DEVELOPMENT OF OPTIMAL HVI STRENGTH INDEX FOR PREDICTION OF YARN TENSILE STRENGTH

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Abstract

Four different HVI Strength Indices were developed for predicting the yarn tensile properties. The "HVI Strength Indices were formed based on HVI tenacity, modulus, toughness and micronaire. The concept of "Best Power Function Search" was developed and applied to formation of two HVI Strength Indices (Q_3 and Q_4). The new indices (Q_3 and Q_4) derived from the best power function regression search were found to be superior to that without (Q_1 and Q_2).

Introduction

The use of raw HVI data has limited usefulness in textile manufacturing as the different HVI measures are often highly correlated among themselves, providing only a weak correlation with yarn and fabric strengths. Under this situation, a structural equation based on HVI measures can be considered as a means for improving the correlation.

Based on our previous work [Suh et. al., 1998], HVI tenacity, modulus, toughness and micronaire were found to be the significant contributing factors in predicting yarn tensile properties. We have developed a composite index that combines the important fiber properties in such a way that it can be shown to have a maximum correlation with the yarn quality or processing performance.

The ultimate objective of this research is to develop an HVI Strength Index for maximization of yarn tensile properties through power function generation and general linear models.

Models for HVI Strength Indices Through Power Function Generation

HVI Strength Indices were developed based on the HVI tenacity, modulus, toughness and micronaire as follows:

HVI Strength Index 1 (Q_1) = (BS x BK)/MIC,
HVI Strength Index 2 (Q_2) = (BS x BK x BT)/MIC,

In order to select the optimal HVI Strength Indices 1 and 2 with respect to the corresponding yarn tensile properties, the tenacity, modulus, toughness and micronaire were raised to the powers ranging from 0.25 to 2.5 by 0.25 increments. The power functions tried for obtaining the HVI Strength Indices were as follows:

HVI Strength Index 3 (Q_3) = $(Bs^i \times Bk^j) / MIC^l$,
HVI Strength Index 4 (Q_4) = $(Bs^i \times Bk^j \times BT^k) / MIC^l$,
i, j, k, l = 0, 0.25, 0.5, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00, 2.25, 2.50,

where, BS(gf/tex) = HVI bundle Tenacity, BK(gf/tex) = HVI bundle Modulus, BT(kgf/tex) = HVI bundle toughness and MIC(mg/inch) = HVI micronaire.

Selection of Optimal HVI Strength Indices Through Best Power Function Regression Search

Considering all possible combinations of powers, the values of Q_3 and Q_4 were simulated for 1,331 data sets (i x j x l = 11 x 11 x 11) and 14,641 data sets (i x j x k x l = 11 x 11 x 11 x 11), respectively, both before and after carding. The data sets for Q_3 and Q_4 were also used for predicting yarn tenacity and work-to-break of yarn, respectively.

In order to find the optimal power function forms of Q_3 and Q_4 with respect to the corresponding yarn tensile properties, 1,331 sets of simple regression analyses were run using SAS® system between Q_3 and yarn tensile strength, and 14,641 sets between Q_4 and the work-to-break of yarn. A total of 2,662 regression equations were run for yarn tenacity and 29,282 regression equations for work-to-break of yarn. The regression models using HVI Strength Indices as predictor variables are as follows:

Regression Model I : $\hat{Y}T_1 = \beta_1 + \alpha_1 \cdot Q_1$

Regression Model II : $\hat{Y}W_2 = \beta_2 + \alpha_2 \cdot Q_2$

Regression Model III : $\hat{Y}T_3 = \beta_3 + \alpha_3 \cdot Q_3$

Regression Model IV : $\hat{Y}W_4 = \beta_4 + \alpha_4 \cdot Q_4$

where, YT (gf/tex) = Yarn Tenacity and YW (kgf × cm) = Work-to-Break of Yarn.

In order to conduct optimal search with respect to Q_3 and Q_4, the power function models III and IV were sorted by R^2 values. It was decided to limit the study to those R^2 values for which the power function regression models III and IV are greater than the R^2 values obtained from the regression models I and II, respectively.

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Test of Significance on the Power Function Regression Models

The significance of the improvement from the power function regression models over models I and II was tested using an F-statistic. The *SSE* (error sum of square) from the models I and II were compared against that(SSE_p) from models III and IV, respectively. The appropriate F-statistic is

$$F_{1,n} = \frac{\left(SSE - SSE_p\right)}{MSE_p},$$

where, MSE_p = mean square error of power function regression model III or IV, n = degree of freedom of error in error of power regression model III or IV. The numerator degree of freedom for the F-test is 1 since the comparison consists of one contrast.

If the computed F values are greater than the table value $F_{1, 34, a}$, then improvement by the power regression model III or IV is assumed to be significant. When the power function regression model III using ($BS^{0.5}$ x $BK^{0.25}$)/$MIC^{0.25}$ as a predictor variable is compared against model I using (BS x BK)/MIC as a predictor variable, the resulting F-statistic was as follows:

SSE = 40.172, SSE_p = 33.614 and MSE_p = 0.989,

$$F = \frac{40.172 - 33.641 / 1}{0.989} = 6.6036 > 4.134\left(= F_{1,34,0.05}\right).$$

Therefore, we conclude that a significant improvement over Q_1 has been made by using the power function regression model III, or Q_3 = ($BS^{0.5}$ x $BK^{0.25}$)/$MIC^{0.25}$ by using the before carding data. In other words, ($BS^{0.5}$ x $BK^{0.25}$)/$MIC^{0.25}$ is a statistically superior predictor over Q_1 = (BS x BK)/MIC. The test of significance on the improvement made by the power function regression models are given in Tables 1 ~ 4. They include the best power functions for HVI properties, R^2 and F-statistics. For the significance tests, both 90% and 95% confidence levels were tried.

For predicting the yarn tenacities with before carding fiber data, 8 power functions were selected by applying model III, whereas 9 power functions were selected by applying model IV for the after carding data. For predicting the work-to-break of yarn, 28 and 23 power functions were selected by applying model IV to before and after carding data, respectively. Only best power function models were shown selectively in Tables 1 ~ 4. It is interesting to note in Tables 3 and 4 that the best power for HVI bundle strength is zero for Q_4, suggesting that HVI bundle modulus, toughness and micronaire are the only significant contributors to yarn tenacities for both before and after carding data.

Study of the Relationship Between Optimized HVI Strength Indices and Yarn Tensile Properties

Based on the selected power functions of Q_3 and Q_4, some of the best power regression models are suggested for yarn tenacity and work-to-break of yarn.

In making the analyses, Q_3, Q_4 and AFIS® fiber lengths and HVI fiber lengths were used as predictor (X) variables, whereas the yarn tenacity and work-to-break of yarn as dependent (Y) variables. Tables 6 shows the suggested power regression models III and IV for yarn tensile properties. The regression models I and II are given in Table 5.

The results based on power function model III (Table 6 and Figures 5 and 6) show that Q_3 measured before carding and AFIS® length by number are the two significant predictor variables ($p < 0.1$) whereas Q_3 measured after carding is the only significant predictor variable for yarn tenacity. The R^2 values for model III are shown to increase significantly (0.033 ~ 0.053) when Q_3 is used instead of Q_1 (Table 5 and Figures 1 and 2).

The results based on power function model IV (Table 6 and Figures 7 and 8) show that Q_4 measured before carding and AFIS® length (upper quartile length by number) are the two significant predictor variables ($p < 0.1$), whereas Q_4 measured after carding is the only significant predictor variable for work-to-break of yarn. The R^2 values for model IV are shown to increase significantly (0.058 ~ 0.069) when Q_4 is used instead of Q_2 (Table 5 and Figures 3 and 4). It is clearly shown from the table and figures that R^2 value improves when we use Q_3 and Q_4 measured after carding.

Summary and Conclusions

1. Four HVI Strength Indices has been developed based on HVI data only in predicting the resulting yarn tensile properties. Two indices (Q_1, Q_3) are for predicting yarn tensile strength and the other two (Q_2, Q_4) for predicting work-to-break of yarn.
2. For predicting of yarn tenacity, HVI Strength Indices Q_1 and Q_3 make use of HVI tenacity, modulus and micronaire. For predicting work-to-break of yarn, HVI Strength Indices Q_2 and Q_4 make use of HVI tenacity, modulus, toughness and micronaire.
3. HVI Strength Indices Q_3 and Q_4 obtained by the best power function regression search were found to be significantly superior to Q_1 and Q_2 obtained without use of the best power functions.
4. For predicting yarn tenacity, HVI Strength Index Q_3 and AFIS® Mean Length by Number were found to be the best predictor variables. For predicting work-to-break of yarn, HVI Strength Index Q_4 and AFIS® UQL by Number were the best predictor variables.

References

Moon W. Suh, Hyun-Jin Koo and Michael D. Watson, "Estimation of HVI Bundle Modulus and Toughness as Determinants to Tensile Properties of Spun Yarns," Proceedings of 1998 Beltwide Cotton Conferences, PP 1530-1537, 1998.

Table 1. The Analyses Results of HVI Strength Index 3 and Yarn Tenacity (Before Carding)

i	*j*	*k*	R^2	ESS_p	MSE_p	F-Statistic
0.25	0.25	0.25	0.728	34.756	1.022	5.298
0.75	0.25	0.25	0.728	34.721	1.021	5.338
0.50	0.25	0.50	0.731	34.297	1.009	5.824
0.75	0.25	0.50	0.732	34.170	1.005	5.972
0.50	0.25	0.25	0.737	33.614	0.989	6.633

Table 2. The Analyses Results of HVI Strength Index 3 and Yarn Tenacity (After Carding)

i	*j*	*k*	R^2	*ESSp*	*MSEp*	F-Statistic
1.00	0.25	0.50	0.760	30.599	0.900	4.480
1.75	0.50	0.50	0.760	30.676	0.902	4.384
1.25	0.25	0.50	0.761	30.519	0.898	4.581
1.25	0.50	0.50	0.761	30.511	0.897	4.591
1.50	0.50	0.50	0.762	30.382	0.893	4.755

Table 3. The Analyses Results of HVI Strength Index 4 and Work-to-Break of Yarn (Before Carding)

i	*j*	*k*	*l*	R^2	ESS_p	MSE_p	F-Statistic
0.25	2.00	0.75	2.00	0.583	0.0268	0.00079	3.381
0.00	0.50	0.50	0.50	0.583	0.0267	0.00079	3.409
0.00	2.50	1.25	2.25	0.584	0.0267	0.00079	3.430
0.50	0.25	0.25	0.50	0.584	0.0267	0.00079	3.465
0.00	0.25	0.25	0.25	0.586	0.0266	0.00078	3.667

Table 4. The Analyses Results of HVI Strength Index 4 and Work-to-Break of Yarn (After Carding)

i	*j*	*k*	*l*	R^2	ESS_p	MSE_p	F-Statistic
0.00	1.25	0.75	1.00	0.734	0.0171	0.00050	5.440
0.00	1.50	1.00	1.25	0.734	0.0170	0.00050	5.480
0.00	1.00	0.75	0.75	0.735	0.0170	0.00050	5.520
0.00	1.50	1.00	1.50	0.735	0.0170	0.00050	5.560
0.00	2.00	1.25	1.50	0.746	0.0163	0.00048	7.250

Table 5. Summary of Multiple Regression Analyses based on Q_1, Q_2 and AFIS® Length on Yarn Tensile Properties

Process	Model	Prob. > |t|	R^2
Bale	Model I: $YT_1 = 1.82 + 0.011\ Q_1 + 10.85\ X_1$	Q_1: 0.0001 X_1: 0.1547	0.704
	Model II: $YW_2 = 0.27 + 0.000009\ Q_2$	Q_2: 0.0001	0.541
Carding	Model I: $YT_1 = 0.47 + 0.012\ Q_1^*$	Q_1^*: 0.0001	0.729
	Model II: $YW_2 = 0.237 + 0.01\ Q_2^*$	Q_2^*: 0.0001	0.692

Notes:

YT_1 = Yarn Tenacity
YW_2 = Work-to-break of Yarn
Q_1 = HVI Strength Index 1 before Carding
Q_1^* = HVI Strength Index 1 after Carding
Q_2 = HVI Strength Index 2 before Carding
Q_2^* = HVI Strength Index 2 after Carding
X_1 = AFIS® Fiber Mean Length by Number

Table 6. Summary of Power Regression Analyses based on Q_3, Q_4 and AFIS® Length on Yarn Tensile Properties

Process	Model	Prob. > |t|	R^2
Bale	Model III : $YT_3 = -8.62 + 1.86\ Q_3 + 12.82\ X_1$	Q_3: 0.0001 X_1: 0.0728	0.757
	Model IV : $YW_4 = -0.092 + 1.82\ Q_4 + 0.304\ X_2$	Q_4: 0.0001 X_2: 0.1061	0.610
Carding	Model III : $YT_3 = 7.529 + 0.748\ Q_3^*$	Q_3^*: 0.0001	0.762
	Model IV : $YW_4 = 0.248 + 9.549\ Q_4^*$	Q_4^*: 0.0001	0.750

Notes:

YT_3 = Yarn Tenacity
YW_4 = Work-to-break of Yarn
Q_3 = HVI Strength Index 3 (i = 0.5, j = 0.25, l = 0.5) before Carding
Q_3^* = HVI Strength Index 3 (i = 1.5, j = 0.5, l = 0.5) after Carding

Q_4 = HVI Strength Index 4 (i = 0, j = 0.75, k = 0.5, l = 1) before Carding
Q_4^* = HVI Strength Index 4 (i = 0, j = 2, k = 1.25, l = 1.5) after Carding
X_1 = AFIS® Fiber Mean Length by Number
X_2 = AFIS® Fiber Upper Quartile Mean Length by Number

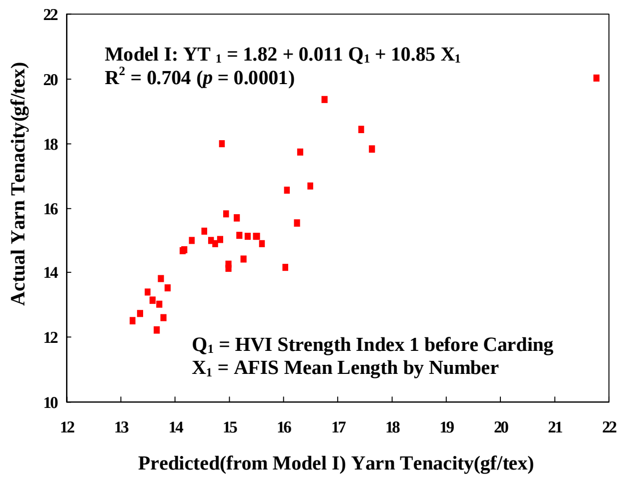

Figure 1. Predicted(from Model I) and Actual Yarn Tenacities Based on Q_1 (before Carding) and AFIS® Length as Predictor Variables

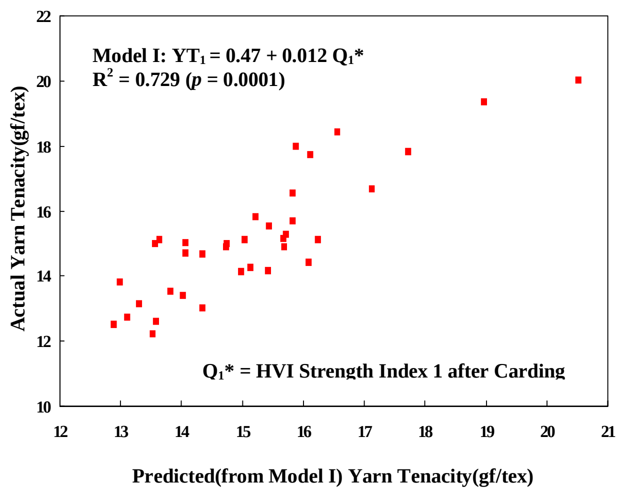

Figure 2. Predicted(from Model I) and Actual Yarn Tenacities Based on Q_1^* (after Carding) as a Predictor Variable

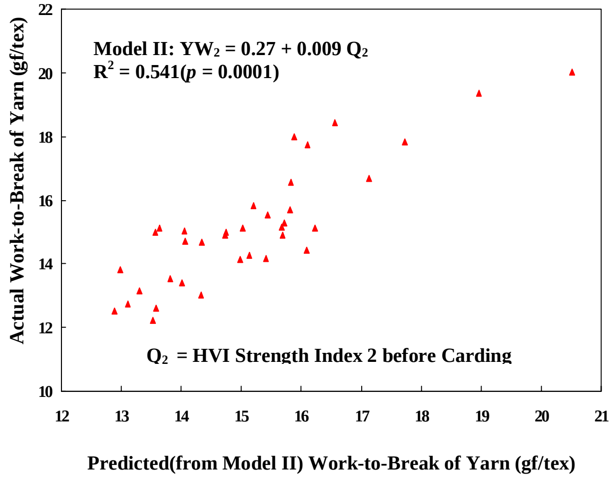

Figure 3. Predicted(from Model II) and Actual Work-to-Break of Yarn Based on Q_2 (before Carding) as a Predictor Variable

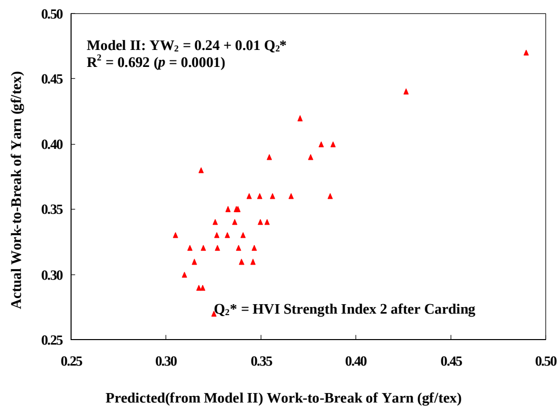

Figure 4. Predicted(from Model II) and Actual Work-to-Break of Yarn Based on Q_2* (after Carding) as a Predictor Variable

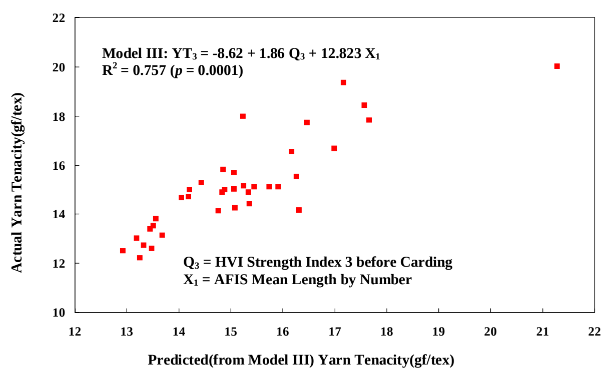

Figure 5. Predicted(from Model III) and Yarn Tenacities Based on Q_3 (before Carding) and AFIS® Length as Predictor Variables

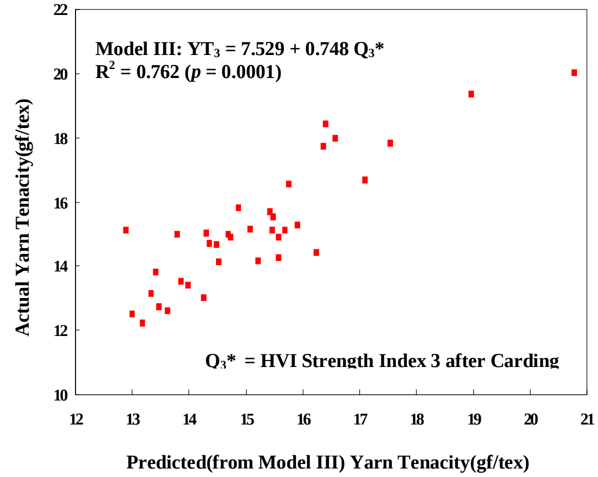

Figure 6. Predicted(from Model III) and Yarn Tenacities Based on Q_3* (after Carding) as a Predictor Variable

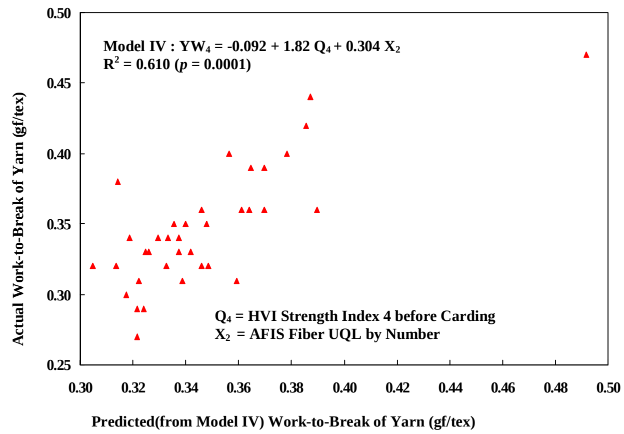

Figure 7. Predicted(from Model IV) and Actual Work-to-Break of Yarn Based on Q_4 (before Carding) and AFIS® Length as Predictor Variables

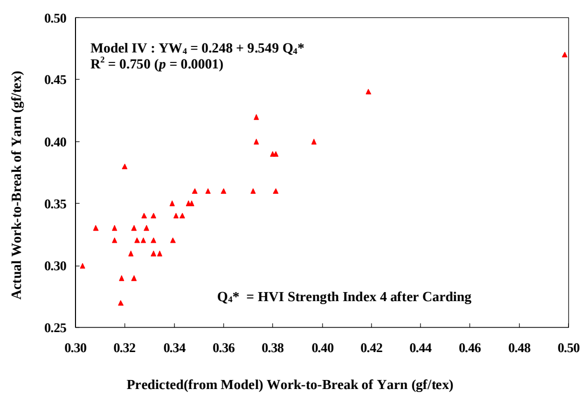

Figure 8. Predicted(from Model IV) and Actual Work-to-Break of Yarn Based on Q_4* (after Carding) as a Predictor Variable