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Effect of MVS process parameters on knitted fabric characteristics

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Regression analysis of response surface has been used to evaluate the fabric samples made of 100% viscose vortex spun yarns on the basis of air permeability, ball bursting strength, abrasion resistance and fabric thickness. The experimental results reveal that the fabrics knitted with MVS yarns spun at higher yarn delivery speed exhibit lower air permeability. On the other hand, at higher yarn delivery speed, the air permeability of fabrics increases with the increase in nozzle pressure. But, at low yarn delivery speed, the air permeability shows opposite trend with the increase in nozzle pressure. Both ball bursting strength and thickness of MVS yarn fabrics initially decrease with the increase in nozzle air pressure of Murata vortex spinner and then increase. With the increasing yarn delivery speed, ball bursting strength exhibits an initial decrease followed by a rapid increase with further increase in yarn delivery speed, whereas thickness and abrasion resistance of these fabrics improve with the increase in yarn delivery speed. An increase in sliver hank enhances thickness, but has a deleterious effect on abrasion resistance of these fabrics.

Keywords: Abrasion resistance, Air permeability, Ball bursting strength, Fabric thickness, Knitted fabric, Murata Vortex Spun yarn, Viscose yarn

1 Introduction

The quality requirements of knitted fabrics are highly demanding especially in terms of appearance and comfort. Air-jet spun yarns have limited use in knitting due to harsh fabric hand and find use only in woven fabrics such as table cloths, bed-sheets, covers, etc. Murata vortex spinner was developed by Murata Machinery Ltd. to target regular wear and casual markets. Due to the unique mechanism of producing yarn and unique structure of vortex spun yarns, many disadvantages and drawbacks of the fabrics made of ring-spun or air jet spun yarns are overcome by the fabrics made of vortex spun yarns for certain types of end-uses[1]. The performance of fabric made of vortex spun yarns is affected not only by the fabric structure but also by the structure and properties of vortex spun yarns[2-4]. The varying process parameters of vortex spinning will bring about a structure-property change in vortex spun yarns such as fibre alignment categories, spatial configuration within the yarn, fibre packing density of the yarn cross-section, yarn stress relaxation property, yarn tensile property, evenness and hairiness[5-10].

Finally, it affects the performance of fabric made of vortex spun yarns. Previous studies have been confined to the performance comparison of different fabrics made of ring, compact, open-end rotor and vortex spun yarns[11-15]. But there has been little research on the relationship of yarn formation process and fabric performance. Tyagi *et al.*[3,4] studied the low-stress characteristics and thermal comfort characteristics of woven fabrics made of polyester-cotton MVS yarns in relation to twisting jet pressure, delivery speed and nozzle distance. Zou[2] studied the effect of process parameters, namely nozzle pressure, yarn delivery speed and yarn count, on the properties of viscose knitted fabrics. The scarcity of available literature on relationship between yarn process parameters and fabric characteristics leaves the spinners in a state of confusion while deciding the process parameters to spin yarns for fabrics with characteristics at desired levels. The need is being felt for a study which will help the yarn manufacturers for optimization of MVS process parameters for particular end-use of fabrics, and thus will enhance the scope of MVS yarns in the production of knitted garments. The present study focuses on the effects of three MVS process parameters such as yarn delivery speed, nozzle pressure and sliver hank on four output

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responses namely air permeability, ball bursting strength, abrasion resistance and fabric thickness.

2 Materials and Methods

2.1 Samples

100% viscose fibres were used to prepare yarn samples of 30 Ne on Murata Vortex Spinner No. 861 according to experimental plan as per the Box and Behnken design[16]. The actual values of three variables corresponding to the coded levels are given in Tables 1 and 2.

Experimental MVS yarns were used to knit fabric samples on a single jersey circular knitting machine with 22 gauges, 18 inch diameter, 1250 number of needles and 28 feeders. All greige fabrics were scoured, dyed with reactive Everzol Blue ED-G dyestuff and then undergone compaction under the same conditions.

2.2 Test Methods

Conditioning of all yarn and fabric samples was done for 48 h in atmosphere of 20±2 ºC and 65±2 % RH before testing.

Yarn diameter was determined on projection microscope (100 observations/sample) and yarn hairiness on Uster® Tester 5-S-400 in accordance with ASTM D5647 standard.

Fabric air permeability was determined in accordance with ASTM D737-96. Twenty observations for each sample were taken and mean value was calculated.

Ball bursting strength of fabric was determined in accordance with ASTM D3787. Ten tests were carried out for each sample and mean value of ball bursting strength was taken.

Abrasion resistance of fabric was determined by Martindale abrasion tester in accordance with ASTM D3884. Four tests were carried out for each type of fabric samples and average weight loss per 100 cycles was calculated.

Fabric thickness was calculated in accordance with ASTM D1777-96. Fifty observations were taken for each sample and mean value was noted.

Table 1 — Experimental plan for MVS machine variables used for yarn samples

Combination No.	Delivery speed (x_1)	Nozzle pressure (x_2)	Sliver hank (x_3)
1	–1	–1	0
2	1	–1	0
3	–1	1	0
4	1	1	0
5	–1	0	–1
6	1	0	–1
7	–1	0	1
8	1	0	1
9	0	–1	–1
10	0	1	–1
11	0	–1	1
12	0	1	1
13	0	0	0
14	0	0	0
15	0	0	0

Table 2 — Actual values corresponding to coded levels

Coded level	Actual values		
	Delivery speed (x_1), m/min	Nozzle pressure (x_2), MPa	Sliver hank (x_3), Ne
–1	370	0.4	0.14
0	400	0.5	0.16
1	430	0.6	0.18

3 Results and Discussion

3.1 Statistical Analysis

Experimental results for various properties of different MVS yarns and fabrics were input into a computer statistical tool program MATLAB (version R2015a) to obtain the response surface equations using forward step regression procedure. The response surface equations and the squared multiple correlation coefficients of yarns and fabrics are given in Tables 3 and 4 respectively. The negative

Table 3 — Response surface equations for characteristics of yarn

Characteristic	Response surface equation	Squared multiple regression coefficient (R^2)
Diameter mm	$204.02 + 9.54\,x_1 - 23.52\,x_2 - 1.52\,x_3 + 22.62\,x_2^2$	0.96
Hairiness	$3.88 + 0.2275\,x_1 - 0.22\,x_2 - 0.1125\,x_2 x_3$	0.91

Table 4 — Response surface equations for characteristics of fabric

Characteristic	Response surface equation	Squared multiple regression coefficient (R^2)
Air permeability $cm^3/cm^2/mm$	$84.553 - 5.075\,x_1 + 3.306\,x_2 + 10.314\,x_1 x_2 + 7.101\,x_1 x_3$	0.878
Ball bursting strength , KPa	$289.1 + 7.737\,x_1 - 12.237\,x_2 + 10.587\,x_1^2 + 11.937\,x_2^2 - 9.787\,x_3^2 - 10.32\,x_1 x_2$	0.889
Abrasion resistance (weight loss/100 cycles), %	$0.591 - 0.162\,x_1 + 0.088\,x_3 + 0.142\,x_1 x_2 - 0.127\,x_1 x_3$	0.91
Fabric thickness mm	$0.486 + 0.007\,x_3 - 0.149\,x_1^2 + 0.012\,x_2^2 + 0.013\,x_1 x_2 + 0.01\,x_1 x_3$	0.88

coefficient of a variable in a response surface equation indicates that a particular characteristic decreases with the increase in that variable, whereas a positive coefficient of the variable indicates an increase in the characteristic with the increase in variable. The sign and magnitude of the coefficients of the squared terms and interaction terms modify the trend. This is shown in the spatial diagrams (Figs 1-4) drawn from the response surface equations.

3.2 Yarn Parameters

The response surface equations for yarn diameter and yarn hairiness are given in Table 3. Effect of nozzle pressure is most significant and nonlinear. As the nozzle pressure increases, yarn diameter initially decreases and then slightly increases. This decrease in diameter with increasing nozzle pressure can be accounted to increased incidence of wrapper fibres and tight regular wrappings. Increase in diameter with further increase in nozzle pressure may be attributed to the increased number of wild fibres and irregular wrappings. It is clear from Table 3 that yarn hairiness also reduces with the increase of nozzle pressure. It may be due to the fact that the wrapper fibres whirl around the yarn core with a greater force when the nozzle air pressure is increased. Yarn delivery speed also influences yarn diameter and hairiness significantly. As the yarn delivery speed increases, yarn diameter and hairiness both exhibit an increase.

3.3 Fabric Characteristics

3.3.1 Air Permeability

The three dimensional response surfaces in Fig.1 depict the nature of the variation in air permeability of the fabrics made of MVS yarns with the change in process parameters. Yarn delivery speed is the most important parameter in influencing air permeability of MVS yarn fabrics followed by nozzle pressure. In general, the air permeability is lower for the MVS yarn fabrics knitted with yarns spun at higher yarn delivery speed. Yarn delivery speed determines the residence time of fibres in yarn formation zone. As

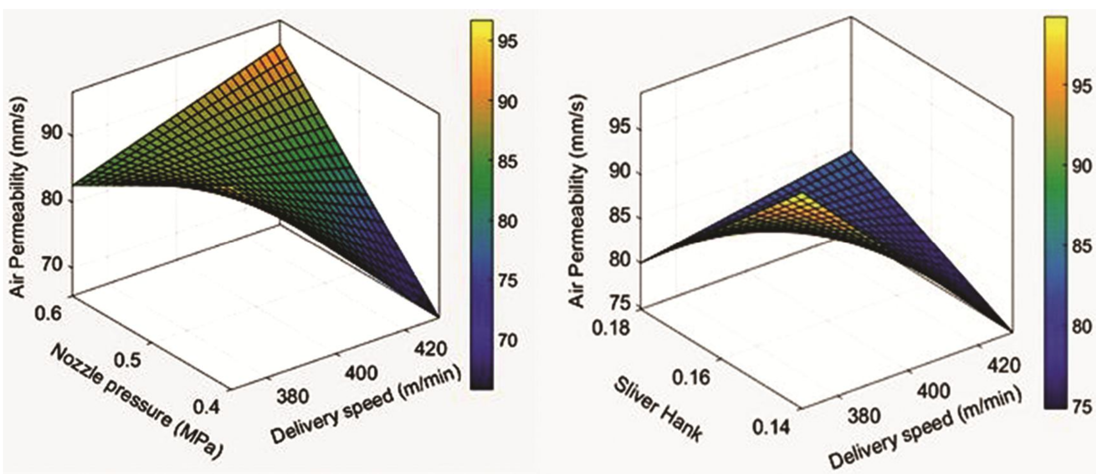

Fig. 1 — Response surface plots for the effect of process variables on fabric air permeability

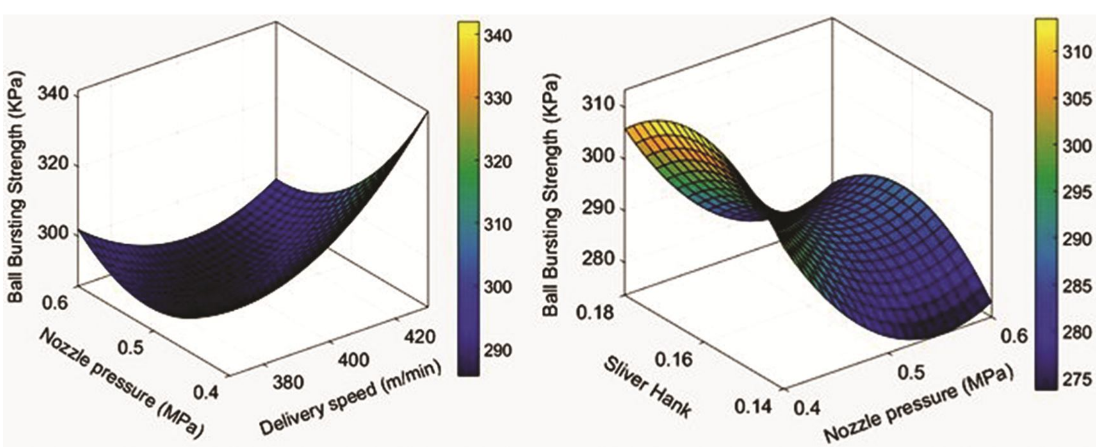

Fig. 2 — Response surface plots for the effect of process variables on fabric ball bursting strength

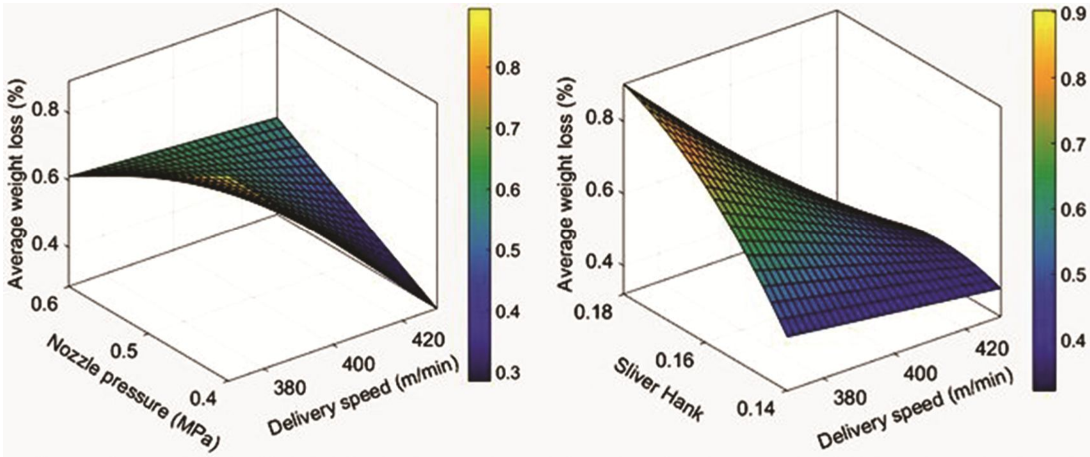

Fig. 3 — Response surface plots for the effect of process variables on fabric abrasion resistance

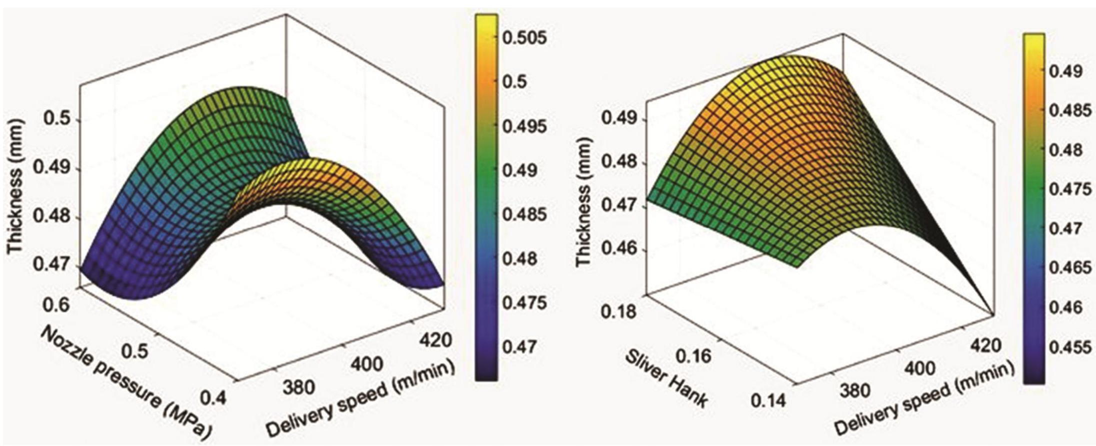

Fig. 4 — Response surface plots for the effect of process variables on cloth thickness

the yarn delivery speed increases, it deteriorates the yarn structural integrity, which, in turn, leads to an increase in yarn diameter and hairiness and consequently, less space is available in fabric for the passage of air, which, in turn, leads to low air permeability of fabrics. The yarn delivery speed affects the air permeability of MVS yarn fabrics in interaction with both sliver hank and nozzle air pressure. It is evident from Fig. 1 that the effect of yarn delivery speed on air permeability is more pronounced at smaller sliver hank and the trend is much less pronounced and actually opposite at higher sliver hank. The air permeability of MVS yarn fabrics shows a marked change in air permeability with the change in nozzle air pressure also. At higher yarn delivery speed, air permeability of fabrics increases with the increase of nozzle pressure. This is expected to be the consequence of the increase in tight regular wrappings and incidence of wrapper fibres, which result in a compact yarn with reduced hairiness. However, at low yarn delivery speed, air permeability shows opposite trend with the increase in nozzle pressure, probably due to irregular wrappings and wild fibres, which, in turn leads to an increase in yarn diameter and hairiness leaving less space for the passage of air. From Table 4, it is shown that R^2 value of the model is 0.878, which means that 87.8 % variation can be explained by this model and only 12.2 % of total variation cannot be explained, which is an indication of good accuracy.

3.3.2 Ball Bursting Strength

Knitted fabrics strength is best assessed by conducting ball bursting strength test, which involves pushing a steel ball of diameter 25 mm through stretched fabric and force required to do so is recorded. The three dimensional response surfaces (Fig. 2) depict the nature of the variation in ball bursting strength of MVS yarn fabric with the change in process parameters. Response surface equation

(Table 4) clearly shows that the ball bursting strength of fabrics is affected significantly by yarn delivery speed and nozzle pressure in their linear, quadratic and interaction terms, while sliver hank affects ball bursting strength of fabrics in its quadratic term only. The value of R^2 indicates that 88.9 % variations in ball bursting strength can be explained by this model and only 11.1 % of total variations cannot be explained, which is an indication of good accuracy. In general, Ball bursting strength is higher for the MVS yarn fabrics knitted with yarns spun at lower nozzle pressure. As the nozzle pressure increases from 0.4 MPa to 0.5 MPa, the ball bursting strength of fabrics reduces, which is expected to be the consequence of the increase in tight regular wrappings and incidence of wrapper fibres. This results in a compact yarn with reduced hairiness, which, in turn, reduces the compactness of fabric structure with increased yarn mobility and thus reducing ball bursting strength. However, on further increase in nozzle pressure up to 0.6 MPa, ball bursting strength shows a slight increase. This is attributed to the increase in irregular wrappings and wild fibres, which increases yarn diameter and thus compactness of fabric structure with reduced yarn mobility. The correlation coefficient between yarn diameter and fabric ball bursting strength is found to be 0.7488, which is very high and is indicative of a very good relation between knitted fabric ball bursting strength and its structural compactness. The ball bursting strength of MVS yarn fabrics shows a slight decrease with the increase of yarn delivery speed from 370 m/min to 400 m/min. This is attributed to the reduced staying time in yarn formation zone at higher delivery speed, which deteriorates yarn structural integrity and low wrapping strength. However, for fabrics knitted with yarns spun at yarn delivery speed (>400), ball bursting strength increases rapidly. This is due to the production of bulky yarns with an increase in irregular wrappings at higher yarn delivery speed, which, in turn, increases the compactness of fabric structure with reduced yarn mobility.

3.3.3 Abrasion Resistance

The fabric abrasion resistance is best assessed by the average weight loss/100 cycles (%). A lower weight loss/100 cycles (%) means excellent abrasion resistance of fabric and vice versa. Figure 3 shows three dimensional response surfaces constructed to show the effects of the yarn process parameters (yarn delivery speed, nozzle pressure and sliver hank) on the fabric abrasion resistance. It is evident from Table 4 that yarn delivery speed and sliver hank affect the fabric abrasion property in linear terms and interaction terms, whereas nozzle pressure has no significant effect on fabric abrasion property (p-values > 0.05). In general, fabrics made of MVS yarns spun at higher delivery speed have more fabric abrasion resistance. This is expected to be the consequence of bulky yarn caused by the short staying time of open-end trailing fibres in the twisting chamber, which, in turn, makes the fabric structure more compact, resulting in lower fabric weight loss rate. With the increase in sliver hank, weight loss perceptibly increases. This is due to the feeding of fine slivers to produce yarn of same count; main draft ratio becomes low, making the drafting force (in drafting zone) lower than the peak value basically achieved by the optimum draft level. This, in turn, causes poor fibre slipping performance. This lower main draft is not enough to acquire appropriate fibre arrangement along the yarn, consequently reducing abrasion property of the fabric. From Table 4, it is evident that R^2 value of the model is 0.91. The meaning behind this is that 91 % variation can be explained by this model and only 9 % of total variation cannot be explained, which is an indication of good accuracy.

3.3.4 Fabric Thickness

Effect of process variables on fabric thickness of viscose vortex spun yarn fabrics are shown in Fig. 4. Fabric thickness is influenced significantly by sliver hank and quadratic terms of yarn delivery speed and nozzle pressure (Table 4). There is high degree of correlation between the calculated and the experimental values as reflected by high values of R^2 (0.88). In general, thickness is lower for MVS yarn fabrics knitted with yarns spun at higher nozzle air pressure. This is expected to be the consequence of yarn compactness, which increases due to increase in incidence of wrapper fibres and tight regular wrappings at higher nozzle air pressure. However, for fabrics knitted from yarns spun above 0.5 MPa nozzle pressure, fabric thickness slightly increases due to larger yarn diameter owing to an increase in irregular wrappings and wild fibres at higher nozzle air pressure. It is evident from Fig. 4 that yarn delivery speed is also a dominant factor for thickness of MVS yarn fabrics. Thickness is generally more for fabrics knitted with yarns spun at higher yarn delivery speed, which could be due to a looser yarn structure and coarser yarn diameter, caused by the shortened staying time of open-end trailing fibres in the twisting chamber at higher yarn delivery speed. Bulkier and thicker MVS yarn fabrics are produced when MVS yarns are spun from thinner slivers. This is possibly due to the fact that feeding finer slivers leads to lowering of main draft ratio, which makes the drafting force lower than the optimum draft level. This lower value of main draft causes poor fibre slipping performance and is not enough to acquire appropriate fibre arrangement along the yarn.

4 Conclusion

It may be concluded that fabrics knitted with MVS yarns spun at higher yarn delivery speed exhibit lower air permeability. At higher yarn delivery speed, air permeability of fabrics increases with the increase of nozzle pressure. But at low yarn delivery speed, air permeability shows opposite trend with the increase in nozzle pressure. Both ball bursting strength and thickness of MVS yarn fabrics initially decrease with the increase in nozzle air pressure and then increase on further increase in nozzle air pressure from 0.5 MPa to 0.6 MPa. The ball bursting strength also seems to depend on the yarn delivery speed, and any increase in yarn delivery speed leads to a decrease in ball bursting strength of MVS yarn fabrics. However, the ball bursting strength increases rapidly as the yarn delivery speed is increased further above 400 m/min. Both the yarn delivery speed and sliver hank are predominant factors contributing to fabric thickness, and any increase in these parameters leads to an increase in thickness of MVS yarn fabrics. The abrasion resistance of MVS yarn fabrics is significantly influenced by both yarn delivery speed and sliver hank. In general, fabrics made of MVS yarns spun at higher delivery speed or by feeding coarse slivers have more fabric abrasion resistance.

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