TWO-YEAR PRODUCTION EXPERIMENT FOR YARN AND FABRIC STRENGTH MAXIMIZATION -AN ANALYSIS REPORT

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Abstract

A large scale production experiment has been conducted at a denim plant. A total of 121,200 bales (4,180 laydowns) was tested for HVI bundle strength, elongation, micronaire, length and other variables. The cotton bales were processed to produce 6/1 ring spun yarns and woven into an identical style of denim fabric. The HVI data and lab test results on tensile properties of yarns and fabrics were analyzed to evaluate the relationship between them. The study has shown that the variance of bundle breaking elongations between bales is useful as a criterion for bale selection based on the large scale production experiment.

Based on a new model for estimating single fiber tensile properties form HVI bundle tensile data, the variance of breaking elongations was estimated for all fibers contained in each laydown. The estimated single fiber tensile properties together with HVI data provided an enhanced method for optimizing the yarn and fabric strengths. MANTIS® single fiber test results were used for obtaining the single fiber tensile properties from the HVI bundle data.

Introduction

Physical properties of cotton fibers are highly non-uniform and vary widely fiber to fiber and bale to bale. Consequently, these variations are carried over to the properties of spun yarns and woven fabrics making it difficult to predict or optimize the properties. In manufacturing a spun yarn, it is necessary to develop a theory on optimal selection of the component fibers in order to optimize the yarn and fabric properties resulting from them. The optimal fiber selection is, therefore, a critical process for controlling the ultimate qualities of cotton yarns and fabrics. The purpose of this research was to study the relationships between the cotton fiber properties and the resulting spun yarn and fabric properties and single out the most important factor affecting yarn and fabric strengths so that a method for optimizing them can be developed in a general form.

In the previous paper (1), the study assumed that minimizing the between-bale variance of HVI elongations within a laydown is equivalent to minimizing the variance of single fiber elongations for the entire laydown. The experiment made use of these concepts by forming laydowns based on HVI elongation data and by fixing other values at population averages.

Because of the shortcomings and limitations in the planned experiment, a large scale production experiment has been conducted at a denim plant by obtaining the cotton fiber measurement data from HVI and the resulting yarn and fabric tensile properties during a two-year period.

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 2:1476-1479 (1996)
National Cotton Council, Memphis TN

Experimental

The planned experiment has limitations in that it is almost impossible to fix the auxiliary variables at constant levels. One way to overcome this is to run a production experiment based on many weeks of data under no strict control of the major variables. Following this approach, a production experiment was run during a two-year period. A total of 121,200 bales (4,180 laydowns) was tested for HVI bundle strength, elongation, micronaire, length and other properties. The cotton bales were processed to produce 6/1 ring spun yarns and woven into an identical style of denim fabric. The tensile and tear strengths of the denim fabrics were tested at 2 or 3 locations per dye set, 3 specimens per location (20 dye sets per a week). In addition, the tensile strengths of 6/1 spun yarns were tested twice a week, 20 bobbins per test using the standard test method. The weekly average of HVI data and lab test results on tensile properties of yarns and fabrics were analyzed to see the relationship between the cotton fiber properties and the resulting spun yarn and fabric properties.

A Preliminary Analysis

In evaluating the relationship between the HVI properties and the yarn and fabric strengths, a preliminary regression analysis was run using SAS® system. The HVI properties and the yarn and fabric strengths were sorted and averaged by week to form the regression data points. The average HVI properties of a given week were matched against the average yarn and fabric strengths obtained after one and two weeks, respectively.

In Figure 1, it is very difficult to find a significant correlation between HVI properties and the fabric tear strength. Because the elongation data were missing for some laydowns, only 75 weeks (43,500 bales) out of 101 were available. In Figure 2, the variances of HVI elongations show a negative correlation with the fabric tear strengths. In other words, the fabric tear strength increases when the variance of HVI elongations decreases. Similar results are shown for the yarn and fabric tensile strengths.

In making the multiple regression analyses, the average HVI length, strength, micronaire, elongation and elongation variance were used as predictor (X) variables, and the yarn and fabric strengths as dependent (Y) variables.

For the yarn tensile and fabric tear strengths, the Durbin-Watson statistics (2) showed significant autocorrelations, but the correlation coefficients among HVI length, strength, micronaire and elongation were not significant. Therefore, A set of simple regression analyses was run after removing all non-contributory variables. The results were that the HVI elongation variances were the only significant predictor (X) variables. The results are given in Table 1. In Figure 3 and 4, the predicted values of the yarn tensile and fabric tear strengths were obtained by using the variance of HVI elongations as a predictor variable. It is clearly shown in the figures that the yarn tensile and fabric tear strengths increase when the variance of the HVI elongation decreases. The most important observation is that, unlike the findings from previous paper (1), the variance of the HVI elongation is applicable to optimal blending aimed at enhancement of yarn and fabric strengths in production situations. While the significance levels of the regression fit were not high, it is quite remarkable to observe the clear existence of the effects while no other HVI factor is shown to be significantly correlated with the yarn tensile and fabric tear strengths.

For the fabric tensile strength, the Durbin-Watson statistic showed a significant autocorrelation while the HVI length and elongation showed a negative correlation. A new independent variable was created by merging the length effects to the elongation effects through a simple regression analysis with the HVI elongation as the predictor variable (X) and the HVI length as the dependent variable (Y) ;

Predicted Value of HVI length	= 1.079 - 0.00203 x HVI Elongation
Composite Elongation Effect	= HVI Elongation + Predicted Value of HVI length
	= 1.079 + 0.9978 x HVI elongation

The first equation above is meaningful since the HVI length and HVI elongation values were found to be highly negatively correlated.

A set of multiple regression analyses was run to assess the combined effects of composite elongation effect, HVI micronaire and variance of HVI elongations. The results are given in Table 1. In Figure 5, the predicted values of fabric tensile strength were obtained by using the composite elongation effect, micronaire and variance of the HVI elongations as predictor variables. In the figure, the fabric tensile strength is shown to increase when the composite elongation effect increases and the variance of HVI elongation decreases. It is shown that neither the regression fit nor the effect of variance of HVI elongations was highly significant. We may speculate that the lack of significance here may be due to the differences in the total number of yarns broken in the test direction and other fabric construction factors associated with the fabric tensile test method.

In summary, the most useful variable for optimization of yarn and fabric strengths is the variance of HVI elongations. This does not mean that other HVI variables such as HVI length and strength do not affect the yarn and fabric strengths. Because the range of the HVI data collected was so narrow, it might not have been possible to observe the relationship between other HVI properties and yarn and fabric strengths.

An Improved Analysis with Single Fiber Tensile Data

In order to improve the preceding analysis further and develop a new optimization method, a new theory and an in-depth analysis were developed based on the work by Suh et al (1, 3). Because the elongation data were missing for some laydowns and the needed single fiber information was not available for certain types of cottons, only 30 weeks (29,145 bales) out of 101 were available for an improved analysis.

From the HVI data for each of the 29,145 bales, three single fiber tensile properties (breaking load, breaking elongation and variance of breaking elongation) were estimated by applying the theory developed (1, 3). They were in turn averaged into each laydown of 29 bales.

In evaluating the relationships between the effects of estimated single fiber tensile properties and the yarn and fabric strengths, a simple regression analysis was run with the estimated single fiber tensile properties as predictor variables (X) and the yarn and fabric strengths as the dependent variables (Y).
In Figure 6, the predicted value of yarn tensile strength was obtained by using the variance of the estimated single fiber elongations as the predictor variable. From the figure, it is quite clear that the yarn tensile strength increases when the variance of the estimated single fiber elongations within a laydown decreases and that the statistical significance is much greater than the case with HVI elongation. However, the same enhancement could not be confirmed for the fabric tensile and tear strengths. This, in part, may be due to other important factors such as the effects of non-uniform fabric construction and sample preparation errors in the fabric testing methods.

Conclusions

A large scale production experiment for exploring the possibility of improving yarn and fabric strengths through HVI measurements produced several important results:

1. The HVI data, in their raw form, are found to be not highly useful for optimization of yarn and fabric strengths.

2. The variance of HVI elongations within a laydown is found to be significantly correlated with some of the yarn tensile and fabric tear test data, suggesting a strong possibility for strength optimizations through a proper bale selection method.

3. The estimated single fiber tensile properties together with HVI data provided an enhanced method for optimizing the yarn and fabric strengths.

References

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Table 1. Multiple Regression Analysis Results

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Equations	t values for H_0: parameter=0	Probability > |t|	R^2
FTR=6180.00 – 379.60 X1	X1 : – 2.332	X1 : 0.0232	0.3878
YTN=345.05 – 24.10 X1	X1 : – 2.254	X1 : 0.0283	0.3501
FTN=134.03 – 1.77 X1+3.27 X2+8.61 X3	X1 : – 0.509 X2 : 2.094 X3 : 2.821	X1 : 0.6127 X2 : 0.0407 X3 : 0.0066	0.3917
YTN=409.51 – 1.14 X4	X4 : – 4.396	X4 : 0.0003	0.4915

Notes: FTR = Fabric Tear Strength
YTN = Yarn Tensile Strength
FTN = Fabric Tensile Strength
X1 = HVI Elongation Variance
X2 = Composite Elongation Effect
X3 = Micronaire
X4 = Variance of Estimated Single Fiber Elongations

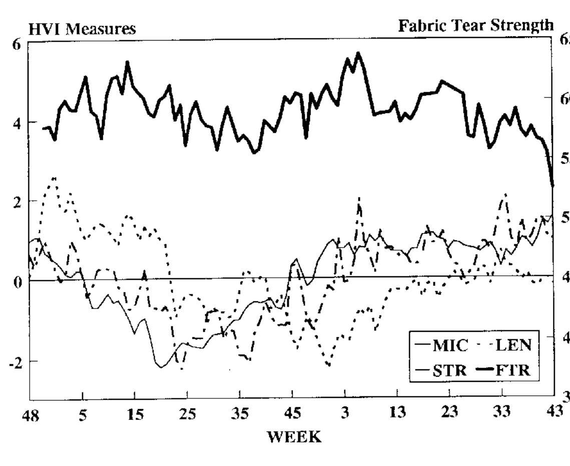

Figure 1. The Effects of HVI Measures on Fabric Tear Strength

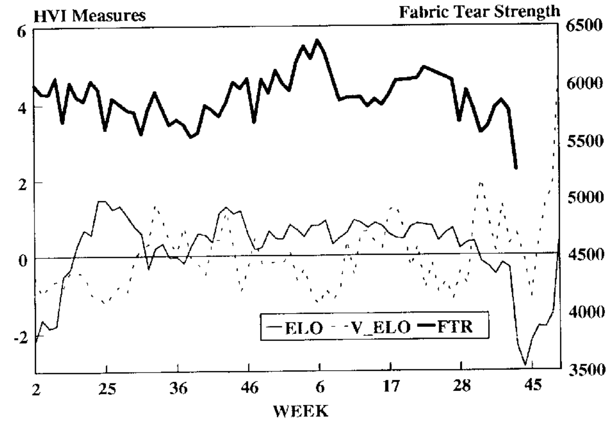

Figure 2. The Effects of HVI Measures on Fabric Tear Strength

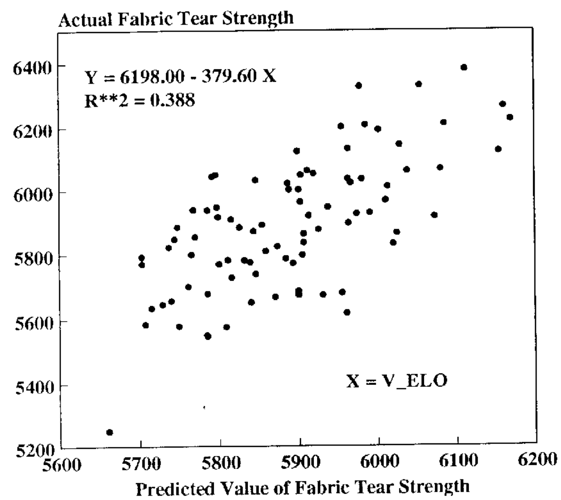

Figure 3. Relationship between Actual and Predicted Fabric Tear Strengths

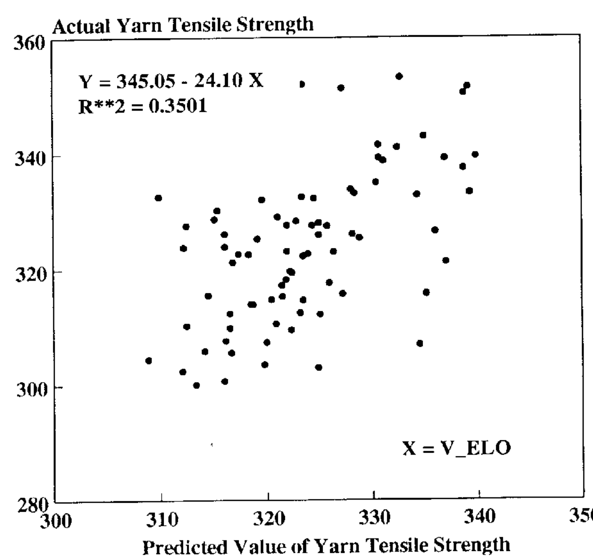

Figure 4. Relationship between Actual and Predicted Yarn Tensile Strengths

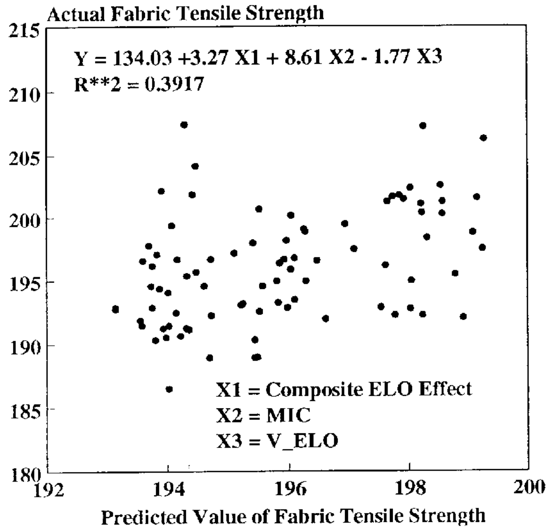

Figure 5. Relationship between Actual and Predicted Fabric Tensile Strengths

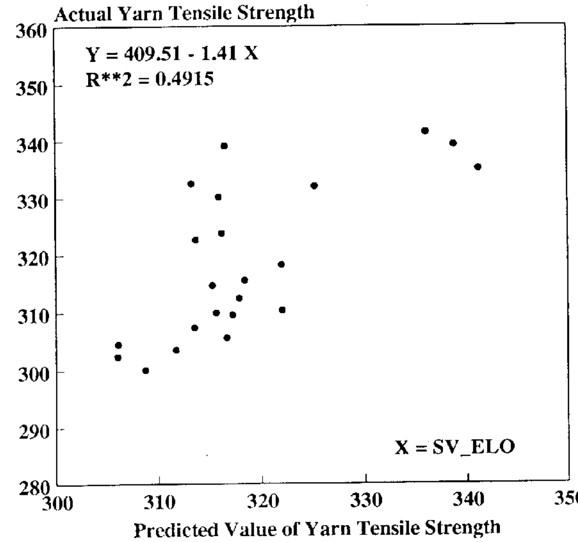

Figure 6. Relationship between Actual and Predicted Yarn Tensile Strengths