OPEN-END YARN PROPERTIES PREDICTION USING HVI FIBRE PROPERTIES AND PROCESS PARAMETERS

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Abstract:

This article provides three models to predict rotor spun yarn characteristics which are breaking strength, breaking elongation and unevenness. These models used noncorrelated raw material characteristics and some processing parameters. For this purpose, five different cotton blends were processed into rotor spun yarns having different metric numbers (Nm10, Nm15, Nm18, Nm22, Nm30 and Nm37). Each count was spun at different twist levels. Response surface method was used to estimate yarn quality characteristics and to study variable effects on these characteristics. In this study, predicting models are given by the analysis of response surface after many iterations in which nonsignificant terms are excluded for more accuracy and precision. It was shown that yarn count, twist and sliver properties had considerable effects on the open-end rotor spun yarn properties. This study can help industrial application since it allows a quality management-prediction based on input variables such as fibre characteristics and process parameters.

Keywords:

HVI characteristics, open-end rotor yarn, process parameters, response surface method

Introduction

Rotor spinning, which was invented in 1965, has a high percentage of production around the world [8]. Nowadays, this spinning process still has a large production in the world, because, compared with ring spun yarn, rotor spun yarn has the advantage of good evenness, less count variation and imperfections. Furthermore, rotor spinning, compared with ring spinning method, exhibits less energy cost because of less machinery involved in the yarn production process. Also, yarn breakage rate in rotor spinning is lower. This fact enhances production and yarn quality.

The study of rotor yarns has attracted the interest of many researchers in different sides, such as yarn structure [5,6], rotor spun yarn tensile properties [1,4,7,10], the effect of twist level and other process parameters on yarn properties as well as the prediction of the mechanical behaviour [9].

Generally, yarn quality is defined in two main characteristics which are tenacity and elongation. Indeed, breaking strength is an important quality characteristic that affects the determination of its application possibilities. Nevertheless, customers usually require much more quality criteria like yarn unevenness expressed by mass variation coefficient. This parameter is defined as the irregularity of the yarn linear density in the direction of its length. These properties are influenced by raw fibre characteristics, process variables and machine parameters.

Statistical models were the first approaches used in the textile engineering field to explore the relationship between variables and yarn properties and optimise them [3]. However, regression analysis has the drawback that it is limited by the problem of nonlinearity. But, we can avoid this disadvantage using response surface method. This methodology is a mathematical technique that has been successfully used to develop processes [2]. It was also used to model processes and to optimise processing parameters and rotor spun yarn quality.

Thus, the purpose of this study is to develop response surface regression models for the prediction of cotton open-end rotor spun yarn strength, elongation and unevenness using fibre properties, slivers characteristics, yarn count and yarn twist.

The novelty of our research is that the conceived models are more practical and more powerful since they contain less input number than other models seen in different researches and all nonsignificant terms are removed as it will be indicated in the next section.

Materials and methods

Sample yarn production and experimental

The data used in the predicting models were collected from cotton yarns produced on the same rotor machine using five different cotton blends taken from various origins. Two second

draw slivers were furnished for each blend with metric number of 0.206 and 0.222.

The correlation coefficients between the fibre properties used in the study were determined before the regression analysis. The results revealed that there is a strong correlation between some factors. Therefore, we will investigate only two fibre properties which are SFI and Str.

Rotor spun yarns having metric number 15 are given by the first sliver, other yarns having metric number are given by the second sliver. Furthermore, each count was spun at different twist levels as given in Table 1.

Table 1. Process characteristics of produced yarns

Metric numbers	Twist levels
10	400
15 ,18,20	400
15 ,18,20	500
15 ,18,20	600
15 ,18,20	700
30	600
30	700
30	1000
37	600
37	700
37	1000

Yarn cones were selected randomly from the lots of each yarn and tested for their characteristics after conditioning in a standard atmosphere for 24 hours. Yarn tensile properties were measured by Uster Tensorapid 3 which provides strength, elongation, RKM and work. Similarly, Uster tester 3 was used to determine CVM, total imperfections (thin places, thick places and neps) and hairiness. Summary statistics of fibres, slivers and yarns factors are given in the following table.

Model construction and analyses using response surface method

After creating response surface design, we have to analyse it in order to build the predicting model which contains three types

Table 2. Fibres, slivers and yarns properties statistics summary

Factor	Symbol	Minimum-value	Mean-value	Maximum-value
Short fibre Index	SFI	7.9	9.12	10.7
Fibers strength	Str	25.5	28.100	31.2
Yarn metric number	Nm	10	37	22.04
Twist level	Twist	400	1000	598.461
Sliver metric number	NmR	0.206	0.222	0.218
Sliver unevenness	RgR	2.52	2.94	2.6533

of terms: linear terms, squared terms and interaction terms. As a consequence, the general relationship between the response y and the different parameters (x_i and y_i) will be expressed as follows:

$$y = a_0 + \sum_{i=1}^n a_i x_i + \sum_{i=1}^n a_{ii} x_i^2 + \sum_{i=1}^{n-1} \sum_{j=2}^n a_{ij} x_{ij} \quad (1)$$

where a_0 = the constant term, a_i = the coefficients of main factor effects, a_{ii} = the coefficient of quadratic effect, a_{ij} = the coefficient of interaction effects and n = the number of factors chosen (six in this case).

However, to get a more appropriate predicting model, we adopted several iterations in which we have to exclude some insignificant terms having p-values more than 0.05 and we must be careful not to decrease adjusted R^2 . This process is given in detail in figure 1. The statistical analyses were performed using the minitab 16 software program.

Figure 1. Research flowchart

Result and discussion

Study of yarn strength

The response surface regression equation predicting the yarn strength is given as follows:

$$\begin{aligned} \text{Strength (Kgf)} = & -1.7538 - 0.1299SFI + 0.0821Str \\ & -0.1960Nm + 0.0039Twist + 12.8298NmR + 0.0022Nm^2 \\ & + 0.0034SFI \times Nm - 0.0001Str \times Twist \end{aligned}$$

(2)

This model has a very high predictive power since we have $R^2 = 97.8$ as given by figure 2:

Figure 2. Experimental and predicted values of breaking elongation

As depicted in table 3, the most important parameter affecting yarn strength is the metric number ($T = -14.366$) and it has a negative effect. Thus, when we have a coarser yarn, we will have more fibres in cross section and so more fibres will participate in yarn strength. Furthermore, the effect of metric number depends on short fibre index and twist. Then, we have the sliver count ($T = 10.554$), so, thicker sliver gives stronger yarns. Moreover, SFI and Str have both significant effects

on yarn strength but these two effects are opposite. Indeed, stronger fibres give stronger yarns. But, the shorter fibres are, the weaker the yarn becomes.

Besides, the twist level has, also, a positive and a significant effect on breaking strength. Thus, with a higher twist level, fibre friction increases and so more fibres would participate in yarn strength. The effects of these several factors on yarn strength are shown in surface plots figure.

It is evident from these plots that twist level and metric number have both quadratic effects on yarn strength. These results agree with T-values for $Twist^2$ and Nm^2 given by Table 3. Also, Figure3b shows that yarn strength rises until about 800 turns/m then it decreases.

Study of yarn elongation

A more appropriate response surface model predicting yarn elongation is given by the following equation:

$$\begin{aligned} \text{Elongation (\%)} = & -6.3400 - 0.5289SFI \\ & + 0.0609Str - 0.2519Nm + 3.1659RgR \\ & + 0.0040Twist + 49.2076NmR + 0.0023Nm^2 \end{aligned} \quad (3)$$

According to table 4, breaking elongation is highly influenced by twist level. So, elongation increases with higher twist and decreases with lower one. In addition, metric number has an important and a negative effect on breaking elongation. So, coarser yarns have more elongation than finer yarns. The metric number of roving has also a considerable effect ($T = 3.402$).

As far as fibre characteristics are concerned, short fibre index has a negative effect on yarn elongation ($T = -0.867$). However, fibre strength affects positively breaking elongation.

Furthermore, yarn count has a quadratic effect (T-value for $Nm^2 = 2.227$) indicating that the relationship between this parameter and breaking elongation follows a curved line.

Table 3. Regression coefficients, T and P values of model for yarn strength

Terms	Coefficient	T	P
Constant	-1.7538	-2.466	0.018
SFI	-0.1299	-4.553	0.00
Str	0.0821	4.136	0.00
Nm	-0.1960	-14.366	0.00
Twist	0.0039	4.004	0.00
NmR	12.8298	10.554	0.00
Nm^2	0.0022	12.968	0.00
$Twist^2$	0.0000	-3.415	0.001
SFI*Nm	0.0034	2.853	0.007
Str*Twist	-0.0001	-2.240	0.030
Nm*Twist	0.0000	1.526	0.135

The following figure shows the scatter plot of the predicted and experimental values of yarn elongation and the coefficient R^2

Study of CVm

Response surface model estimated for yarn unevenness is given by the following equation:

$$CV_m = -5.8596 + 0.1686SFI + 0.4246Str + 0.8323Nm + 13.9518NmR + 0.0023Nm^2 - 0.0280Str \times Nm \quad (4)$$

The above table shows that, as expected, yarn count has the most significant effect ($T=4.640$). Therefore, coarser yarns have the best evenness. Moreover, the relationship between yarn unevenness and Nm follows a curved line and depends on fibre strength characteristic as given by figure 5.

Among fibre properties, strength has a significant and a positive impact on CVm ($T=3.125$). Also, short fibre index has a positive effect on CVm. So, the longer fibres are, the better evenness is.

Figure 6 shows the scatter plot of the predicted and experimental values of yarn unevenness and the coefficient R^2

Figure 4. Experimental and predicted values of breaking elongation

a)

b)

c)

Figure 3. Effects of (a) SFI and Nm (b) Str and twist (c) Nm and twist on yarn strength

Table 4. Regression coefficient, T and P values for yarn elongation

Terms	Coefficient	T	P
Constant	-6.3400	-1.819	0.076
SFI	-0.5289	-0.867	0.391
Str	0.0609	1.091	0.281
Nm	-0.2519	-4.721	0.000
RgR	3.1659	1.245	0.220
Twist	0.0040	8.868	0.000
NmR	49.2076	3.402	0.001
Nm ²	0.0023	2.227	0.031

Table 5. Regression coefficients, T and p values for yarn CVm

Terms	Coefficient	T	P
Constant	-5.8596	-1.277	0.208
SFI	0.1686	1.960	0.056
Str	0.4246	3.125	0.003
Nm	0.8323	4.640	0.000
NmR	13.9518	1.363	0.180
Nm ²	0.0023	2.237	0.030
Str*Nm	-0.0280	-4.810	0.000

Conclusion

Open-end rotor spun yarn characteristics are influenced by HVI fibre characteristics and process parameters which are sliver properties, metric number and twist level. In this study, we tried to predict three important yarn characteristics which are strength, elongation and CVm with response surface regression method using these parameters. The predicting models have good prediction performance as the regression coefficient R^2 -values of these models are high and have a greater significance.

Our study shows that yarn count and twist level are the most decisive factors for yarn properties. Also, sliver number and regularity as well as the two selected fibre properties all have considerable effects.

This paper shows that the statistical approach gives good results and takes into consideration the nonlinearity between predictors. So, this method is still important and very useful as it indicates explicitly the relationship between responses and variables unlike the artificial neural network approach.

In addition, this study will be extended to find the optimal processing parameters and fibre characteristics for the open-end yarn properties optimisation and look for a new yarn quality expression that investigates the three properties studied in this article.

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Figure 5. Effect of Nm and fibre strength on CVm **Figure 6.** Experimental and predicted values of yarn CVm

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