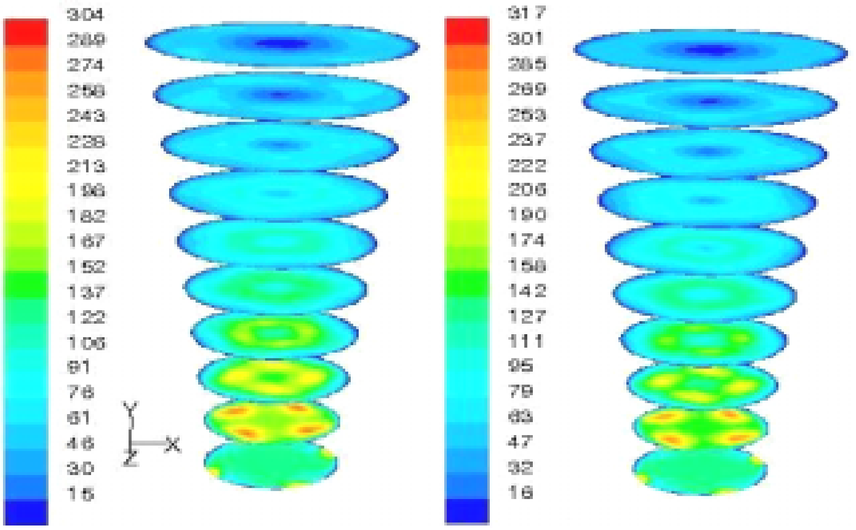


Figure 3. Influence of jet angle and yarn tex on S3 values for winding speed of 1000 m/min



(a) (b)

Figure 4. Contours of axial air velocities (m/s) of the jets (a) 45º, 2.2 mm (b) 40º, 2.2 mm

Keeping the jet-coordinate system in mind, Figure 4a and 4b indicates that the jet is cut into 10 equal sections along the axial height of the jet. The yarn lies at the centre of these cut sections. In the case of the jet at 45º (Figure 4a), the axial air velocities experienced by the yarn throughout the jet, i.e. from top to bottom of the sections, are as follows; 15, 15, 30, 46, 76, 122, 137, 152, 182 and 137 m/s. The average air axial velocity in the jet at 45º is 91 m/s. Similarly, the axial air velocities shown in Figure 6b in the case of the jet at 40º is as follows; 16, 16, 32, 32, 63, 111, 111, 142, 174 and 142 m/s. The average axial air velocity in case of the jet at 40º is 84 m/s. A higher axial velocity in the jet at 45º, in comparison to the jet at 40º, increases the swirling intensity, more wrapping of fibres around the yarn body, leading to more reduction in yarn hairiness in the former case.

Influence of jet diameter, yarn linear density and winding speed on S3 values

From Figure 5 it is clear that with an increase in yarn linear density and winding speed, the S3 values increase, following the same trend as described earlier. Again, the lowest speed and tex gives the best result in terms of optimum values of the variables.

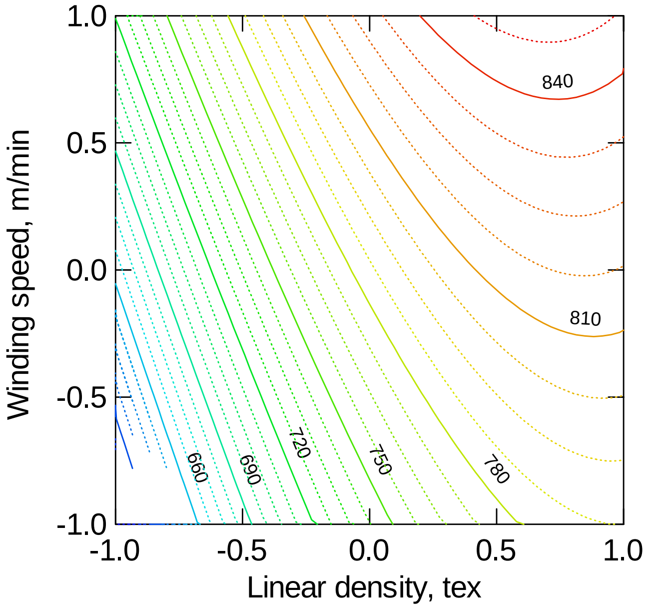


Figure 5. Influence of winding speed and yarn tex on S3 values for jet diameter of 2.2 mm

The influence of jet diameter and yarn linear density on the S3 values for a winding speed of 1200 m/min is shown in Figure 6. From the above contours, the best result is found between -0.5 to 0.0 level of diameter (approx. 2.1 mm), followed by -1.0 level (1.8 mm), and the worst for the case of 1.0 level (2.6 mm). We used CFD modelling in describing the results. We have compared the total air velocities of the jet at 2.2 mm, with the second best jet at 1.8 mm.

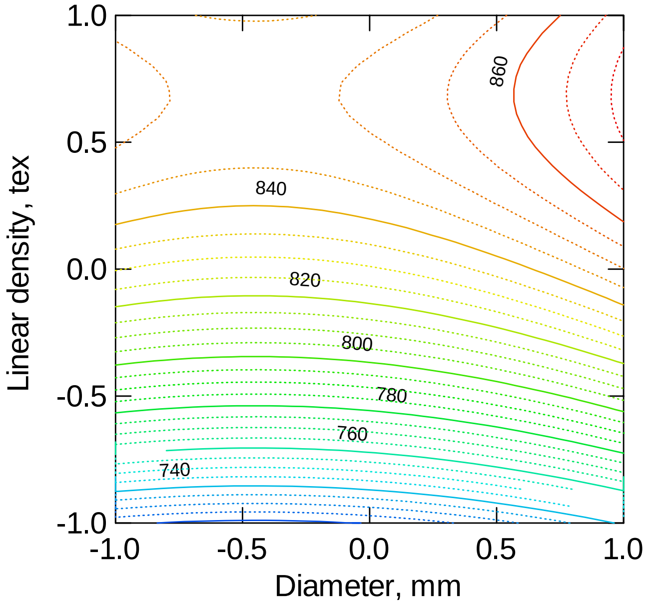
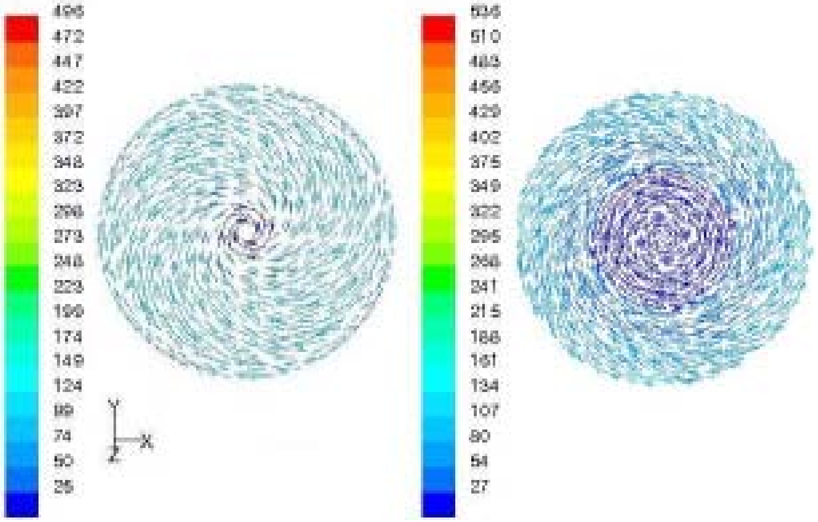


Figure 6. Influence of jet diameter and yarn tex on S3 values for winding speed of 1200 m/min

Figures 7a and 7b show the vector profile of the total air velocity, at a plane near the exit of the jet. In the case of the jet at 2.2 mm, the total air velocity at the centre of the jet is 25 m/s, less than that for the jet at 1.8 mm, where the air velocity is 27 m/s. The jet at 2.2 mm gives a better result in terms of hairiness reduction in comparison to the jet at 1.8 mm. This may be due to the fact that, although the jet 2.2 mm has a slightly lower total air velocity at the centre, the region surrounding the centre of this jet has a comparatively high velocity (approx. 124 m/s) higher than that in the jet at 1.8

mm, where the air velocity is around 27 m/s. This high air velocity observed around the centre of the jet, where protruding hairs are likely to present from the yarn inside the jet, is probably the reason for the better wrapping of fibres around the yarn body in the former case, in comparison to the latter, i.e. the 1.8 jet, end at the some for letter reduction of yarn hairness.



(a) (b)

Figure 7. Vector profile of total air velocities (m/s) of the jets (a) 40º, 2.2 mm (b) 40º, 1.8 mm

Conclusion

By CFD (computational fluid dynamics) analysis of the airflow pattern, an insight into the mechanism of hairiness reduction is obtained. A jet angle of 45^0, 10 tex yarn and a winding speed of 800 m/min gives the best results in terms of hairiness reduction. A jet diameter of 2.2 mm, 10 tex yarn and a lowest winding speed of 800 m/min shows another optimised region. The axial air velocity and air velocity away from the centre of the jet influence the reduction of yarn hairiness.

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Acknowledgement

We are grateful to the Department of Science and Technology, New Delhi, Government of India, for providing funds to carry out a part of this research work through a sponsored research project. We are also grateful to Fluent India Pvt. Ltd. for providing the computational resources to carry out the numerical analysis for the present studies.

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