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 strength 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 \( X_1, X_2, \ldots, X_p \) denote the proportions of ‘\( p \)’ components of a mixture, then:

\[
0 \leq X_i \leq 1, \quad i = 1, \ldots, p
\]

\[
X_1 + X_2 + \cdots + X_p = 1
\]

(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>
<thead>
<tr>
<th>Parameter</th>
<th>Mic.</th>
<th>Length, mm</th>
<th>Unf., %</th>
<th>SFI</th>
<th>Strength, g/tex</th>
<th>Elongation, %</th>
<th>SCI</th>
<th>CSP</th>
<th>Rd</th>
<th>b</th>
<th>C-G</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean</td>
<td>3.80</td>
<td>28.95</td>
<td>83.2</td>
<td>6.50</td>
<td>29.1</td>
<td>6.7</td>
<td>142</td>
<td>2277</td>
<td>77.5</td>
<td>8.50</td>
<td>31.1</td>
</tr>
<tr>
<td>s.d.</td>
<td>0.25</td>
<td>0.84</td>
<td>0.92</td>
<td>0.80</td>
<td>1.19</td>
<td>0.18</td>
<td>6.47</td>
<td>47.08</td>
<td>1.21</td>
<td>0.50</td>
<td>-</td>
</tr>
<tr>
<td>Cv, %</td>
<td>6.63</td>
<td>2.90</td>
<td>1.11</td>
<td>12.29</td>
<td>4.09</td>
<td>2.72</td>
<td>4.54</td>
<td>2.07</td>
<td>1.56</td>
<td>5.85</td>
<td>-</td>
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Table 2. Test results for the polyester fibers.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fineness, dtex</th>
<th>Length, mm</th>
<th>Strength, gN/tex</th>
<th>Elongation, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean</td>
<td>1.59</td>
<td>33.31</td>
<td>0.740</td>
<td>22.90</td>
</tr>
<tr>
<td>s.d.</td>
<td>3.01</td>
<td>0.26</td>
<td>0.573</td>
<td>5.426</td>
</tr>
</tbody>
</table>
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 crossed model for the strength of the blended rotor yarns. The regression equation of this model is as follows:

\[
Z = -0.29 X_1^2 + 0.003 X_1 X_2 + 0.002 X_1 Z + 0.003 X_2 Z + 0.02 X_2^2 - 0.19 X_2 Z - 0.29 X_1 X_2 Z + 0.98 \]

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}

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

<table>
<thead>
<tr>
<th>Design points</th>
<th>Blend ratios, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>X_1 (polyester)</td>
</tr>
<tr>
<td>b</td>
<td>0</td>
</tr>
<tr>
<td>c</td>
<td>25</td>
</tr>
<tr>
<td>d</td>
<td>50</td>
</tr>
<tr>
<td>e</td>
<td>75</td>
</tr>
<tr>
<td>f</td>
<td>100</td>
</tr>
</tbody>
</table>

**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 |
|---------------------|-----------|-----------------|
| Rotor speed, rpm    | 36.9      | 29.5            |
| Opening roller speed, rpm | 75.000 | 24.6            |
| Type of rotor       | 21.1      | 18.5            |
| Type of opening roller | 0.13    | 0.13            |
| Type of navel       | 0.13      | 0.13            |
| Count of blended sliver, Ne | 4        | 4               |
| Twist, tpmm         | 492.9     | 4               |
| Draft               | 123.07    | 4               |
| Yarn delivery speed, m/min | 119.06  | 97.24           |
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.

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:

\[
y_{\text{breaking elongation}} \% = 8.24X_1 + 4.77X_2 + 6.56X_1X_2 + 0.09X_1Z - 0.02X_2Z + 0.33X_1X_2Z + 14.42X_1X_2(X_1 - X_2) + 0.17X_1X_2Z(X_1 - X_2)
\]  

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

Figure 4. Correlation between predicted and observed strength values.

Figure 6. Correlation between predicted and observed breaking elongation.
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

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References


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