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Influence of the Yarn Formation Process on the Characteristics of Viscose Fabric Made of Vortex Coloured Spun Yarns

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Abstract
In this study, based on the Box-Behnken design, regression statistical analysis is introduced to evaluate the influence of yarn formation process variables (nozzle pressure, yarn delivery speed and yarn count) on the properties (breaking strength, air permeability rate, dynamic drape coefficient and mass loss rate) of viscose fabric fabricated from vortex colored spun yarns. Quadratic regression models for response variables affected by different combinations of model items are given. Research results show that the air permeability rate and dynamic drape coefficient for viscose fabric decreases with an increase in the yarn delivery speed from 320 to 380 m/min, while the fabric mass loss rate and fabric breaking strength are less affected by the yarn delivery speed. The mass loss rate of viscose fabric increases, reaches a peak, and then decreases with increasing nozzle pressure, while its dynamic drape coefficient, affected by the nozzle pressure, takes on the opposite trend. However, nozzle pressure has less significant effects on fabric breaking strength and fabric air permeability. The air permeability rate and mass loss rate of viscose fabric increases firstly and then decreases with a decreasing yarn count, while the effect of yarn count on the fabric breaking strength and dynamic drape coefficient exhibits an opposite trend. Decreasing the yarn count makes the fabric dynamic drape coefficient drop firstly and then augment.

Key words: *Vortex spinning, yarn formation process, fabric, performance analysis.*

Introduction

Vortex spinning technology, making high whirl airflow twisting open-end trailing fibres into yarn, has achieved great success in the textile industry at present [1]. Rieter's J20 and Murata's No. 870 and No. 861, being marketed worldwide, are successful applications of vortex spinning technology, having the highest productivity and prominent yarn properties for present yarn manufacturing. The combination of coloured spinning and vortex spinning technologies diversifies the pattern of vortex spun yarns, making the resultant fabrics have the effect of three dimensional mixed colours, which creates a twilight and beautiful vision. Fabric made of vortex spun yarns has outstanding resistance to pilling and abrasion, high moisture absorption and diffusion properties, as well as quick drying characteristics [2 - 4]. 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 yarn. The varying process parameters of vortex spinning will bring about a structure-property change in vortex spun yarn, such as fibre alignment categories and spatial configuration within the yarn, the fibre packing density of the yarn cross-section, yarn stress relaxation property, yarn tensile property, yarn flexural rigidity, yarn unevenness, yarn imperfections, and yarn hairiness, and so on [5 - 12]. Finally it affects the performance of fabric made of vortex spun yarns.

Pervious studies have reported a performance comparison of different fabrics made of ring, compact, open-end rotor and vortex spun yarns [2, 4]. The low-stress characteristics of scoured and finished fabrics woven with polyester-cotton MVS yarns produced by varying process parameters, such as the twisting jet pressure, nozzle distance, and delivery speed, were analyzed by Tyagi et al, showing that chemical finishing makes the compressional energy, shear energy, coefficient of friction and bending rigidity decrease significantly [13]. However, there has been little research on the relationship of the yarn formation process and fabric performance. The aim of this study was to investigate the influence of

Table 1. *Actual values corresponding to coded levels.*

Coded variable level	Actual value		
	Nozzle pressure x_1, MPa	Delivery speed x_2, m/min	Reciprocal of yarn count x_3, 1/tex
-1	0.45	320	1/29.52
0	0.50	350	1/19.68
1	0.55	380	1/14.76

Table 2. *Experimental plans for MVS machine variables used for vortex coloured spun yarn samples.*

Combination No.	Nozzle pressure x_1, MPa	Delivery speed x_2, m/min	Reciprocal of yarn count x_3, 1/tex
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

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the yarn formation process, such as nozzle pressure, yarn delivery speed and yarn count, on the performance characteristics of viscose fabric made of vortex coloured spun yarns.

Materials and methods

Materials and preparation of yarn and fabric samples.

The Box-Behnken Design, being that for quantitative factors with all factors on three levels, was applied in this work to investigate the effect of process variables for preparing vortex coloured spun yarns on the properties of knitted fabrics made therefrom. Actual values corresponding to coded levels for yarn formation process variables in this experiment are listed in ***Table 1***. Experimental plans of preparing vortex colored yarn samples spun by an MVS No. 861 machine are shown in ***Table 2***. All yarn samples consisted of a 60/40 colored/gray viscose fibre mixture, whose properties are given in ***Table 3***. All yarn samples were spun by the following process parameters: 19 g/5 m sliver weight, 4mm condenser specification, 20 mm distance between the front roller nip point and hollow spindle, 1.1 mm hollow spindle inner diameter, 130 d, L 8 - 8.8 needle holder, 1.00/0.99 feed ratio/take up ratio, and 41 × 43 mm roller settings. The coloured viscose fibre was dyed by reactive dyes of 3BSH and 3RN as well as RK10 (mass percentage: 0.73%, 1.22% and 4%, respectively). Fabrics were knitted from the yarn samples designed on a loop wheel knitting machine with the same knitting process.

Table 3. *Fibre properties.*

Viscose fibre	Properties				
	Length, mm	Fineness, dtex	Breaking strength, cN/tex	Percentage elongation at break, %	Initial modulus, cN/dtex
Grey fibre	38	2.03	22.4	23.69	39.96
Colored fibre	38	2.12	21.3	23.28	39.25

Table 4. *Experimental responses of viscose fabric fabricated from vortex colored spun yarns.*

Combination No.	Breaking strength Y_1, N	Air permeability rate Y_2, mm/s	Dynamic drape coefficient Y_3, -	Mass loss rate Y_4, %
1	95.6	3155.34	60.79	0.431
2	129.0	3200.68	62.25	0.452
3	116.1	2802.87	57.37	0.635
4	117.2	2867.03	61.17	0.401
5	197.1	2403.78	58.78	0.565
6	148.1	2476.07	62.44	0.511
7	135.0	2343.27	60.42	0.398
8	124.0	2221.01	64.46	0.163
9	167.3	2702.55	61.55	0.748
10	183.1	2287.22	60.02	0.514
11	146.4	2907.55	59.63	0.579
12	130.1	2128.63	59.54	0.484
13	107.5	2697.37	56.82	0.851
14	121.5	2790.91	55.98	0.814
15	103.3	2719.95	54.89	0.878

Test methods

A Desktop Dual Column Electronic Universal Materials Testing Machine (H-10K- L, America Tinius Olsen) was used to test the tensile properties of fabric samples. Three tests for one fabric sample were done according to tensile test parameters as follows: a specimen test gauge length of 100 mm and extension rate of 100 mm/min. The air permeability of the fabric sample was measured by a Digital Air Permeability Tester (YG (B) 461E-II, Wenzhou Darong Textile Instrument Co., Ltd, in China), using a circular vent of 20 cm^2 and nozzle of No. 8. The resultant value of fabric air permeability for one fabric sample is the mean of 5 test values. The fabric draping ability was assessed by the dynamic drape coefficient, which was determined by a computer-aided fabric drape tester (YG811D-2, Nantong SanSi Electromechanical Science & Technology Co., Ltd, in China). A dynamic drape image of a fabric sample with a diameter of 240 mm was captured by CCD camera at a rotational speed of 100 r/min and was sent to a computer to analyse the dynamic drape coefficient. The abrasion resistance of the fabric sample was measured by a disk fabric abrasion machine (Y522, Ningbo Textile Instrument Factory, in China), according to ASTM Method D3884. The fabric abrasion property in this experiment was assessed by the mass loss rate of the fabric sample after 50 friction times.

Results and discussion

Statistical analysis

Experimental responses of viscose fabric fabricated from vortex coloured spun yarns are given in ***Table 4***. For the three-level three-factorial Box-Behnken experimental design, the relationship between the response variable and independent variable can be shown by ***Equation 1***:

$$Y = b_0 + \sum_{i=1}^{n} b_i x_i + \sum_{i=1}^{n} b_{ii} x_i^2 + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} b_{ij} x_i x_j \quad (1)$$

where, Y is the predicted response, and b_0, b_i, b_{ii} & b_{ij} are coefficients of the model constant, linear terms, quadratic terms and interaction terms, respectively, estimated from experimental results by computer simulation and applying the least square method using Minitab Statistical Analysis Software (version No. 16).

Except for linear terms, any model terms having probability values (p-value) larger than 0.05 (indicating statistical significance at 95% confidence level) were discarded. Quadratic regression models for different response variables, such as the breaking strength, air permeability rate, dynamic drape coefficient and mass

$$Y_1 = 112.886 - 3.1875x_1 + 1.025x_2 - 20.0125x_3 + 41.0018x_3^2 \quad (2)$$

$$Y_2 = 2774.52 + 7.44125x_1 - 235.046x_2 - 3\ .645x_3 + 203.123x_2^2 - 442.324x_3^2 \quad (3)$$

$$Y_3 = 55.8967 + 1.62x_1 - 0.765x_2 + 0.1575x_3 + 2.91917x_1^2 + 1.57917x_3^2 + 2.70917x_3^2 \quad (4)$$

$$Y_4 = 0.787385 - 0.06275x_1 - 0.022x_2 - 0.08925x_3 - 0.262423x_1^2 - 0.160923x_3^2 \quad (5)$$

Equations 2 - 5.

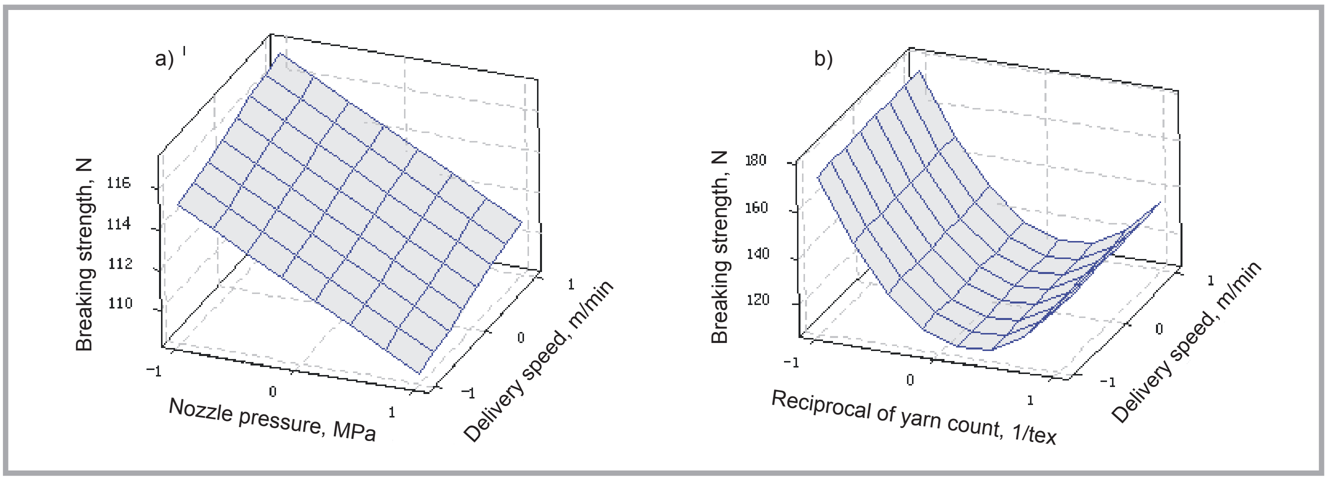

Figure 1. *Response surface plots for the effect of nozzle pressure, delivery speed and reciprocal of yarn count on fabric breaking strength: a) nozzle pressure & delivery speed, b) reciprocal of yarn count & delivery speed.*

loss rate are given by ***Equations 2 - 5***, respectively:

A minus sign in front of the model item coefficient denotes that the increasing factor value is negative for the change of response variable, while a positive coefficient value of the model item denotes that response the variable increases with an increasing factor value. Squared multiple regression coefficients of regression models for the breaking strength, air permeability rate, dynamic drape coefficient and mass loss rate are 0.8066, 0.9241, 0.8937 and 0.7979, respectively. A higher squared multiple regression coefficient value of the regression model indicates that there was good agreement between the experimental and predicted values from the model. ***Table 5*** shows the analysis of variance for response surface quadratic models for different response variables, such as the breaking strength, air permeability rate, dynamic drape coefficient and mass loss rate. The model term has a significant effect on the response variable if its p-value is less than 0.05. A p-value of the lack of fit more than 0.05 indicates that the quadratic regression model for the response variable is reasonable. For all response variables selected in this paper, interaction actions between the yarn formation process variables are insignificant to the response.

Fabric breaking strength

Based on the P values shown in ***Table 5***, the reciprocal of yarn count and its quadratic term were found to have significant effects on the fabric breaking strength, whereas the nozzle pressure and yarn delivery speed showed a less effect on the breaking strength of viscose fabric made of vortex coloured spun yarns prepared. ***Figure 1*** shows three dimensional response surfaces constructed to show the effects of the yarn formation process (nozzle pressure, yarn delivery speed and yarn count) on the fabric breaking strength Y1. The fabric breaking strength decreases slightly with enhancing nozzle pressure and increases slowly with increasing yarn delivery speed, as can be seen from ***Figure 1***. However, decreasing the yarn count makes the fabric breaking strength drop firstly and then augment, with the lowest fabric breaking strength given as the yarn count being 19.68 tex. Previous research has shown that coarser yarn yields better yarn tensile properties [14]. However, compared with the breaking strength of fabric made of 30 Ne yarns, that of fabric made of thinner yarns (14.76 tex) is higher, which may be caused by the variation of fabric structure due to yarn count change.

Table 5. *Analysis of variance for response surface quadratic models for different response variables.*

Source of data	Breaking strength Y_1, N		Air permeability rate Y_2, mm/s		Dynamic drape coefficient Y_3, -		Mass loss rate Y_4, %	
	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value
x_1	0.35	0.565	0.04	0.856	16.52	0.004	2.60	0.141
x_2	0.04	0.852	35.01	0.000	3.68	0.091	0.32	0.586
x_3	13.96	0.004	0.72	0.419	0.16	0.703	5.26	0.047
x_1^2	-	-	-	-	24.76	0.001	21.12	0.001
x_2^2	-	-	12.14	0.007	7.24	0.027	-	-
x_3^2	27.35	0.000	57.57	0.000	21.32	0.002	7.94	0.020
Model	10.43	0.001	21.93	0.000	11.20	0.002	7.11	0.006
Linear term	4.78	0.026	11.92	0.002	6.79	0.014	2.73	0.106
Quadratic term	27.35	0.000	36.93	0.000	15.62	0.001	13.67	0.002
Lack of fit	2.91	0.281	6.53	0.139	1.48	0.457	14.80	0.065

Air permeability property

The fabric air permeability property can be characterised well by the air permeability rate. A low air permeability rate means the fabric has a bad air permeability property, and vice versa. For the air permeability property of viscose fabric made of vortex coloured spun yarns, it is affected significantly by the yarn delivery speed and its quadratic term, as well as the quadratic term of the reciprocal of the yarn count, while nozzle pressure has less significant effects on the fabric air permeability, as can be seen from ***Table 5***. Response surface plots of the fabric air permeability rate affected by the yarn formation process, such as nozzle pressure, yarn delivery speed and yarn count, are shown in ***Figure 2***.

The air permeability rate of viscose fabric takes a downward trend when the yarn delivery speed varies from 320 m/min to 380 m/min, which could be accounted for by the fact that a looser yarn structure and coarser yarn diameter, caused by the shortener staying time of open-end trailing fibres in the twisting chamber at a lower yarn delivery speed, makes the fabric have less pore space between yarns, resulting in a bad fabric air permeability property. The air permeabil-

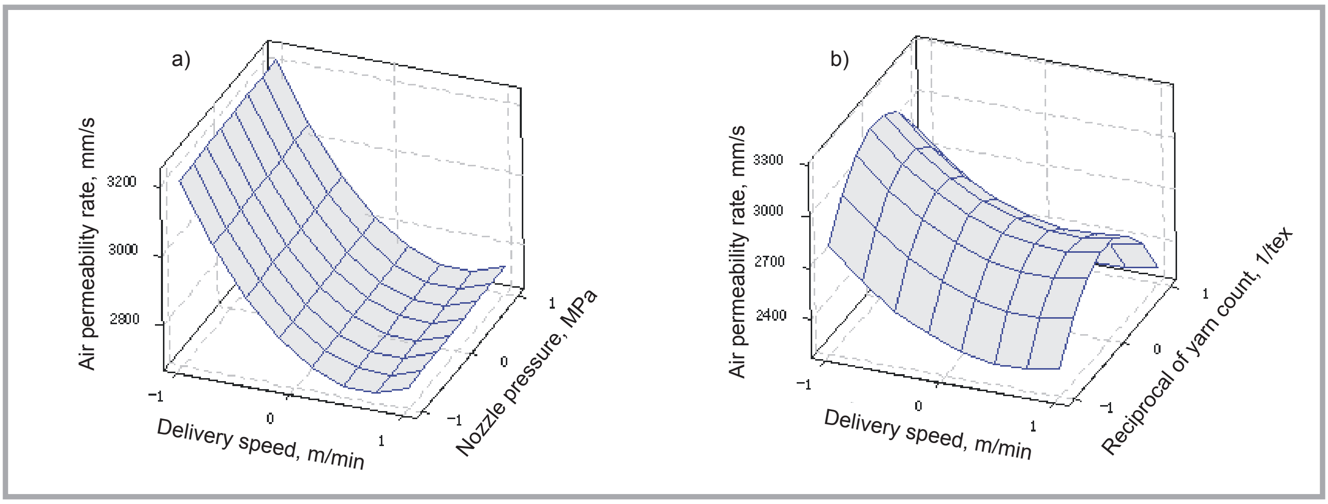

Figure 2. *Response surface plots for the effect of the nozzle pressure, delivery speed and reciprocal of the yarn count on the fabric air permeability rate: a) nozzle pressure & delivery speed, b) reciprocal of yarn count & delivery speed.*

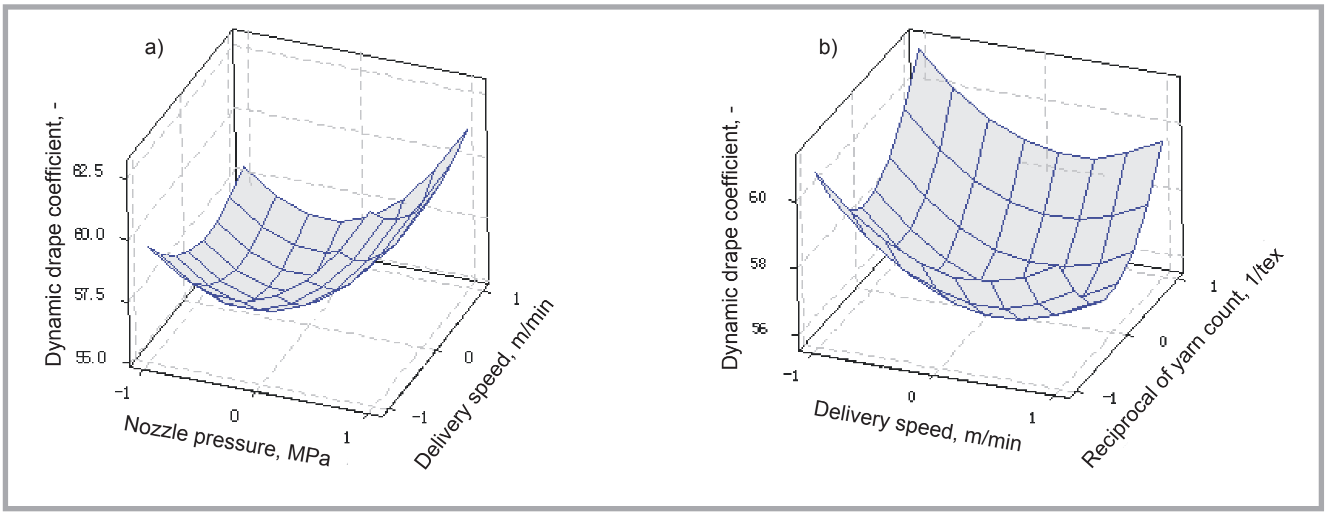

Figure 3. *Response surface plots for the effect of the nozzle pressure, delivery speed and reciprocal of the yarn count on the fabric dynamic drape coefficient: a) nozzle pressure & delivery speed, b) reciprocal of yarn count & delivery speed.*

ity rate of viscose fabric increases firstly and then decreases with a decrease in the yarn count from 29.52 tex to 14.76 tex, the reason for which may be that coarser vortex yarn has more fibres in the yarn cross-section, resulting in fabric with a more compact structure and less pore space, and then a decrease in the fabric air permeability property. When the yarn count is lower, the same nozzle pressure acts on the reduced open-trailing fibres in the twisting chamber, resulting in a more compact yarn structure and more yarn hairiness for thinner vortex yarn, and then a decrease in the air permeability property of fabric made with the same knitting process parameters.

Dynamic drape behaviour

Drapability, considered to be one of the important properties for fabric, can be assessed by static and dynamic behaviors, which are mostly related to the beautiful appearance of clothes [15]. The dynamic drape coefficient of fabric is used to discuss the dynamic drapability of viscose fabric made of vortex coloured spun yarns. A lower dynamic drape coefficient means fabric with better drapability. The analysis of variance shows that the drapability of viscose fabric is affected significantly by the nozzle pressure (p-value is 0.004) and quadratic terms of three process variables used in the experiment (all p-values are less than 0.05), as given in ***Table 5***. ***Figure 3*** shows the three-dimensional response surfaces which were constructed to show the effects of the yarn formation process variables (nozzle pressure, yarn delivery speed and yarn count) on fabric dynamic drape behaviour.

As can be seen from ***Figure 3***, when the nozzle pressure is lower than 0.5 MPa, the fabric dynamic drape coefficient decreases slightly with an increase in the nozzle pressure, resulting in an improvement in the drapability property of viscose fabric, while a higher nozzle pressure will make the fabric dynamic drape coefficient increase sharply, resulting in a worse fabric drapability property, which is caused by high yarn bending rigidity. The reason is that open-end trailing fibres wrap around the yarn body tightly in the twisting chamber due to the higher airflow force under higher nozzle pressure. Improving the yarn delivery speed from 320 m/min to 380 m/min makes the value of the fabric dynamic drape coefficient drop slowly, because of the lower yarn bending rigidity caused by shortening the staying time of open-end trailing fibres in the twisting chamber at a higher yarn delivery speed. The fabric dynamic drape coefficient decreases firstly and then in-

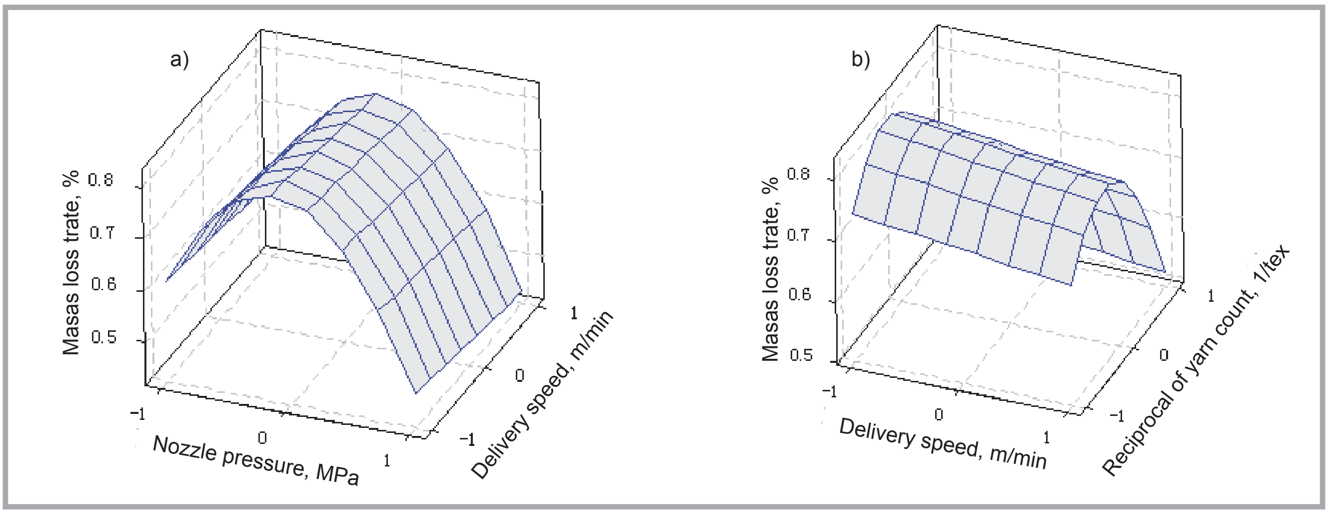

Figure 4. *Response surface plots for the effect of the nozzle pressure, delivery speed and reciprocal of the yarn count on the fabric mass loss rate:* a) nozzle pressure & delivery speed, b) yarn count & delivery speed.

creases with an decrease in yarn count from 29.52 tex to 14.76 tex. The dynamic drapability property of viscose fabric made of coarser coloured vortex yarns is worse, because the yarn has more fibres in the yarn cross section and the fabric structure is more compact for a coarser yarn diameter. Viscose fabric made of thinner coloured vortex yarn also has a bad dynamic drapability property for a compact yarn structure, caused by the higher airflow force acting on open-trailing fibres in the twisting chamber due to reduced fibres in the thinner yarn cross section.

Fabric abrasion property

The fabric abrasion property is assessed by the mass loss rate due to periodic dynamic friction. A lower mass loss rate of fabric means its excellent abrasion property. From the analysis of variance for the mass loss rate seen in ***Table 5***, the p-values of x_3, x_1^2 and x_3^2 are less than 0.05, which indicates that the mass loss rate of viscose fabric is affected by the reciprocal of the yarn count and its quadratic term, as well as the quadratic term of the nozzle pressure. Response surface plots under 50 times periodic dynamic friction for the effect of nozzle pressure, delivery speed and yarn count on the fabric mass loss rate are presented in ***Figure 4***. The response plots show that the mass loss rate of viscose fabric increases, reaches a peak, and then decreases when the nozzle pressure increases from 0.45 MPa to 0.55 MPa. The fabric structure may be more compact, which is caused by the coarser yarn diameter under lower nozzle pressure, resulting in a lower fabric mass loss rate. However, a higher nozzle pressure also makes the fabric mass loss rate drop, because a too high nozzle pressure makes the yarn structure more compact due to a higher twisting airflow force. Compared with the effect of nozzle pressure on the fabric mass loss rate, the yarn count has a reverse effect on it. Viscose colored yarn with a high yarn count has a higher fibre number in the yarn cross section, which makes the fabric structure more compact and thick, resulting in a low fabric mass loss rate. When the yarn count is lower, a decreasing fibre number in the yarn cross section means a higher airflow force acting on open-trailing fibres in the twisting chamber, resulting in a more compact yarn structure, and then an improving fabric abrasion resistance. However, increasing the yarn delivery speed will make the fabric mass loss rate drop slightly due to a looser yarn structure caused by the shortening staying time of open-end trailing fibres in the twisting chamber.

Conclusions

The influence of process variables on the properties of viscose fabric fabricated from vortex coloured spun yarns was analyzed by the regression analysis of different response variables, such as the breaking strength, air permeability rate, dynamic drape coefficient and mass loss rate. The higher squared multiple regression coefficient value determined in this paper shows a good quality of the fitting of the quadratic regression model to the response variable. Different response variables are affected by different model items. The fabric breaking strength is significantly affected by the reciprocal of the yarn count and its quadratic term. The air permeability property of viscose fabric is affected significantly by the yarn delivery speed and its quadratic term, as well as by the quadratic term of the reciprocal of the yarn count, while the nozzle pressure has less significant effects on fabric air permeability. The drapability of viscose fabric is affected significantly by the nozzle pressure and quadratic terms of the three process variables used in the experiment. The mass loss rate of viscose fabric is affected by the reciprocal of the yarn count and its quadratic term, as well as the quadratic term of the nozzle pressure.

The fabric breaking strength decreases slightly with the enhancement of the nozzle pressure and increases slowly with an increase in the yarn delivery speed, while the effect of gthe nozzle pressure and yarn delivery speed on the fabric breaking strength is not significant. Decreasing the yarn count from 29.52 tex to 14.76 tex makes the fabric breaking strength drop firstly and then augment slightly. The air permeability rate of viscose fabric decreases when the yarn delivery speed varies from 320m/min to 380m/min. However, a decreasing yarn count firstly makes the air permeability rate increase, and then decrease. The dynamic drape coefficient decreases at first and then increases with improving nozzle pressure or a decreasing yarn count. Increasing the yarn delivery speed makes the fabric dynamic drape coefficient decrease slowly. The mass loss rate of viscose fabric increases, reaches a peak, and then decreases with increasing nozzle pressure or decreasing yarn count.

Increasing the yarn delivery speed makes the fabric mass loss rate drop slightly.

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