Pınar Duru Baykal,
Osman Babaarslan
Rızvan Erol*

Department of Textile Engineering
Çukurova University
01330-Balcalı/Adana, Turkey
E-mail: pduru@cu.edu.tr
teksob@cu.edu.tr

* **Department of Industrial Engineering**
Çukurova University
01330-Balcalı/Adana, Turkey
E-mail: rerol@cu.edu.tr

Prediction of Strength and Elongation Properties of Cotton/Polyester-Blended OE Rotor Yarns

Abstract
This study aims to predict the strength and elongation properties of cotton/polyester blended rotor yarns, using blend ratios and yarn count as predictors. A simplex lattice design with two replications at each design point is constructed to determine the combinations of the fibres' mixture ratios . Prepared cotton/polyester blended slivers were used to produce rotor yarns with five different counts on a laboratory-type rotor spinning machine (quickspin). Based on experimental observations, mixture-process crossed regression models with two mixture components and one process variable (yarn count) are constructed to predict strength and elongation properties. All statistical analysis steps are performed on Design-Expert statistical software.

Key words: *cotton/polyester blends, rotor spinning, experimental design, prediction, yarn strength, yarn elongation.*

Introduction

Blending different types of fibres is a widely practiced means of enhancing the performance and the aesthetic qualities of a fabric. Blended yarns from natural and man-made fibres have the particular advantage of successfully combining the good properties of both fibre components, such as comfort of wear with easy care properties. These advantages also permit an increased variety of products to be made, and yield a stronger marketing advantage.

Blending cotton/polyester fibres is common practice in the textile industry. In comparison with 100% cotton, cotton/polyester blends have higher breaking and abrasion strength, crease resistance, are more comfortable to wear, and display better easy-care properties. On the other hand, in comparison with 100% polyester, cotton/polyester blending has many advantages such as less pilling, less static electrification, easier spinning, better evenness for sliver, roving and yarn [1].

Prediction of the mechanical properties of blended yarns has also been studied by numerous authors [2, 3, 4, 5, 6]. Theoretical and mathematical models have been proposed in these studies.

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

Materials and method

Materials

Cotton is one of the blending components for this study. The properties of the cotton fibres measured on an Uster HVI 900 (High Volume Instrument) tester are presented in Table 1.

The second component of the prepared blends is polyester staple fibres produced by SASA-Dupont SA. Test results for fineness, length, strength and elongation properties of the polyester staple fibres are summarised in Table 2.

Method

Experimental design

A simplex lattice design with two replications at each design point is constructed to determine the combinations of the fibres' mixture ratios [7,9]. In mixture experiments, the blend ratios are not independent. For example, if X_1, X_2, ..., X_p denote the proportions of 'p' components of a mixture, then:

$$0 \le X_i \le 1 \qquad i = 1,2,\ldots,p$$
$$X_1 + X_2 + \cdots + X_p = 1 \qquad (1)$$

For two components, the design space includes all the ratio combinations of the two components that lie on the line segment $X_1 + X_2 = 1$, where each component ratio varies between 0 and 1 (Figure 1).

Simplex designs are widely used to study the effects of mixture components on a response variable. A {p, m} simplex lattice design for 'p' components con-

Table 1. *HVI test results for the cotton fibers; Mic. - microinaire, Unf. - uniformity index, SFI - short fibre index, SCI - spinning consistency index, CSP - count strength product, Rd - light reflectance coefficient, b - yellowing degree, C-G - colour grade.*

Parameter	Mic.	Length, mm	Unf., %	SFI	Strength, g/tex	Elongation, %	SCI	CSP	Rd	b	C-G
mean	3.80	28.95	83.2	6.50	29.1	6.7	142	2277	77.5	8.50	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.*

Parameter	Fineness, dtex	Length, mm	Strength, cN/tex	Elongation, %
mean	1.59	33.31	0.740	22.90
s.d.	3.01	0.26	0.573	5.426

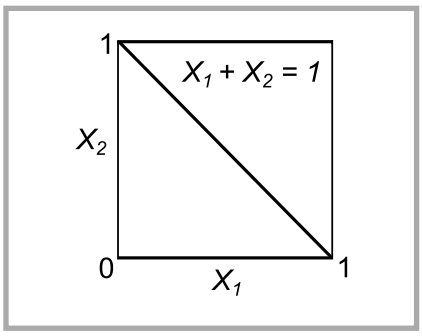

Figure 1. *Design space for mixtures with two components [8].*

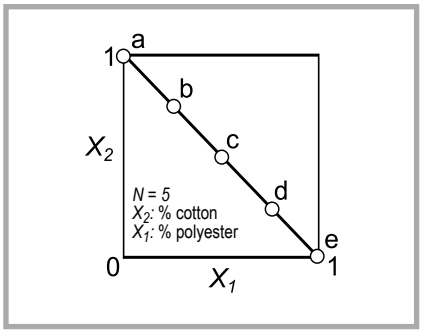

Figure 2. *Design space for A{2, 4} simplex lattice design [9].*

sists of points defined by the following coordinate settings; the ratios of each component take m+1 equally spaced values from 0 to 1.

$$X_i = 0, 1/m, 2/m, \ldots, 1 \qquad i = 1, 2, \ldots, p$$

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

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

In this study, the **A{2, 4} simplex** lattice design shown below is used to determine cotton/polyester blends.

The design points (blend ratios) used in this study are shown in Table 3.

Production of cotton/polyester-blended OE rotor yarns

The 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 are modern short-staple preparation and carding systems. The fibres are processed on this system using standard mill procedures, adjustments and practices. Cotton slivers are blended with polyester slivers. At first, drawing frame and blended slivers were passed through a second drawing frame and formed as a final feeding material for spinning.

The cotton/polyester-blended slivers are spun on a laboratory-type rotor spinning machine (quickspin) in standard atmospheric conditions (20±2°C heat and 65±2% relative humidity). Quickspin has a conventional spin-box (R20). The production parameters in this system are given in Table 4.

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

Results and discussion

The strength and elongation properties of the spun yarns are tested on an Uster Tensorapid-3 in standard atmospheric conditions (20 ± 2 °C heat and 65 ± 2% relative humidity). 25 single measurements are performed for each bobbin, and the mean values of the test results are used in statistical analysis.

The best fitting regression models that define the relationship between independent variables (blend ratios and yarn count) and response variables (strength and elongation 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 [10].

Prediction of blended yarn strength

The strength test results of the blended rotor yarns were used to analyse the mixture-process crossed design. The analysis of variance, lack of fit tests and residual analysis were performed to select the proper model for the yarn strength. These statistical analyses show that the best fitting model is the **quadratic x quadratic** crossed model for the strength of the blended rotor yarns. The regression equation of this model is as follows:

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

$$\text{yarn strength(cN/tex)} = [7.13\,X_1 + 16.91\,X_2 - 7.39\,X_1X_2 + 1.14\,X_1Z + 0.19\,X_2Z - 0.02\,X_1Z^2 + 0.003\,X_2Z + 0.29\,X_1X_2Z + 0.002\,X_1X_2Z^2]\ 0.98 \qquad (3)$$

In this equation; X_1 and X_2 are the polyester and cotton ratios respectively, and Z is the yarn English cotton count. The strength of the cotton/polyester-blended rotor yarns can be predicted by this equation. Figure 3 illustrates the relationship between blend ratios and yarn strength.

The blending of a relatively weak fibre (i.e., cotton) with a strong fibre (i.e., polyester) leads, as expected, to some losses in yarn strength. The properties of the blended yarns cannot merely be explained in terms of the proportions of the different constituent fibres in the blends. In fact, the overall properties of the blended yarns are related to the blend ratios, the corresponding properties of each component and the interactions of the components themselves.

The number of fibres in the yarn cross-section affects the mechanical properties of the yarn. When the blended yarn is subjected to a force, the fibres of both

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				
	36.9	29.5	24.6	21.1	18.5
Rotor speed, rpm	75.000	75.000	75.000	75.000	75.000
Opening roller speed, rpm	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, Ne	0.13	0.13	0.13	0.13	0.13
Twist, tpm	629.92	704.27	771.25	833.07	890.54
Coefficient of twist, α_e)	4	4	4	4	4
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

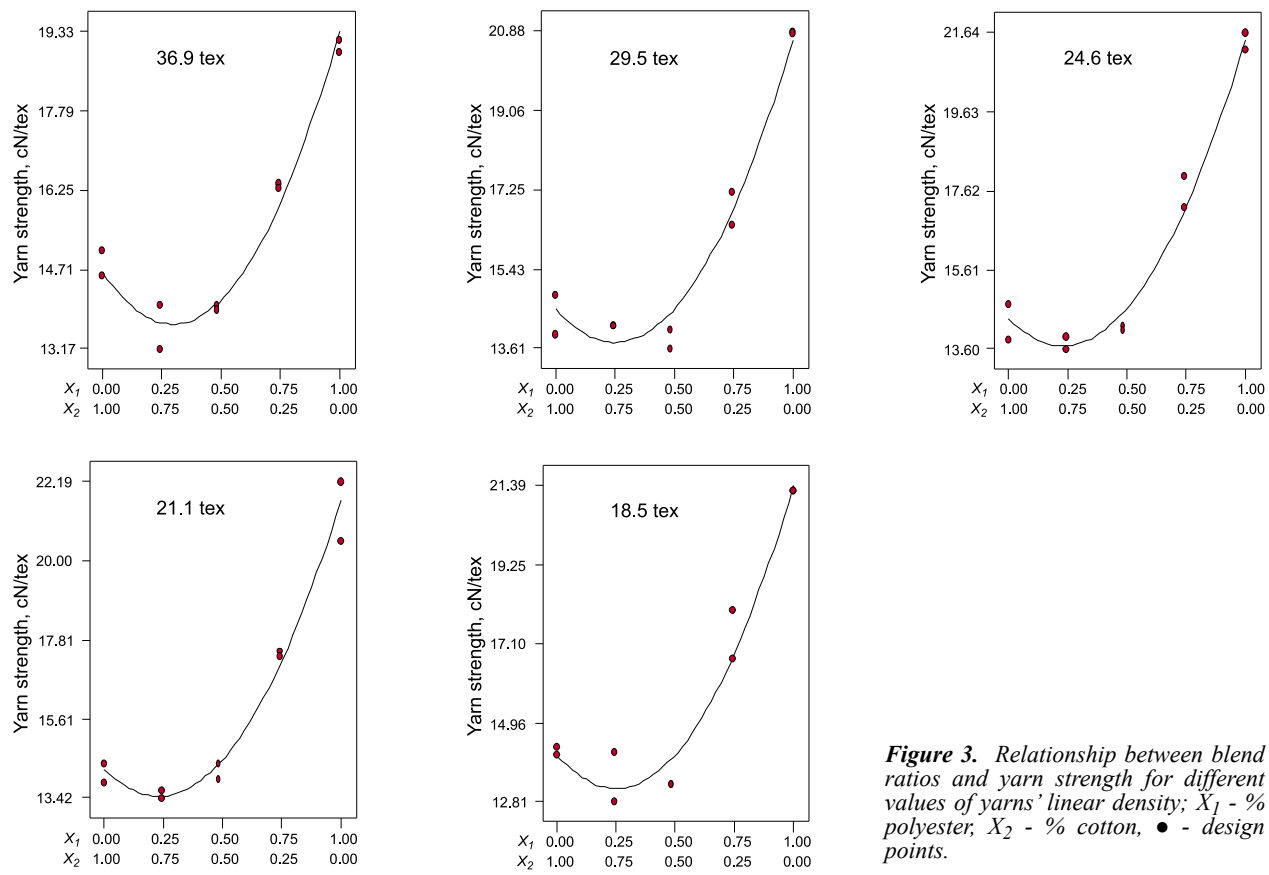

Figure 3. *Relationship between blend ratios and yarn strength for different values of yarns' linear density; X_1 - % polyester, X_2 - % cotton, ● - design points.*

components will be elongated as the force increases, until the fibres with smaller elongation break and so transfer the entire load to other fibres. If there are enough fibres with higher elongation in the yarn cross-section, the blended yarn will not break. Fibre slippage plays a particularly important role when component fibres in a blended yarn have different values of fibre breaking elongation.

When the polyester ratio changes from 0 to 25%, the strength of the blended yarn decreases. However, the yarn strength increases after 25% polyester. This trend is observed for all the yarns spun with five different counts. The loss of strength in the blended yarn is attributed to the differences in the breaking elongation of the constituent fibres.

When the blended yarn with 0 to 25% polyester is subjected to increasing load, the cotton fibres with smaller elongation break first, and then polyester fibres are exposed to entire load. If there are not enough polyester fibres in the yarn cross-section, they cannot carry the entire load, resulting in a loss of strength in the blended yarn.

When the polyester ratio is over 25% in the blended yarn, the yarn strength increases because there are sufficient polyester fibres in the yarn cross-section. If the ratio of one of the components is insufficient, the yarn's properties will not meet our expectations.

The correlation coefficient between the predicted and observed strength values is 0.986. Figure 4 illustrates this strong positive correlation.

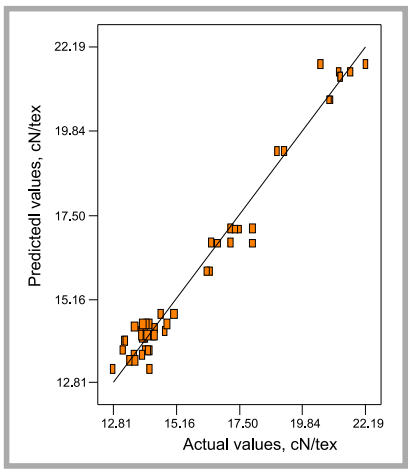

Figure 4. *Correlation between predicted and observed strength values.*

Predicting blended yarn elongation

Statistical analysis shows that the proper model for the breaking elongation data of the blended yarns is the **cubic x linear** model. The regression equation for the breaking elongation of the blended yarn is as follows;

$$\begin{aligned} &\textit{yarn beraking elongation (\%)} = \\ &= 8.24\,X_1 + 4.77\,X_2 + 6.56\,X_1X_2 + \\ &+ 0.09\,X_1Z - 0.02\,X_2Z + \\ &- 0.33\,X_1X_2Z + 14.42\,X_1X_2(X_1 - X_2) + \\ &- 0.17\,X_1X_2\,Z(X_1 - X_2) \end{aligned} \qquad (4)$$

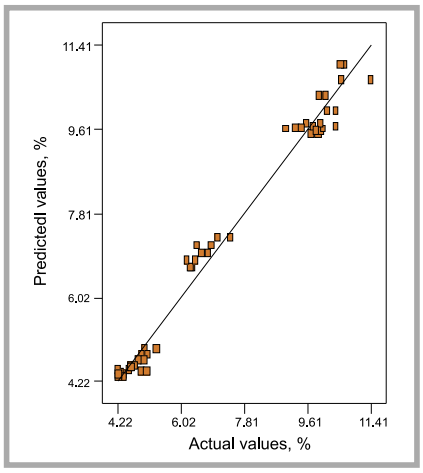

Figure 6. *Correlation between predicted and observed breaking elongation.*

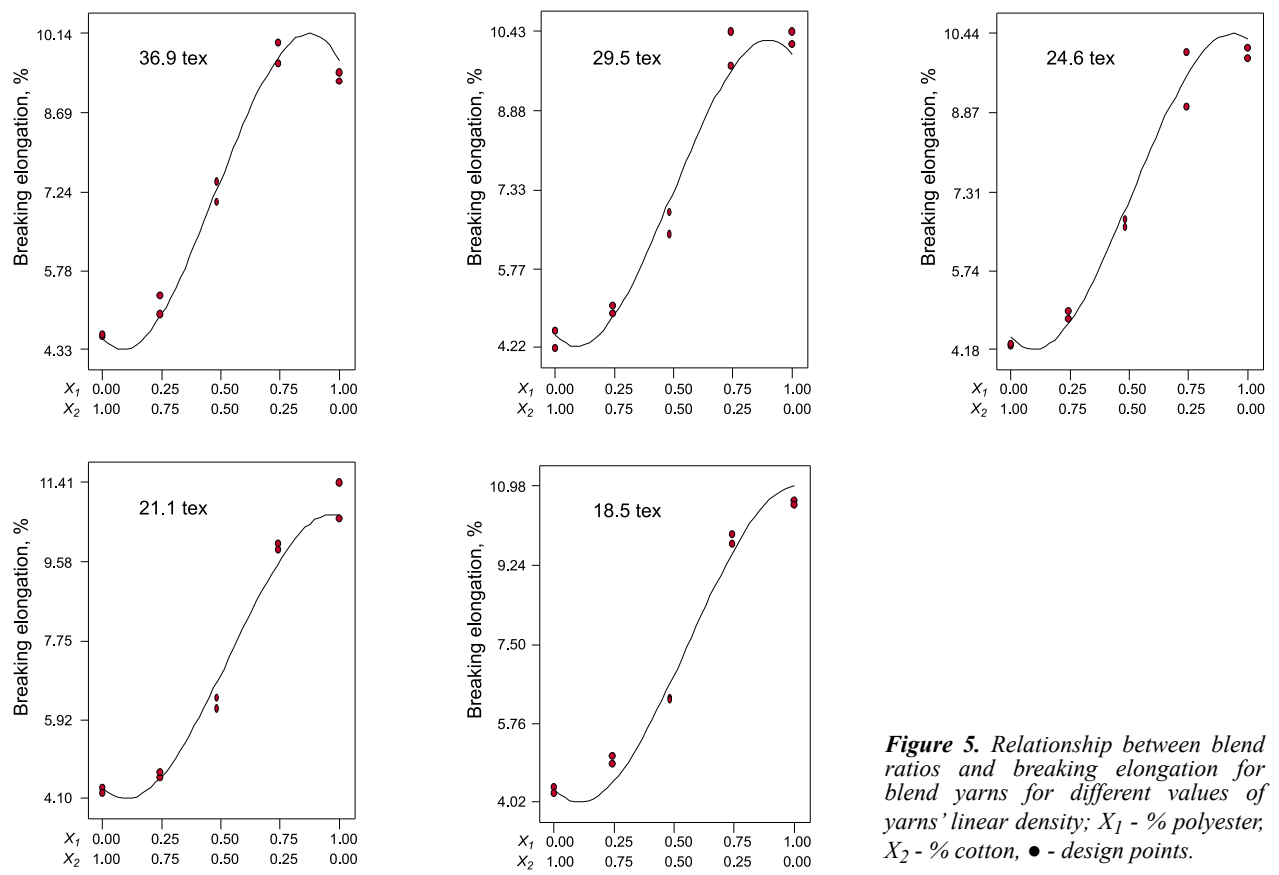

Figure 5. *Relationship between blend ratios and breaking elongation for blend yarns for different values of yarns' linear density; X_1 - % polyester, X_2 - % cotton, ● - design points.*

Figure 5 illustrates the relationship between blend ratios and the breaking elongation of the yarns spun into different counts. Experimental results show that when the polyester ratio changes from 10 to 90%, the breaking elongations of the blended yarns spun into five different counts increase, since the breaking elongation of polyester fibres is better than those of cotton fibres in the blend.

The use of a small amount of polyester actually causes a decrease in the yarn elongation. In addition, blend inhomogeneities might be the cause of breaking elongation losses due to high polyester blends. The coarser counts are more extensible than the finer ones, according to Equation 4.

Good agreement is observed between the predicted and the observed values, as supported by the high correlation coefficient (0.990) and Figure 6.

Conclusions

The strength and elongation properties of blended OE-rotor yarns are modelled through proper regression models with blend ratios and yarn count as independent variables. These models have strong prediction capability, as indicated by high correlation coefficients. Using these regression models, we can predict the strength and elongation properties of cotton/polyester-blended OE-rotor yarns for unobserved blend ratios and yarn count within the design space used in this study. A similar approach can be carried out for different types of cotton and polyester fibres.

Acknowledgment

The authors wish to express their thanks to the owners and staff of the Matesa and Kivanç Textiles Corporations for providing the blended slivers and test equipments.

References

1. *Lunenschloss, J., Frey, M., 'Die Mischung von Polyester-Fasern mit Baumwolle', Melliand Textilberichte, 6-8-9/59.*
2. *Pan, N., Chen, K., Monego, C. J., Backer, S., 'Studying the Mechanical Properties of Blended Fibrous Structures Using a Simple Model', Textile Research Journal, 70(6), 502-507, 2000.*
3. *Jianchun, Z., Peixing, F., 'Predicting the Tensile Strength of Lyocell/PET Blended Yarns', ITB International Textile Bulletin, 28-30, 6/99.*
4. *Pan, N., Postle, R., 'Strengths of Twisted Blend Fibrous Structures: Theoretical Prediction of the Hybrid Effects', Journal of the Textile Institute, 86, 559-580, 1995.*
5. *Kemp, A., Owen, J. D., 'The Strength and Behaviour of Nylon/Cotton Blended Yarns Undergoing Strain', Journal of the Textile Institute, 46, T-684, 1995.*
6. *Ratnam, T. V., and etc., 'Prediction of the Quality of Blended Yarns from that of the Individual Components', Textile Research Journal, 38, 360-365, 1968.*
7. *Cornell, J. A., 'Experiments With Mixtures-Designs, Models, and the Analysis of Mixture Data', John Wiley & Sons, Inc., USA, 632 p., 1990.*
8. *Montgomery, D. C., 'Design and Analysis of Experiments', John Wiley & Sons, Inc., USA, 649 p., 1991.*
9. *Duru Baykal, P., 'Prediction of Cotton/Polyester Blended OE Rotor Yarn Properties and Optimization of Blending', PhD Thesis, Çukurova University, Department of Textile Engineering, Balcalı/Adana, Türkiye, 211 p., 2003.*
10. *Myers, R. H., and Montgomery, D. C., 'Response Surface Methodology', John Wiley & Sons, Inc., USA, 798 p., 2002.*

Received 25.01.2005 Reviewed 17.08.2005