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Evaluation of the Significance of Processing Parameters for the Characteristics of Interlaced Yarn

Abstract
We studied the significance of three processing parameters: pressure of the air supplied, yarn speed and overfeed ratio for the number and strength of tangles of interlaced yarn and the correlation between the number of tangles and strength of tangles by the statistical method. The interlaced yarn was characterised by the number and strength of tangles. Interlaced yarn was produced by an interlacer with a yarn duct of elliptical cross-section. Factorial analysis and correlation analysis methods were used. After carrying out the analysis and discussion, it was discovered that the overfeed ratio is the most important processing parameter with respect to the number of tangles. The yarn speed is the most important processing parameter with respect to the strength of tangles. To fully characterise interlaced yarn, it is necessary to test both the number of tangles and their strength.

Key words: *interlaced yarn, significance, processing parameters, statistical method.*

Introduction

Interlacing is an effective and convenient method of imparting a desired cohesive force to multi-filament yarn to facilitate post-processing. The characteristics of interlaced yarn strongly affect the performance of final products. Since the advent of the first patent for interlacing in 1961, many researches have been conducted. A lot of papers have paid great attention to the effects of processing parameters, such as the air pressure supplied, yarn speed and overfeed ratio, on interlaced yarn characteristics [1, 2]. However, they did not mention which processing parameter is the most important for the characteristics of interlaced yarn. Knowing the most significant processing parameter is helpful to produce the interlaced yarn desired in a factory. Furthermore, among most of those papers, the characteristics of interlaced yarn were evaluated only by the number of tangles [2, 3]. The number of tangles only indicates the number of tangled parts per unit length in an interlaced yarn, not the durability of tangled parts under the action of a force. The correlation between the number and strength of tangles is discussed to find whether it is proper to evaluate the characteristics of interlaced yarn by the number of tangles only.

The statistic method can help us to find relations between the experimental conditions and experimental results [4, 5]. Furthermore, it gives us some clues to carry out more exhaustive research. SPSS (Statistical Package for the Social Sciences, SPSS Inc., Chicago, IL) is one of the most widely used statistic software in the world for analysing data [6-8].
In this study, SPSS was used to perform factorial ANOVA (analysis of variance) and correlation analysis to evaluate the significance of three processing parameters: supplied air pressure, yarn speed and overfeed ratio for the number and strength of tangles of interlaced yarn and to implement correlation analysis to investigate the correlation between the number and strength of tangles in the interlaced yarn.

Experiments

Raw yarn made of polyester multi-filament, 16.7 tex/48 filaments, was used as a test material.

The interlacer used in this experiment is shown in ***Figure 1***. ***Figure 1.a*** shows the size of the interlacer, and ***Figure 1.b*** shows the size of the yarn duct, which is of elliptic cross-section.

The experiment was carried out under the following conditions: the air pressure supplied (gauge pressure) p was regulated from 0.1 to 0.5 MPa with a step of 0.1 MPa; the yarn speed v was changed from 200 to 800 m/min with a step of 200 m/min; the overfeed ratio F_R, the percentage of the feeding speed in excess of the delivery speed, was changed from 1 to 5% with a step of 1%. The initial yarn tension was fixed at 4.41 mN/tex during the interlacing process.

For each interlaced yarn sample, three specimens were taken from different parts of the interlaced yarn package. The length of each specimen was 12 m. We distinguished the tangled parts and 'open' parts in the interlaced yarn using

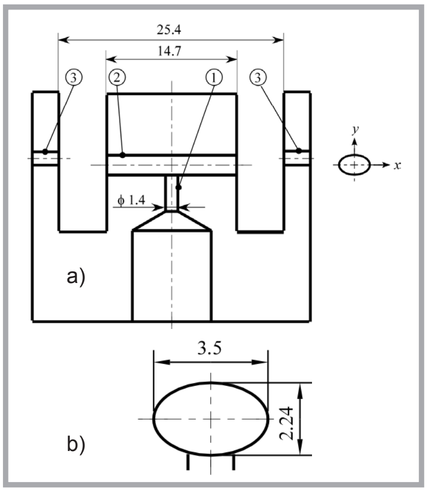

***Figure 1.** Interlacer (unit: mm); a) dimensions of interlacer, b) cross-sectional shape and size of yarn duct, 1 - Air jet nozzle, 2 - Yarn duct 3 - Yarn guide.*

the eye and confirmed them by use of a needle in a tensionless state. The length of the interlaced yarn was measured at a tension of 2.97 mN/tex.

The number of tangles N was defined as the number of tangled parts in the interlaced yarn per meter. The strength of tangles S was defined as N_r/N, where N_r was the residual number of tangled parts in the interlaced yarn per meter after the action of a load of 132 mN/tex for 3 min [3].

Analysis results and discussion

As indicated in ***Table 1***, the three processing parameters of supplied air pressure p, yarn speed v and overfeed ratio F_R are three experimental factors i.e., independent variables. Among them, p has five levels, v - four levels and F_R has five levels. The number of tangles N and strength of tangles S are experimental indicators, i.e., dependent variables.

Significance test of the processing parameters

Factorial analysis is a kind of ANOVA method which can test both the effect of each factor and the effect of interaction between factors on indicators [5]. The factorial design experiment can indicate the effect of each factor and their interactions on experimental results, because all the factors can be combined when carrying out the experiment.

GLM (General linear model) in SPSS was used to perform factorial analysis, which was the significance test of the processing parameters and their interactions for the characteristics of the interlaced yarn. ***Table 2*** shows the result of the factorial analysis.

From ***Table 2*** each factor and their interactions, except for the interaction of the air pressure supplied and yarn speed ($F = 1.75$, $P > 0.01$), the air pressure supplied ($F = 249.70$, $P < 0.01$), yarn speed ($F = 1230.35$, $P < 0.01$), overfeed ratio ($F = 1603.46$, $P < 0.01$), interaction of the air pressure supplied and overfeed ratio ($F = 8.92$, $P < 0.01$), interaction of the yarn speed and overfeed ratio ($F = 86.23$, $P < 0.01$) and interaction of the air pressure supplied, yarn speed and overfeed ratio ($F = 2.30$, $P < 0.01$) are all significant for the number of tangles. The air pressure supplied ($F = 60.40$, $P < 0.01$), yarn speed ($F = 461.48$, $P < 0.01$), overfeed ratio ($F = 189.73$, $P < 0.01$), interaction of the air pressure and yarn speed ($F = 2.90$, $P < 0.01$), interaction of the air pressure and overfeed ratio ($F = 9.03$, $P < 0.01$), interaction of yarn speed and overfeed ratio ($F = 33.41$, $P < 0.01$) and interaction of the air pressure, yarn speed and overfeed ratio ($F = 4.17$, $P < 0.01$) are all significant for the strength of tangles.

The result of the factorial analysis indicates that p, v and F_R are all significant for N and S. That is, changing the values of the processing parameters will greatly affect the characteristics of the interlaced yarn. Till now, we cannot decide which processing parameter is the most significant for the N and S of interlaced yarn.

Correlation analysis between the processing parameters and the number and strength of tangles

The distribution type of experimental data can be determined by one sample K-S (Kolmogorov-Smirnov) test. ***Table 3*** shows the result of the distribution test of N and S. Since the Asymp. Sig. (Asymptotic Significance) value of N is 0.22 (> 0.05), the distribution of N is normal. The value of Asymp. Sig of S is 0.002 (< 0.05), hence the distribution of S is abnormal.

In SPSS, the Bivariate Correlation procedure is used to calculate Pearson and Spearman correlation coefficients and their significance levels.

Table 4 shows the test result of the Pearson correlation between p, v, F_R, their interactions and N. ***Table 5*** shows the result of Spearman correlation between p, v, F_R, their interactions and S. Two pieces of information are provided in each cell: the correlation coefficient r (or *rho*) and the significance P.

From ***Table 4***, regarding the factors and their interactions, since the absolute value of the Pearson correlation coefficient ($r = 0.737$, $P < 0.01$) between F_R and N is the largest, F_R is the most significant factor for the number of tangles. If F_R is higher, yarn tension in the processing section, between the feed and delivery rollers, is lower. Hence, under the action of compressed air, filaments easily open and tangle with each other. As regards p, v and F_R, v shows a negative correlation ($r = -0.573$) with N, which indicates that with v increasing N will decrease. Compared to v and F_R, p has the least correlation with N. As for the interaction, that of p and F_R is the most significant for N. Hence, during the interlacing process, the controlling yarn tension in the processing section is the most important for the characteristics of interlaced yarn. The fluctuation of yarn tension will greatly affect the properties of interlaced yarn. At the same time, adjusting F_R is an effective way to produce interlaced yarn with the N desired.

From ***Table 5***, we can observe that, since the absolute value of the Spearman corre-

Table 1. *Independent and dependent variables.*

Factor	Level	p	v	F_R
		5	4	5
Indicator		N, S		

Table 2. *Result of factorial analysis; Symbol × indicates the interaction of factors.*

Variables	N		S	
	F	P	F	P
p	249.70	0.000	60.40	0.000
v	1230.4	0.000	461.48	0.000
F_R	1603.5	0.000	189.73	0.000
$p \times v$	1.75	0.060	2.90	0.000
$p \times F_R$	8.92	0.000	9.03	0.000
$v \times F_R$	86.23	0.000	33.41	0.000
$p \times v \times F_R$	2.30	0.000	4.17	0.000

Table 3. *Distribution test of N and S.*

Kind of test	N	S
Kolmogorov-Smirnov	1.06	1.86
Asymp. Sig. (2-tailed)	.22	.002

Table 4. *Test result of the Pearson correlation between p, v, F_R, their interactions and N.*

	p	v	F_R	p × v	p × F_R	v × F_R	p × v × F_R
r	0.207	-0.573	0.737	-0.239	0.630	0.073	0.160
P	0.001	0.000	0.000	0.000	0.000	0.226	0.008

Table 5. *Test result of the Spearman correlation between p, v, F_R, their interactions and S.*

	p	v	F_R	p × v	p × F_R	v × F_R	p × v × F_R
rho	0.252	0.611	0.333	0.596	0.412	0.691	0.683
P	0.001	0.000	0.000	0.000	0.000	0.226	0.008

lation coefficient (*rho* = 0.611, $P < 0.01$) between v and S is the largest, v is the most significant factor for the strength of tangles. A positive correlation coefficient indicates that S increases with v. We noted that tangling parts tend to be blown loose if they stay for a longer time in the processing section. As for the interaction, that of v and F_R is the most significant.

Correlation analysis between the number and strength of tangles

In most of the previous researches, only the number of tangles was tested to characterise interlaced yarn. As far as we knew, the purpose of interlacing is to improve the cohesive force between filaments, thereby preventing filaments from dispersing. The strength of tangles is another important characteristic of an interlaced yarn. Till now, the relation between the values of N and S for interlaced yarn is not clear.

As mentioned above, the distribution of S is not normal, hence we used the Spearman correlation to test the correlation between values of N and S. Since the value of the Spearman correlation coefficient *rho* was -0.032 (< 0.05), there is no correlation between N and S. That is, the number of tangling parts per meter only indicates the degree of tangling, not the strength of tangled parts. In some cases, N is larger but S is small, which results in the breakage of filaments during the weaving or knitting process. Hence, evaluating the production performance of an interlacer only from N is not sufficient. In order to evaluate the characteristics of interlaced yarn completely, we should consider both N and S.

Conclusions

In this work, the statistical method was used to evaluate the significance of three processing parameters: the air pressure supplied p, yarn speed v and overfeed ratio F_R for the number of tangles N and strength of tangles S. In addition, we a performed correlation analysis between N and S. After the analysis and discussion we came to the following conclusions:

1) Processing parameters p, v and F_R are all highly significant for the characteristics of interlaced yarn. Changing the values of the processing parameters greatly affects the characteristics of interlaced yarn.
2) The distribution of N is normal, whereas that of S is abnormal.
3) The overfeed ratio F_R is the most significant processing parameter for N. Interlaced yarn with a higher N can be produced with a higher F_R.
4) The yarn speed v is the most significant processing parameter for S. Interlaced yarn with a higher S can be produced with a lower S.
5) To fully evaluate the characteristics of interlaced yarn, both N and S should be tested.

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Editorial note:

1 *The Pearson correlation coefficient r can be calculated from the formula*

$$r = \frac{[n(\sum xy) - (\sum x)(\sum y)]}{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]} \quad (1)$$

where x and y are paired observations and n is the number of the paired observations

2) *The Spearman correlation coefficient rho can be calculated from the formula*

$$rho = 1 - \frac{6\sum D^2}{n(n^2 - 1)} \quad (2)$$

where D is the difference between the ranks of corresponding values of observations.

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