VARIABILITY IN TENSILE PROPERTIES OF COTTON FIBERS - A STATISTICAL STUDY ON SINGLE FIBER STRENGTHS AND ELONGATIONS

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Abstract

As a precursor to optimization of processing conditions in staple yarn spinning, 50,000 cotton fibers have been tested on Mantis® single fiber tester. The fibers were sampled from bales of over 40 American upland cottons in order to study the effects of repeated processing on the tensile behaviors of the cotton. Of particular significance was the effects of single fiber breaking elongation on bundle strength efficiency and spun yarn strength. The complex features of the bivariate distributions of elongation and strength are directly translated into the tensile properties of the resulting yarns and fabrics.

Introduction

Traditionally, the tensile properties of natural fibers have not been measured effectively due to the technical difficulty of measuring and the expenses involved. In 1992, a patent [Shofner et al, 1992] was issued to Schofner Technologies for a rapid single fiber testing apparatus developed under a research funded by Cotton Incorporated. The preliminary results from the tester was reported by Sasser *et al* [Shofner et al, 1992] in 1991 along with the corresponding yarn tensile properties. Subsequently, Zellweger Uster marketed only a limited number of Mantis® single fiber testers for scientific research. With one of these units, the College of Textiles, NCSU has conducted research on tensile properties of single fiber and bundle tensile properties of cotton during the last 10 years. The single fiber database consisting of over 50,000 load-extension diagrams and is the largest of its kind in the world. For each fiber, 1,000 load-extension points leading to break have been stored for simulating strengths of cotton fiber bundles with varying sizes up to 2,000. While the results reported by Suh, Cui and Sasser [Suh and Cui, 1992, Suh and Cui, 1993, Koo and Suh, 1999] were for evaluation of HVI (high volume instrument) bundle test results, the ongoing study has been applied for yarn strength maximization as well [Koo and Suh, 1999]. The large magnitudes of variations found in both breaking strengths and breaking elongations of cotton fibers are considered quite significant in that they have not been previously recognized or applied to decisions leading to optimal yarn and fabric formation. For blending of two different cottons, or cotton and synthetic fibers, these large variations in tensile properties of the component fibers play a vital role within a twisted bundle.

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Variations in Tensile Properties Examples and Discussions

From the 36 varieties of American upland cottons tested, the breaking elongations and wasted fractions were examined for studying their bundle tensile properties. Results for four selected varieties are shown in Figure 1. They are two Delta cottons ("DPL 50" and "STV 474,"), one California cotton ("B 7456") and one Texas cotton ("HS 26"). Each of the four scatter plots were based 400 fibers randomly selected from a much larger pool of fiber test data for that particular variety. The scattergram shows the joint distribution of strength and elongation for each cotton type graphically. Differences and similarities among the four cotton types can be seen easily by examining the diagrams. The large standard deviations of both strength and elongation are shown in the figure. The numerical values can be found in Table 1. In Figure 2, the distributions of breaking elongation are shown for the same four cottons. All distributions were found to be more or less positively skewed and could be fitted best by either a Weibull, Gamma or lognormal distribution as were the cases with B 7456 cotton (Gamma), HS 26 cotton (Gamma), DPL 50 cotton (Weibull), and STV 474 cotton (lognormal), shown by the smoothed lines in Figure 2. The summary statistics (averages and standard deviations of strength and elongation, and single fiber modulus) for the 36 varieties are shown in Table 1 for fiber samples drawn from bales (before carding) and slivers (after carding). For the bale samples, the breaking strength ranged from 4.92gf to 6.66gf, the breaking elongation from 10.74% to 14.80% and the modulus from 0.40 to 0.58. Similar variations can be found for the fiber properties measured after carding (sliver). For the most part, the CV% (ratio between standard deviation and average) are extremely high and exceed 30 – 40% in all properties measured.

In order to study the bundle tensile behaviors and yarn strength from the single fiber test results, the so-called *"wasted fraction"* of bundle strength was computed and compared before and after carding. The results are shown in Table 2. The wasted fraction is defined as the ratio of the number of fibers that break before the maximum bundle load is attained and the total number of fibers in the bundle. Theoretically, the wasted fraction would be zero if all fibers break at the same extension point, or at the same time in other words. Obviously, a larger the standard deviation of breaking elongation is likely to increase the wasted fraction and lower the bundle strength efficiency. In Table 2, the wasted fractions are shown along with the bundle breaking elongations. Although exceptions are there, a higher breaking elongation is likely to increase the wasted fraction. Before carding, the wasted fraction was highly variable (11.50% to 26.75%) but was reduced substantially after carding (11.0% to 20%) perhaps due to removal of fiber crimps and the residual (unrecovered) elongation resulting from the carding process. Naturally, if two different types of cotton with large differences are blended, the strength of the resulting yarn would depend heavily on the compatibility of the two fiber types in terms of their average breaking elongations and their standard deviations. This particular point has already been addressed by Koo and Suh [Koo and Suh, 1999].

Conclusions

The wide variations observed in both breaking strengths and breaking elongations of cotton fibers within and between cotton varieties suggest that decisions leading to fiber selection and determination on blend ratios among the selected fiber types can be and should be optimized based on the features of probability distributions of the single fiber tensile properties, whether they are obtained directly from single fiber testing or other indirect means.

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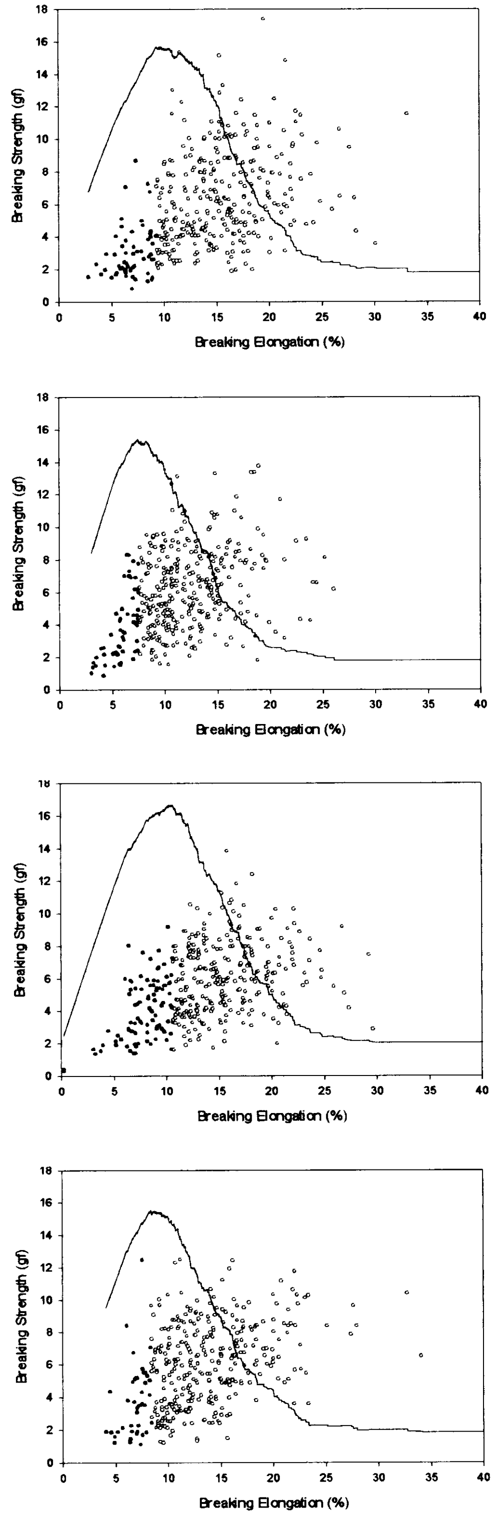

Figure 1. Breaking Strengths vs. Breaking Elongations for Single Fibers and Wasted Fraction Plots of 4 Different Types of Cotton (from top: HS 26, B 7465, DPL 50, STV 474)

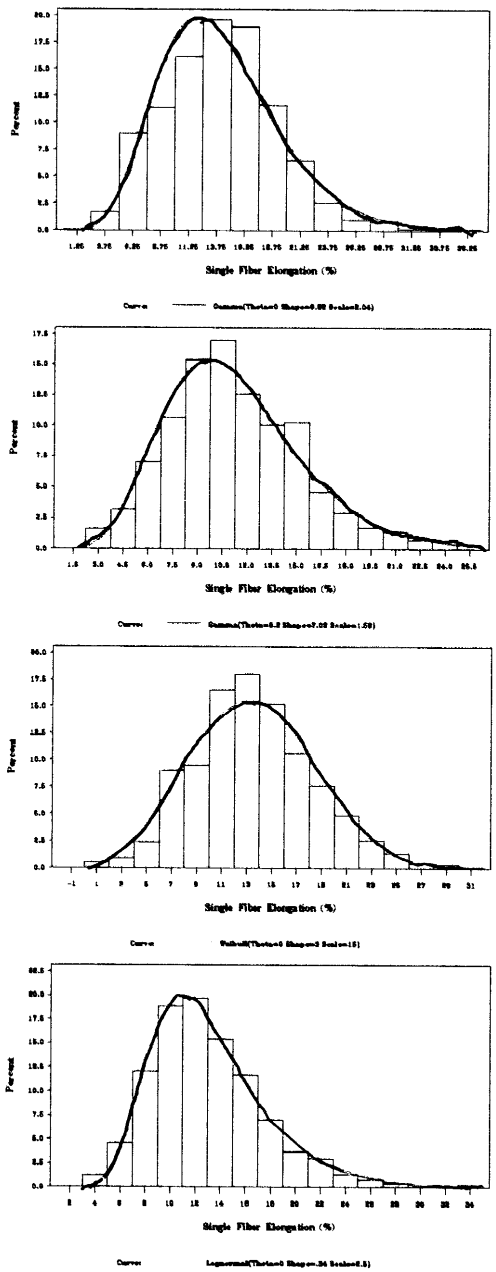

Figure 2. Probability Density Functions of Single Fiber Breaking Elongations for 4 Types of Cotton (from top: HS 26, B 7465, DPL 50, STV 474)

Table 1. Single Fiber Tensile Properties of 36 U. S. Upland Cottons Before and After Carding (Each average is based on 1000 fibers)

Cotton Type		Bale STR (gf)	Bale ELO (%)	Bale K (gf)	Sliver STR (gf)	Sliver ELO (%)	Sliver K (gf)
1	AVG	6.16	13.87	0.47	6.09	12.76	0.50
	STD	2.64	5.28	0.20	2.60	4.43	0.28
2	AVG	6.24	13.60	0.49	6.26	12.81	0.51
	STD	2.76	5.19	0.22	2.84	4.30	0.22
3	AVG	6.66	14.80	0.47	7.04	14.67	0.51
	STD	2.76	4.91	0.18	2.58	4.66	0.20
4	AVG	6.58	12.98	0.53	6.62	12.77	0.54
	STD	2.99	4.59	0.25	2.66	4.10	0.23
5	AVG	6.27	11.98	0.55	6.04	11.80	0.54
	STD	2.89	4.10	0.27	2.58	3.64	0.24
6	AVG	6.60	11.99	0.58	6.54	11.58	0.60
	STD	2.87	4.23	0.25	2.65	4.11	0.24
7	AVG	5.74	11.77	0.51	5.89	11.67	0.53
	STD	2.82	4.22	0.24	2.76	3.76	0.34
8	AVG	6.22	14.07	0.46	6.02	13.99	0.45
	STD	3.01	5.07	0.21	2.74	4.64	0.21
9	AVG	5.16	13.20	0.41	5.16	12.59	0.44
	STD	2.39	4.39	0.21	2.40	4.20	0.21
10	AVG	5.98	11.27	0.56	5.83	11.86	0.52
	STD	2.66	4.07	0.24	2.58	3.77	0.25
11	AVG	5.90	11.89	0.53	5.87	12.31	0.51
	STD	2.66	4.20	0.31	2.45	3.98	0.23
12	AVG	5.50	13.53	0.43	5.90	13.25	0.47
	STD	2.34	4.79	0.20	2.46	4.46	0.19
13	AVG	4.92	11.80	0.46	5.48	12.33	0.47
	STD	2.46	4.13	0.60	2.44	4.23	0.21
14	AVG	5.90	12.95	0.48	5.91	12.42	0.50
	STD	2.53	4.44	0.22	2.36	3.85	0.21
15	AVG	5.54	11.54	0.50	6.15	11.59	0.56
	STD	2.66	4.13	0.23	2.64	3.91	0.25
16	AVG	5.36	10.74	0.52	5.46	11.21	0.51
	STD	2.76	3.96	0.25	2.58	3.98	0.23
17	AVG	5.89	12.14	0.52	5.90	11.63	0.54
	STD	2.76	4.19	0.26	2.59	3.88	0.24
18	AVG	6.43	11.45	0.60	6.09	11.75	0.55
	STD	2.74	3.63	0.30	2.70	3.95	0.26
19	AVG	5.53	11.22	0.52	5.61	11.52	0.51
	STD	2.65	3.86	0.25	2.54	3.69	0.23
20	AVG	5.76	12.48	0.49	5.88	12.76	0.50
	STD	2.58	4.32	0.25	2.61	4.39	0.24
21	AVG	6.58	14.03	0.50	6.17	13.93	0.47
	STD	2.66	4.69	0.23	2.33	4.72	0.19
22	AVG	5.95	11.82	0.54	6.56	12.25	0.56
	STD	2.97	3.96	0.43	3.12	3.97	0.28
23	AVG	5.45	12.60	0.45	5.94	11.71	0.53
	STD	2.71	4.36	0.23	2.66	3.95	0.24
24	AVG	6.46	13.46	0.51	6.62	12.58	0.56
	STD	2.59	4.51	0.22	2.39	3.98	0.23
25	AVG	6.40	11.64	0.58	5.86	11.48	0.54
	STD	2.93	3.92	0.28	2.58	3.76	0.25
26	AVG	5.53	13.24	0.44	5.76	13.01	0.47
	STD	2.72	4.80	0.22	2.68	4.24	0.22
27	AVG	5.94	12.35	0.50	6.19	11.90	0.54
	STD	2.91	4.45	0.22	2.88	3.95	0.26
28	AVG	5.88	13.15	0.47	6.32	13.22	0.50
	STD	2.57	4.72	0.19	2.69	4.35	0.20
29	AVG	5.56	12.48	0.48	5.76	12.96	0.46
	STD	2.31	4.35	0.24	2.33	4.08	0.19
30	AVG	5.13	11.12	0.50	5.43	11.78	0.49
	STD	2.35	4.17	0.25	2.36	3.93	0.22
31	AVG	5.96	13.15	0.48	6.19	13.59	0.48
	STD	2.53	4.60	0.28	2.44	4.37	0.20
32	AVG	5.76	13.84	0.44	5.97	13.93	0.45
	STD	2.65	4.91	0.19	2.56	4.61	0.19
33	AVG	5.48	14.39	0.40	5.78	15.24	0.40
	STD	2.50	4.90	0.19	2.58	5.03	0.19
34	AVG	5.13	14.65	0.40	5.41	15.12	0.38
	STD	2.22	5.28	0.78	2.20	4.93	0.17
35	AVG	5.51	11.71	0.50	5.91	11.91	0.53
	STD	2.38	4.00	0.23	2.48	4.10	0.25
36	AVG	5.40	12.25	0.46	5.86	12.28	0.51
	STD	2.47	4.25	0.21	2.49	4.19	0.25

Table 2. Wasted Fraction of 36 U.S. Upland Cottons Before and After Carding (Each value is an average of 400 fibers)

	Bale(Before Carding)		**Sliver (After Carding)**	
Cotton Type	**Elongation at Max. Strength(gf)**	**Wasted Fraction (%)**	**Elongation at Max. Strength(gf)**	**Wasted Fraction (%)**
1	9.52	19.50	8.59	15.00
2	10.32	26.75	8.67	15.00
3	10.11	14.50	10.73	17.75
4	9.14	18.25	9.20	17.00
5	8.74	19.50	8.94	19.25
6	7.97	15.50	7.84	15.25
7	7.95	14.25	8.13	13.50
8	9.31	15.75	9.10	11.25
9	8.71	11.75	8.38	12.50
10	7.49	15.75	8.54	17.50
11	8.42	17.50	8.61	13.25
12	10.59	25.00	9.35	15.75
13	8.82	23.00	8.42	15.25
14	8.41	11.50	8.49	11.50
15	8.06	20.00	8.49	20.00
16	8.47	26.75	7.70	19.50
17	7.98	13.25	7.77	11.75
18	8.51	19.50	8.10	14.00
19	8.26	19.75	7.79	13.00
20	8.47	13.75	8.30	11.50
21	9.64	15.25	9.41	14.50
22	7.82	11.50	8.43	14.00
23	8.91	19.00	7.61	11.25
24	9.52	17.00	8.48	11.25
25	9.26	27.00	8.24	16.50
26	9.46	19.50	8.68	11.00
27	8.52	18.00	8.20	14.25
28	9.21	18.50	8.74	12.50
29	8.92	18.00	8.86	11.25
30	7.09	14.25	8.14	15.50
31	9.19	17.50	9.50	14.75
32	11.21	30.25	10.06	18.00
33	9.76	15.75	11.11	19.50
34	10.38	19.50	10.41	14.25
35	7.87	15.25	8.11	14.25
36	8.35	15.00	8.20	14.75