EFFECTS OF SPINNING PROCESSES ON HVI FIBER CHARACTERISTICS

Moon W. Suh and Hyun-Jin Koo
College of Textiles, North Carolina State University
Raleigh, NC
Michael D. Watson
Cotton Incorporated
Raleigh, NC

Abstract

The effects of opening, carding, and repeated drawings on single fiber and bundle cotton characteristics were studied by employing Mantis®, AFIS® and HVI testers. Some of the significant changes in single fiber properties were found to be due to process parameters as well as the changes in the fiber crimps, parallelness of fibers within HVI beards, and the actual changes in the tensile properties of the fibers. The study showed that the HVI test data taken just prior to spinning had the highest correlation with the yarn tensile properties. Based on the study results, the authors point out the potential of HVI for future quality and process control in spinning by recommending a set of expanded HVI output that are more scientific and comprehensive for the future control needs.

Introduction

As the use of HVI data continues to expand in the U. S. and throughout the world, the interest is also on the rise to study the potential of HVI output for quality and process control in spinning. As the tensile and length properties change progressively as each process is added, it is imperative to know how they are changing in order to optimize the machine setting and understand fully the implications of adding or deleting a given process step.

The economic measurement methods, other than the uniformity measures of slivers, rovings and yarns, were non-existent in the past due to lack of proper instrument and/or speed. An automated HVI line, therefore, can be an alternative to tedious single fiber tests if the output can indeed provide the necessary scientific details.

As a first step, this study examines the changes in single fiber properties and the corresponding HVI bundle test results in raw cotton bales and cotton samples taken at the end of each process stage of spinning. By establishing the relations between and among the data sets, the idea is to frame a concept of quality/process control in spinning by use of HVI data. Furthermore, the study is to recommend an expanded HVI output for accomplishing the objectives in the future.

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Experimental Procedures

From four cotton types, “I”, “B”, New T (“NT”) and “Y” cottons, 16/1 Ne carded ring-spun yarns (RSK yarns) were produced with TM 4.5 on the laboratory spinning machines at the USDA-ARS-SRRC Labs.

In order to examine the effects of spinning processes on the outcomes of the tests on the fiber properties, samples were taken progressively after each of four processing stages, namely, opening, carding, 2nd and 3rd drawings. The items tested were the single fiber tensile properties, length, diameter and short fiber contents using Mantis® and AFIS® and for the bundle tensile properties using the HVI. The single fiber data before and after processing were compared against the resulting yarn properties to look for the possible relationship between the single fiber and yarn properties.

A total of 25,000 tests, 5 replications of 5,000 tests each, were performed on AFIS® for length, diameter and short fiber contents before and after each stage of processing. The mean values of length, diameter and short fiber contents at the end of each process are given in Tables 1 ~ 4.

A total of 32,000 tests were performed on Mantis® for single fiber tensile properties which involved about 8,000 fibers for each cotton and approximately 2,000 fibers at the end of each processing stage. Mean and standard deviation for each fiber property were calculated for these data and are given in Table 5 ~ 8.

Another lot of 128 tests was performed on HVI for the bundle tensile properties; 32 beards for each cotton, 8 beards each from raw cotton bale, after opening, after carding and after 2nd drawing. The mean values of HVI data at the end of each process are given in Table 9.

For the four different cottons, the tensile properties of 16/1 Ne RSK yarns were tested 20 times per bobbin, 5 bobbins for each cotton using the standard test method. These data were analyzed with respect to the fiber properties obtained at the end of each process. Only a limited amount of the test data was used for our analyses.

Results and Discussion

A. Effects of Spinning Processes on Fiber Length, Short Fiber Contents and Diameter

The effects of processing on fiber length, short fiber contents and diameter are shown in Figures 1 ~ 3. It is seen that the fiber length becomes longer after passing the 2nd drawing. This may be due to a partial removal of fiber crimps accompanied by actual loss of short fibers. The fact that the drawing operation causes to reduce fiber diameters has two possible implications. One is the possible presence of a correlation between length and diameter (negative), and the other may be fiber stretching during the drawing process. It may be that the lateral deformation in the fibers was large and irrecoverable after the processing. Further, a possible inaccuracy in the AFIS® measurements may have to be taken into consideration.

B. Effects of Spinning Processes on Single Fiber and Bundle Tensile Properties

The effects of processing on the single fiber tensile properties are shown in Figures 4 ~ 8. It is seen that the single fiber strengths for NT, I and Y cottons were reduced by the carding process. This implies that carding action may inflict most damages on the fiber and the fact is hardly surprising.

This confirms the general belief that each processing weakens the fibers as they are continuously stretched. At the same time, the fiber crimps and breaking elongations are shown to be decreasing as the fibers do not completely recover from the stress/strain of the previous process or processes.

The effects of processing on HVI bundle strength are shown in Figure 9. It was found that the HVI bundle strength for all cottons became significantly stronger after 2nd drawing. This is not due to an increase in single fiber strength. This might be due to reduction of means and variances of single fiber elongation and crimp after 2nd drawing. The effects of fiber crimp and elongation on bundle tensile strength are given by Cui [1].

The bundle strength decreases as the standard deviation of fiber crimp increases. The bundle strength reduction of as much as 15% was observed compared with the strength of a bundle without fiber crimps. The bundle strengths obtained from different amounts of average fiber crimps, however, did not differ much from each other. This indicates that it is the variation, not the average of fiber crimp, that reduces the bundle strength.

As expected from our intuition, Figures 10 ~ 12 show that an increase in crimp(%) does not change the bundle strength whereas a larger standard deviation of crimp always reduces the bundle strength. In Figure 13, a larger breaking elongation is shown to increase the bundle strength, perhaps due to a positive correlation between the fiber tensile strength and breaking elongation. A larger standard deviation of breaking elongation, on the other hand, is shown to affect the bundle strength adversely.

C. Effects of Spinning Processes on the Relationshipbetween Fiber Properties and Yarn Tensile Properties

Regression analyses were run using SAS® system in order to evaluate the relationship between the fiber properties before and after processing and relate them to the yarn tensile properties. The fiber properties and the yarn tensile properties were averaged by cotton and by process to make up the data for regression analyses. In making the multiple regression analyses, the average single fiber length, strength, diameter, elongation, CV% of elongation and HVI bundle strength were used as the predictor (X) variables, and the yarn strength as the dependent (Y) variables. Two sets of multiple regression analyses were also run by removing all non-contributory variables ($p > 0.05$) through the variable selecting process in stepwise regression. The first set includes single fiber tensile properties and other fiber properties as the predictor (X) variables, and the yarn strength as the dependent (Y) variables. The second set includes HVI bundle strength and other fiber properties as the predictor (X) variables, and the yarn strength as the dependent (Y) variables.

The results related to the first set of analyses show that only fiber length, strength and micronaire were the most significant predictor variables at the end of all manufacturing processes whereas the CV of crimp and length were the only predictor variables at the end of 3rd drawing. The details are given in Table 10.

The results from the second set in Table 11 show that only fiber length and HVI bundle strength were the most significant predictor variables. Fiber length was significant at all manufacturing process. On the other hand, the effects of HVI bundle strength were found to be significant only at the end of carding and 2nd drawing. The R^2 value is shown to be higher at the end of 2nd drawing than after carding. This means that HVI bundle strength and perhaps other data as well become more meaningful when the HVI test samples are taken at the end of a process stage which is closest to spinning.

Conclusion

This study has shown that each processing stage in spun yarn production changes both the single fiber properties and the bundle tensile and other quality characteristics. More specially, the increase in HVI bundle strength, in the absence of an increase in single fiber strength, was due to a gradual improvement in the parallelness of fibers within HVI test beards through removal of crimps. The progressive changes in single fiber length (increase), short fiber contents (decrease), fiber diameter (decrease), fiber strength (no change), fiber elongation (no change after opening), fiber crimp (decrease), variance of fiber crimp(decrease) and variance of breaking elongation (no change), as the processes were added, must be interpreted with caution.

Regression analyses revealed that the HVI data and perhaps other fiber test data become more useful when they are taken at the end of a process which is closest to spinning, if the HVI data are to be used as predictors of spun yarn properties.

In light of this study and other reports, HVI test data taken from raw cotton bales are not highly useful for predicting the quality characteristics of the resulting yarn. Although the value of HVI test data has been well established for fiber selection and bale laydown, it is strongly suggested that a different set of HVI output would be most useful for predicting the yarn qualities in the future. This would include the bundle “load-elongation” diagrams and diagrams for fiber length arrays. These, in turn, are expected to provide an alternative to the existing HVI calibration methods.

Discussions and Recommendations

The single fiber test data, as obtained from Mantis® and AFIS® at various stages of spinning processes, have confirmed some of the fears. Namely, the processing methods can change the fiber characteristics significantly, affecting the yarn qualities likewise. For an effective process control, however, the single fiber testing is considered too expensive and time-consuming and hence impractical.

As an alternative to these, HVI can be used if the output is modified to include some of more scientific quality features of fibers at the end of each process. The load-extension diagram of HVI bundle, the length array diagram, and several indices derivable from these could provide a useful tool for quality and process control in spinning. Addition or deletion of certain processes, severity of each processing through various machine setting, and confirmation of blending uniformity can be checked for their effects.

Economics relating to process selection and setting can be weighted against the quality consequences arising from them only when the measurements can be made scientifically at the end of each textile process. For this, HVI’s potential is considered excellent since the current HVI data are already based on several key statistical distributions and diagrams that are sufficient for providing more scientific details on single fiber and bundle quality characteristics.

The future applications of HVI, once the above improvements have been made, will be in the following three areas;

1. Process and quality optimization and control.

2. Improved product design and quality forecasting.

3. proved ultimate fiber selection and blending algorithms.

References

X. Cui, “Tensile Properties of Bundles and Their Constituent Fibers - An Application to HVI Cotton Testing,” Ph. D. Thesis, College of Textiles, North Carolina State University, Raleigh, N. C.,1995.

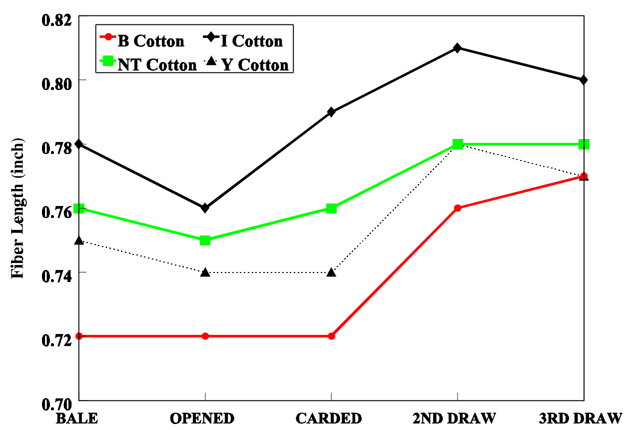

Figure 1. Effects of Processing on Fiber Length

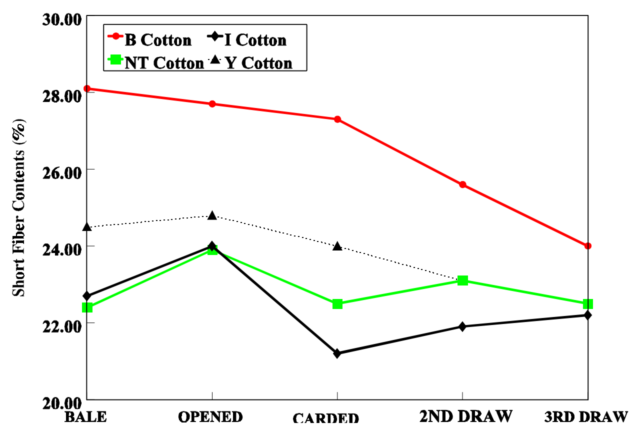

Figure 2. Effects of Processing on Short Fiber Contents

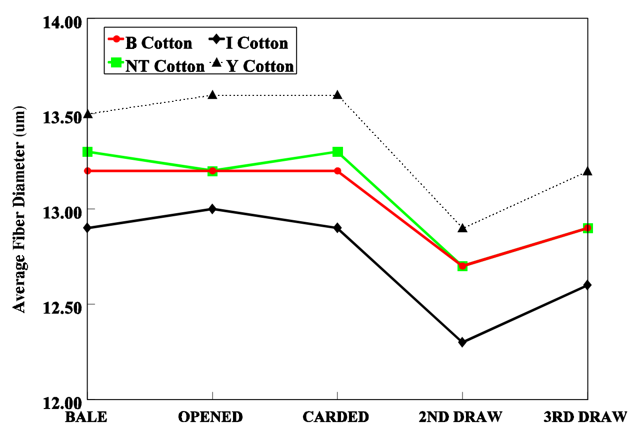

Figure 3. Effects of Processing on Fiber Diameter

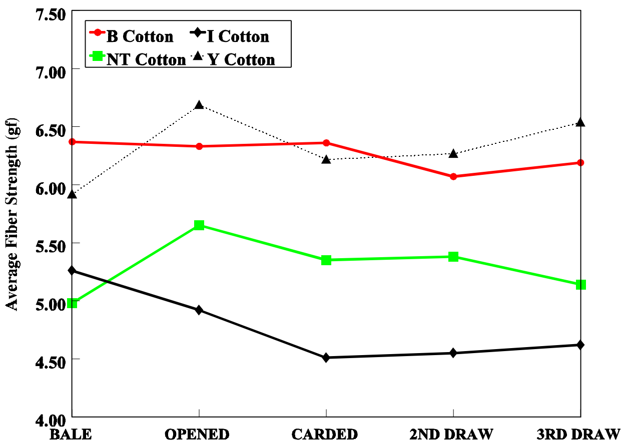

Figure 4. Effects of Processing on Fiber Strength

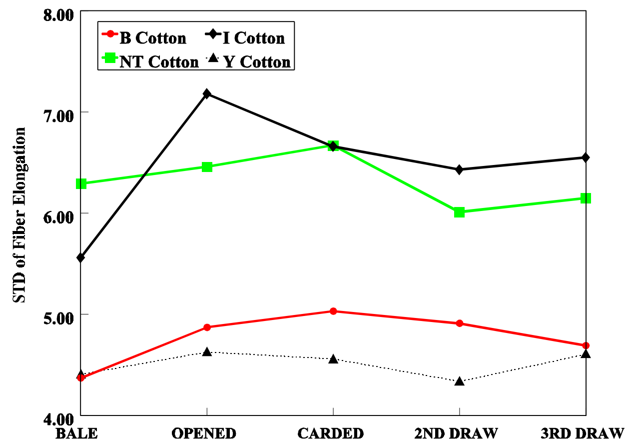

Figure 7. Effects of Processing on Variance of Fiber Elongation

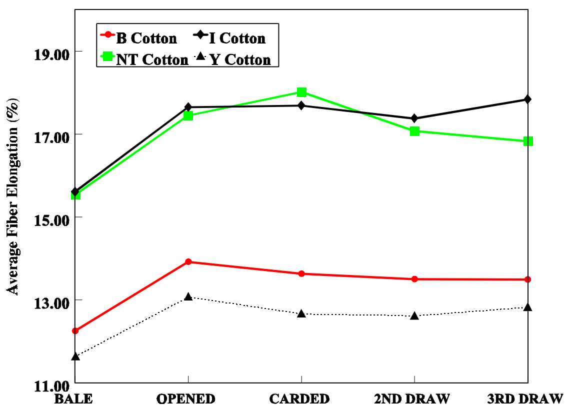

Figure 5. Effects of Processing on Fiber Elongation

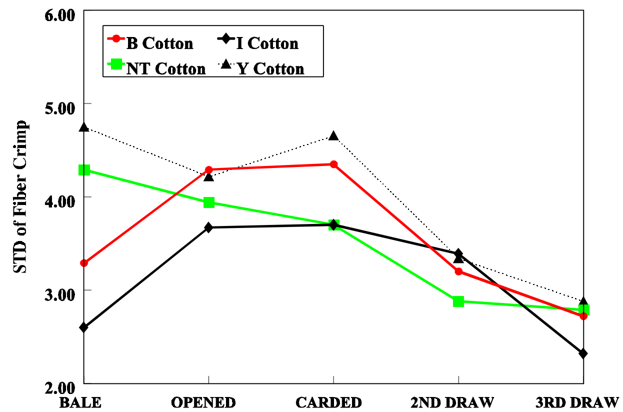

Figure 8. Effects of Processing on Variance of Fiber Crimp

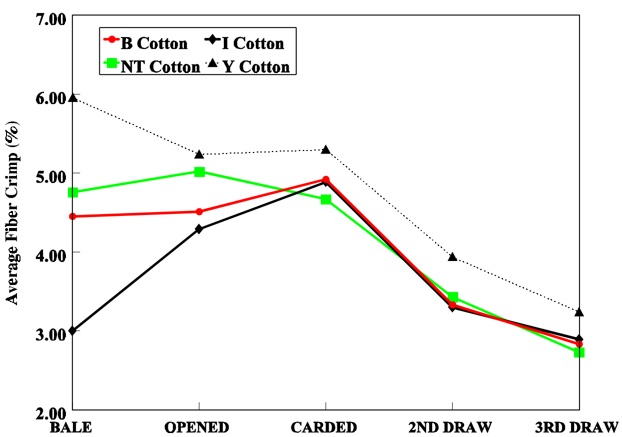

Figure 6. Effects of Processing on Fiber Crimp

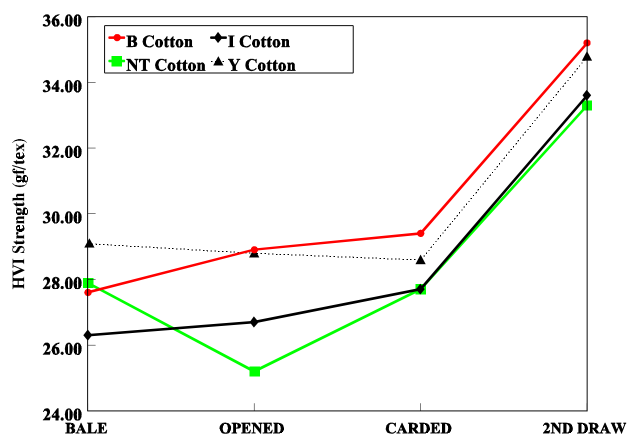

Figure 9. Effects of Processing on HVI Strength

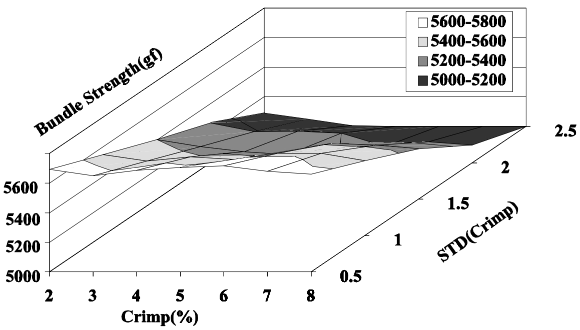

Figure 10. Effects of Fiber Cimp on Bundle Strength

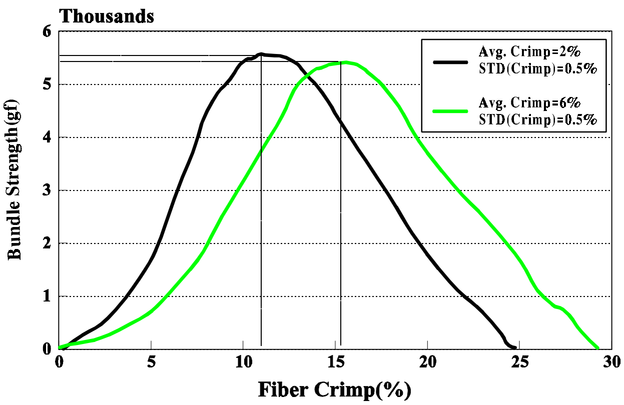

Figure 11. Effects of Fiber Crimp on HVI Load-Elongation Diagrams

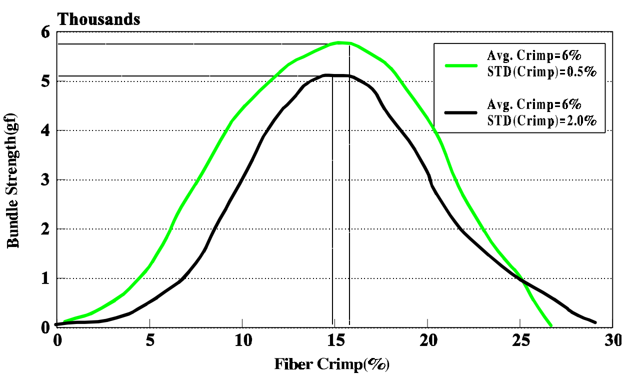

Figure 12. Effects of Fiber Crimp Variation on HVI Load-Elongation Diagrams

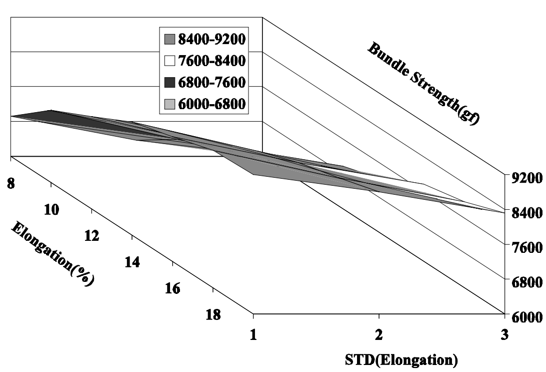

Figure 13. Effects of Fiber Elongation on Bundle Strength

Table 1. Effects of process on fiber length, diameter and short fiber contents (B cotton)

Process	Mean L(n)	Mean L(w)	SFC(n)	SFC(w)	Mean D(n)
Bale	0.72	0.88	28.1	11.9	13.2
Opening	0.72	0.88	27.7	11.5	13.2
Carding	0.72	0.88	27.3	11.8	13.2
2nd Drawing	0.76	0.92	25.6	10.7	12.7
3rd Drawing	0.77	0.92	24.0	10.0	12.9

Table 2. Effects of process on fiber length, diameter and short fiber contents (NT cotton)

Process	Mean L(n)	Mean L(w)	SFC(n)	SFC(w)	Mean D(n)
Bale	0.76	0.90	22.4	9.2	13.3
Opening	0.75	0.89	23.9	10.0	13.2
Carding	0.76	0.89	22.5	9.6	13.3
2nd Drawing	0.78	0.93	23.1	9.5	12.7
3rd Drawing	0.78	0.91	22.5	9.4	12.9

Table 3. Effects of process on fiber length, diameter and short fiber contents (Y cotton)

Process	Mean L(n)	Mean L(w)	SFC (n)	SFC (w)	Mean D(n)
Bale	0.75	0.89	24.5	9.9	13.5
Opening	0.74	0.89	24.8	10.3	13.6
Carding	0.74	0.88	24.0	10.2	13.6
2nd Drawing	0.78	0.92	23.1	9.6	12.9
3rd Drawing	0.77	0.91	22.5	9.3	13.2

Table 4. Effects of process on fiber length, diameter and short fiber contents (I cotton)

Process	Mean L(n)	Mean L(w)	SFC (n)	SFC (w)	Mean D(n)
Bale	0.78	0.92	22.7	9.3	12.9
Opening	0.76	0.91	24.0	9.9	13.0
Carding	0.79	0.93	21.2	8.8	12.9
2nd Drawing	0.81	0.96	21.9	8.7	12.3
3rd Drawing	0.80	0.94	22.2	9.1	12.6

Table 5. Tensile properties of B cotton before and after process

Process		Strength (g)	Elong. (%)	Crimp (%)
Bale	Average	6.37	12.25	4.45
	SD	3.07	4.37	3.29
Opening	Average	6.33	13.92	4.51
	SD	2.94	4.87	4.29
Carding	Average	6.36	13.63	4.92
	SD	2.98	5.03	4.35
2nd Drawing	Average	6.07	13.50	3.33
	SD	2.83	4.91	3.20
3rd Drawing	Average	6.19	13.49	2.83
	SD	2.88	4.69	2.72

Table 6. Tensile properties of NT cotton before and after process

Process		Strength (g)	Elong. (%)	Crimp (%)
Bale	Average	4.98	15.53	4.76
	SD	2.27	6.29	4.29
Opening	Average	5.65	17.45	5.02
	SD	2.76	6.46	3.94
Carding	Average	5.35	18.02	4.67
	SD	2.65	6.67	3.70
2nd Drawing	Average	5.38	17.08	3.43
	SD	2.69	6.01	2.88
3rd Drawing	Average	5.14	16.83	2.73
	SD	2.58	6.15	2.79

Table 7. Tensile properties of Y cotton before and after process

Process		Strength (g)	Elong. (%)	Crimp (%)
Bale	Average	5.92	11.64	5.96
	SD	2.61	4.41	4.75
Opening	Average	6.69	13.08	5.24
	SD	3.08	4.63	4.22
Carding	Average	6.22	12.67	5.30
	SD	2.89	4.56	4.66
2nd	Average	6.27	12.62	3.94
Drawing	SD	2.93	4.34	3.34
3rd	Average	6.54	12.83	3.24
Drawing	SD	2.98	4.61	2.88

Table 8. Tensile properties of I cotton before and after process

Process		Strength (g)	Elong. (%)	Crimp (%)
Bale	Average	5.26	15.61	3.00
	SD	2.56	5.56	2.60
Opening	Average	4.92	17.65	4.29
	SD	2.51	7.18	3.67
Carding	Average	4.51	17.69	4.89
	SD	2.38	6.66	3.70
2nd	Average	4.55	17.38	3.30
Drawing	SD	2.34	6.43	3.39
3rd	Average	4.62	17.84	2.89
Drawing	SD	2.34	6.55	2.32

Table 9. HVI properties before and after process

Cotton	Processes	Strength(gf/tex)	Elongation (%)
B Cotton	Bale	27.6	4.4
	Opening	28.9	4.7
	Carding	29.4	4.6
	2nd Drawing	35.2	4.4
I Cotton	Bale	26.3	6.1
	Opening	26.7	6.0
	Carding	27.7	6.0
	2nd Drawing	33.6	5.7
NT Cotton	Bale	27.9	5.7
	Opening	25.2	5.3
	Carding	27.7	5.6
	2nd Drawing	33.3	5.2
Y Cotton	Bale	29.1	4.5
	Opening	28.8	4.5
	Carding	28.6	4.4
	2nd Drawing	34.8	4.1

Table 10. Multiple Regression Analysis Results (First Set)

Process	Equations	Prob. > |t|	R^2
Bale	$YTS = -1249 + 1866 X_1 + 46 X_2$	X_1: 0.0001 X_2: 0.0001	0.691
Opening	$YTS = 237 + 4773 X_1 + 200 X_2 - 344 X_3$	X_1: 0.0001 X_2: 0.0002 X_3: 0.0002	0.697
Carding	$YTS = -3114 + 5571 X_1 + 200 X_2 - 135 X_3$	X_1: 0.0001 X_2: 0.0002 X_3: 0.0003	0.697
2nd Drawing	$YTS = -246 + 1870 X_1 + 43 X_2 - 82 X_3$	X_1: 0.0001 X_2: 0.0091 X_3: 0.0398	0.697
3rd Drawing	$YTS = 69 + 685 X_1 - 2.02 X_4$	X_1: 0.0394 X_4: 0.0002	0.657

Table 11. Multiple Regression Analysis Results (Second Set)

Process	Equations	Prob. > |t|	R^2
Carding	$YTS = -1691.28 + 33.12 X_5 + 1554.72 X_1$	X_1: 0.0001 X_5: 0.0071	0.574
2nd Drawing	$YTS = -1359.51 + 14.08 X_5 + 1655.38 X_1$	X_1: 0.0001 X_5: 0.0076	0.697

Notes: YTS = Yarn Tensile Strength
X_1 = Fiber Length
X_2 = Single Fiber Strength
X_3 = Diameter
X_4 = CV of Crimp
X_5 = HVI Bundle Strength