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A Statistical Model for the Hairiness of Cotton/Polyester Blended OE Rotor Yarns

Abstract

This study aimed to predict the hairiness of cotton/polyester blended rotor yarns using blend ratios and yarn count as predictor variables. A simplex lattice design with two replications at each design point was constructed to determine the combinations of mixture ratios of the fibre types. Cotton/polyester blended slivers were used to produce rotor yarns with five different counts on a laboratory-type rotor spinning machine (quickspin). Mixture-process crossed regression models with two mixture components and one process variable (yarn count, linear density) were built to predict hairiness properties. All statistical analysis steps were implemented, using Design-Expert statistical software.

Key words: *yarn hairiness, rotor yarns, experimental design, fibre blending.*

Introduction

Blending different types of fibres is widely practiced to enhance the performance and aesthetic qualities of fabric. Blended yarns from natural and man-made fibres have the particular advantage of successfully combining good properties of both fibre components, e.g., comfort in wear with easy-care properties. Furthermore, cotton/polyester blending has many advantages such as less pilling, less static electrification, easier spinning, better evenness for sliver, roving and yarn [1]. These advantages also permit an increased variety of products and a better marketing advantage.

Hairiness is one of these most important yarn characteristics, which affects weaving, knitting, dyeing and finishing processes in textiles. Yarn hairiness is expressed in terms of the number or length of fibres directed outward from the yarn surface. The parameters of fibres and machines atg all production stages are known to be influential on yarn hairiness. When, as a consequence of technological advances, machine speeds are increased and high productivity are required, yarn hairiness become a very undesirable parameter, which was to be measured and controlled. Effects of the material and the machines on yarn hairiness, and the measurement methods of hairiness, have been studied by numerous authors [2 - 10].

This study aimed to predict the hairiness of cotton/polyester blended rotor yarns using blend ratios and yarn count as predictors. It is a critical problem in fibre blending technology to choose appropriate types of fibres and blend ratios depending on the final product's requirements.

Materials and method

Materials

In this study cotton was one of the components in blending. Properties of the cotton fibres measured on Uster HVI 900 (High Volume Instrument) test equipment are presented in Table 1.

The second component of the prepared blends were polyester staple fibres produced by SASA-DupontSA. Test results for the linear density, length, tensile and elongation properties of the polyester staple fibres are presented in Table 2.

Method

Experimental design

A simplex lattice design with two replications at each design point was constructed to determine the combinations of mixture ratios of two fibre types [11, 12]. Let $X_1, X_2, ..., X_p$ denote the proportions of "p" components of a mixture, then :

$$0 \leq X_i \leq 1 \quad i = 1, 2, ..., p$$

A $\{p, m\}$ simplex lattice design for "p" components has the ratios of each component taking $m + 1$ equally spaced values from 0 to 1.

$$X_i = 0, 1/m, 2/m, ..., 1 \quad i = 1, 2, ..., p \quad (1)$$

The number of design points in A{p, m} simplex lattice design is,

$$N = \frac{(p+m-1)!}{m!(p-1)!} \quad (2)$$

In this study, **A{2, 4} simplex** lattice design shown in Figure 1 was used to determine cotton/polyester blends. Design points (blend ratios) used in this study are shown in Table 3.

Production of cotton / polyester blended OE rotor yarns

Cotton and polyester fibres were processed and blended on a traditional short-staple (carding) spinning mill (Matesa Textiles Corp. of Turkey). The processing steps for both cotton and polyester were modern short-staple

Table 1. *HVI test results for the cotton fibres.*

Kind of parameter	Linear density, dtex	Length, mm	Unf., %	SFI	Tenacity, cN/tex	Elonga-tion, %	SCI	CSP	Rd	b	C-G
mean value	1.50	28.95	83.2	6.50	28.5	6.70	142	2277	77.5	8.5	31-1
s.d.	0.25	0.84	0.92	0.80	1.19	0.18	6.47	47.08	1.21	0.50	-
CV, %	6.63	2.90	1.11	12.29	4.09	2.72	4.54	2.07	1.56	5.85	-

Table 2. *Test results for the polyester fibers.*

Kind of parameter	Linear density, dtex	Staple length, mm	Tenacity, cN/tex	Elongation at break, %
mean value	1.59	33.31	0.74	22.90
s.d.	0.13	0.26	0.573	5.426
CV(%)	9.09	0.78	8.39	23.69

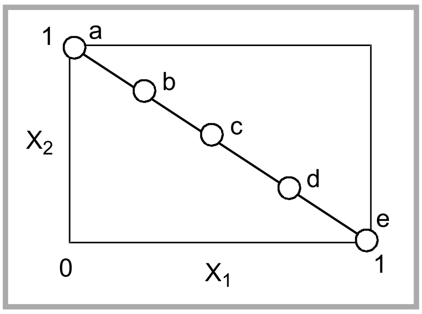

Figure 1. Design space for A{2, 4} simplex lattice design [13]; X_1 - polyester, X_2 - cotton, % N = 5.

Table 3. Design points (blend ratios) used in this study.

Design points	Blend ratios (%)	
	X_1 (polyester)	X_2 (cotton)
a	0	100
b	25	75
c	50	50
d	75	25
e	100	0

preperation and carding systems. The fibres were processed on these systems, using standard mill procedures, adjustments and practices. Cotton slivers were blended with polyester slivers on the first drawing frame and blended slivers were passed through the second drawing frame and formed as a final feeding material for spinning.

The cotton/polyester blended slivers were spun on a laboratory-type rotor spinning machine (quickspin) at standard atmospheric conditions (temperature of 20 ± 2 °C and relative humidity of 65 ± 2%). The quickspin had a conventional spin-box (R20). Production parameters in this system are given in Table 4 [14 - 16].

Five different blends were spun into yarns with five different counts. With two replications at each design point, the total number of yarn bobbins produced was fifty.

Results and discussion

The hairiness of the spun yarns were tested on an Uster Tester-4 at standard atmospheric conditions (temperature of 20 ± 2 °C and relative humidity of 65 ± 2%). Seven single measurements were performed for each bobin, and the mean values of the test results used in statistical analysis are given in Table 5.

Best-fitting regression models that define the relationship between independent variables (blend ratios and yarn count) and response variables (hairiness of yarn) are selected and estimated using Design-Expert software. It is indicated that combined models that include both mixture variables and the process variable are adequate to predict the response variables [17].

Prediction of blended yarn hairiness

The hairiness test results of the blended rotor yarns were used to analyse the mixture-process crossed design. Lack of fit tests and residual analysis indicated that the best fitting model is the **cubic x quadratic** crossed model for the hairiness of blended rotor yarns. The regression equation of this model is as follows [13]:

$$\begin{aligned} \text{yarn hairiness } (H) = {} & 15.97\,X_1 + \\ & + 8.06\,X_2 - 0.60\,X_1X_2 - 0.79\,X_1Z + \\ & - 0.09\,X_2Z + 0.01\,X_1Z^2 + \\ & + 0.0002\,X_2Z^2 - 0.01\,X_1X_2Z + \\ & + 18.02\,X_1X_2(X_1 - X_2) + \\ & + 0.0004\,X_1X_2Z^2 + \\ & - 0.86\,X_1X_2Z(X_1 - X_2) + \\ & + 0.01\,X_1X_2Z^2(X_1 - X_2) \end{aligned} \quad (3)$$

Table 4. Spinning parameters of blended rotor yarns; for 100 % polyester and cotton/polyester blends, ** for 100 % cotton.*

Spinning parameters	Count range of spun yarn, tex (Ne)				
	36.9 (16)	29.5 (20)	24.6 (24)	21.1 (28)	18.5 (32)
Rotor speed, r.p.m.	75.000	75.000	75.000	75.000	75.000
Opening roller speed, r.p.m.	8000	8000	8000	8000	8000
Type of rotor	S D40	S D40	S D40	S D40	S D40
Type of opening roller	OS 21* and OB 21**	OS 21* and OB 21**	OS 21* and OB 21**	OS 21* and OB 21**	OS 21* and OB 21**
Type of navel	KN4	KN4	KN4	KN4	KN4
Count of blended sliver, ktex	4.54	4.54	4.54	4.54	4.54
Twist, t.p.m.	629.92	704.27	771.25	833.07	890.54
Coefficient of twist, α_m	121.2	121.2	121.2	121.2	121.2
Draft	123.07	153.85	184.61	215.38	246.15
Yarn delivery speed, m/min	119.06	106.49	97.24	90.03	84.21

*Table 5. Mean values of the test results; * replications.*

Yarn linear density, tex	Measured mean H-values									
	100 % PES		25/75 % cotton/PES		50/50 % cotton/PES		75/25 % cotton/PES		100 % cotton	
	1*	2*	1*	2*	1*	2*	1*	2*	1*	2*
36.9	7.29	7.26	7.51	8.03	6.48	6.58	6.11	6.17	6.64	6.72
29.5	5.91	5.96	6.49	6.80	5.96	5.90	5.72	5.73	6.22	6.24
24.6	5.34	5.34	5.56	5.72	5.48	5.37	5.41	5.60	6.10	6.14
21.1	5.19	5.14	5.49	5.54	5.26	5.28	5.19	5.18	5.70	5.77
18.5	4.93	4.93	5.00	5.13	5.10	5.15	5.10	5.10	5.42	5.48

Table 6. ANOVA Table for the regressesion model; model terms with p-value < 0.05 are considered significant.

Source	Sum of squares	DF	Mean square	F-Value	p-value
Model	24.44	11	2.22	106.62	<0.0001
Linear mixture	0.00036	1	0.00036	0.017	0.8958
X_1X_2	0.081	1	0.081	3.89	0.0558
X_1Z	6.29	1	6.29	301.74	< 0.0001
X_2Z	1.91	1	1.91	91.51	< 0.0001
X_1X_2Z	0.00167	1	0.00167	0.080	0.7786
X_1Z^2	0.97	1	0.97	46.75	< 0.0001
X_2Z^2	0.0002	1	0.0002	0.0096	0.9226
$X_1X_2 (X_1- X_2)$	0.85	1	0.85	40.82	< 0.0001
$X_1 X_2 Z^2$	0.00006	1	0.00006	0.0029	0.9577
$X_1X_2Z(X_1- X_2)$	0.59	1	0.59	28.34	< 0.0001
$X_1X_2Z^2(X_1- X_2)$	0.0072	1	0.0072	0.35	0.5597
Residual	0.79	38			
Corrected Total	25.24	49			

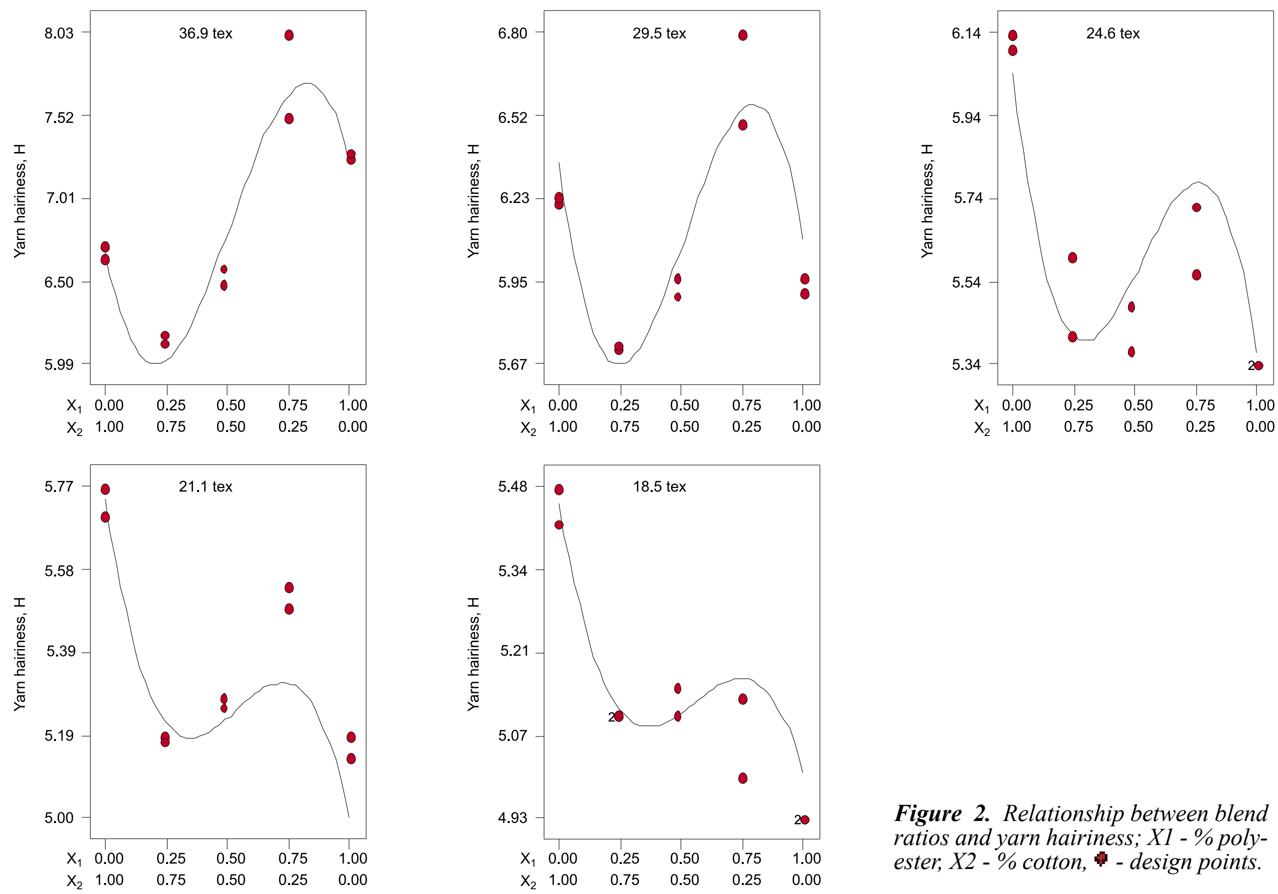

***Figure 2.** Relationship between blend ratios and yarn hairiness; X1 - % polyester, X2 - % cotton, ◆ - design points.*

In this equation, X_1 and X_2 are polyester and cotton ratios, respectively, and Z is yarn count (in Ne - recalculation to tex see Table 4). The Analysis of Variance (ANOVA) summarized in Table 6 indicates that there is a strong interaction between the mixture variables and yarn count, therefore since the model terms X_1Z, X_2Z, X_1Z^2, $X_1X_2(X_1 - X_2)$ and $X_1X_2Z(X_1 - X_2)$ are significant.

The hairiness of cotton/polyster blended rotor yarns can be predicted for different blending ratios and yarn counts using this equation. Figure 2 illustrates regression curves fitted to experimental observations. Although there are separate graphs for each yarn count in Figure 2, we do not fit individual regression models for each yarn count level. The fitted cubic-quadratic crossed model is a single model for all the mixture variables and yarn count. As in most regression models, there may not be a perfect fit across the entire experimental design space. The fitted regression model has a lack of fit at X_1=0.75, X_2=0.25 for yarn counts of 21.1 tex and 18.5 tex. Even though fitting separate regression models for each yarn count can produce a better fit, this would not permit us to analyse significant interactions between the mixture variables and yarn count as suggested by the previous ANOVA analysis.

Influential parameters on yarn hairiness are raw material (fibres) and production stages as expected. Empirical studies show that about 40% of yarn hairiness can be attributed to fibr properties [18]. It is well reported in the literature that fibres with high strength and breaking elongation can reduce yarn hairiness. Therefore, pure polyester yarn should have less hairiness than pure cotton yarn as polyester fibres have greater strength and breaking elongation than cotton fibres. This case can be seen in Figure 2 for yarns besides 36.9 tex.

As the percentage of polyester in the mixture increases, yarn hairiness decreases until turning point and then starts increasing. Yarn hairiness is considerabley low for all yarn count levels when the percentage of polyester is 25%. Yarn hairiness starts increasing when the polyester ratio is between 25% and 75%. We observe another decreasing trend in yarn hairiness after 75% polyester in the blend. Furthermore, as yarn linear density (tex) goes down, yarn hairiness tends to decrease.

The correlation coefficient between predicted H values and observed H values is 0.984 indicating a strong predictive capability of the regression model built (see Figure 3).

Conclusions

Hairiness properties of blended OE-rotor yarns are modelled through a validated regression model, in which blend ratios

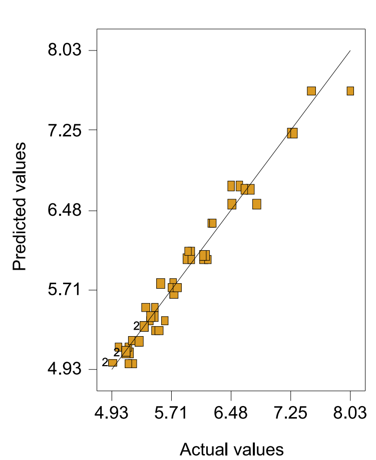

***Figure 3.** Correlation between predicted H values and observed H values.*

and yarn count are predictor variables. The model has strong prediction capability indicated by a high, positive correlation between predicted H values and observed H values. Using this regression model, one can predict the hairiness of cotton/polyester blended OE-rotor yarns for unobserved blend ratios and yarn count within the design space used in this study. A similiar approach can be carried out for different types of cotton and polyester fibres.

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