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Advanced Fiber Information System Length Measurement of Cottons Hand-Sorted by Length Group

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ABSTRACT

With the focus that short fiber content in cotton receives from textile mills, there is a need to improve the precision and accuracy of this measurement. In order to do this, it is necessary to understand the opportunities that exist to improve the measurement of short fiber. Since the Advanced Fiber Information System (AFIS) is the most widely recognized method for determining short fiber content in cotton, it is the focus of this study. Hand sortings of fibers were collected by length groups from three bales of upland cotton with micronaire values of 3.7, 4.3, and 5.4. These fibers were tested for micronaire and strength by the Fibronaire and Stelometer, respectively, and then tested on AFIS to determine the lengths of the fibers ranging from 9.53 mm to 25.44 mm. Although short fibers were not present in a sample prior to testing on AFIS, the machine reported a short fiber content measurement. In addition, frictional properties and convolutions of individual fibers were determined by the RotorRing and by Favimat, respectively, for each sample. These tests indicated that the high micronaire cottons exhibited more convolutions than the low micronaire counterparts, and that the longer fibers exhibited higher frictional properties than shorter fibers.

Short fiber content, fibers less than 12.7 mm (0.5 in) long, in cotton has a significant influence on the marketability, processing, and end-product quality of cotton. The accurate and precise measurement of short fiber content in a given cotton sample has been the goal of many research efforts (Zeidman et al., 1991). The American Society of Testing and Materials (ASTM) recognizes two methods for measuring short fiber content in cotton. The first is the Suter-Webb Array method (Alfred Suter, New York, New York) (ASTM, 1997a), which was first recognized as the standard for short fiber content measurement as early as 1990 (Behery, 1993). This method is too slow for commercial use. Approximately 2 to 3 h is required to test one sample (Backe, 1992). The second method for measuring short fiber content recognized by the ASTM is the Peyer AL-101 (Siegfried Peyer Ltd., Wollerau, Switzerland) (ASTM, 2001a). Although this method is faster (20 minutes per sample) than the Suter-Webb, it is still too slow for commercial use (Backe, 1992). Backe (1992) demonstrated a correlation (r^2) of 0.95 between the Suter-Webb and Peyer AL-101 measurement of short fiber content.

Another method of determining short fiber content, which is not currently an ASTM standard, is AFIS (Uster Technologies; Knoxville, TN). This method with a quoted testing time of 2 to 3 min per sample is faster than the two previously mentioned methods (Uster Technology, 2000). When quoting short fiber content of commercial cotton bales for industry consumption, testing results from AFIS are used. Short fiber values using AFIS are typical industrial values because of the speed of the instrument. Backe (1992) demonstrated a correlation ($r^2 = 0.90$) between AFIS short fiber content measurement and the Suter-Webb standard. Bragg and Shofner (1993) also compared length measurements from AFIS to the Suter-Webb method, and found that AFIS measurement of cotton fiber length is biased toward the shorter fiber lengths. Bragg and Shofner (1993) explained this bias as a breakage of fibers in the fiber individualizer of the instrument (Figure 1). The upper half mean (UHM) of fiber length was reduced by 1 to 2 mm and short fiber content increased almost 7% compared with the traditional (Suter-Webb) hand-sorting method. In another study (Cui et al., 1999), the association between fiber fineness and length distribution had only a minor influence on short fiber content with AFIS.

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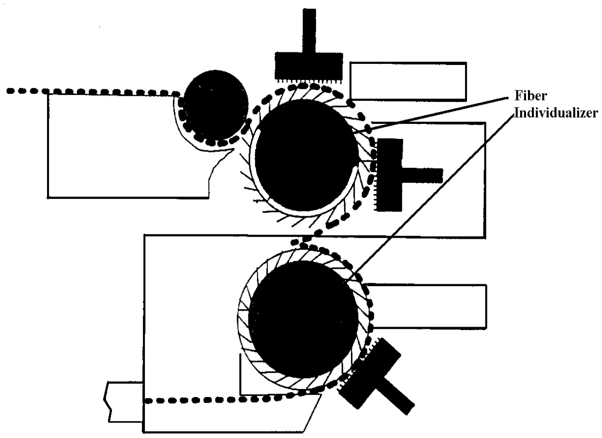

Figure 1. Schematic of the AFIS fiber individualizer

Ghosh, Rodgers, and Ortega (1992) demonstrated that fiber cohesion (friction) measurements for man-made staple fibers was influenced by fiber length, finish type (the lubricant on a synthetic fiber) and level, fiber geometry, crimp type and level, fiber additives, degree of fiber entanglements, and fiber surface roughness. These researchers quantified the fiber cohesion (measured in joules) between fibers (fiber-to-fiber) and between fiber and metal (fiber-to-metal), and found a strong relationship (r = 0.85) between fiber crimp and fiber-to-fiber cohesion with the RotorRing test method. This is important because cotton has convolutions that are similar to crimp in synthetic fiber, which affects the mechanical separation of fiber. In earlier work, convolutions in cotton fiber (similar to crimp in synthetic fiber) played an important role in the friction between a single cotton fiber and a straight-edge probe (cantilever assembly). Cyclic changes in the frictional force occurred at repeat distances between successive convolutions in the fiber (Basu et al., 1978). Lord (1955) found that the coefficient of friction of a fiber tends to increase as the frequency of convolutions increase.

The cotton industry needs a precise, accurate, and rapid method for the determination of short fiber content. Measurements using AFIS need to be studied further in order to bring about improvements in the way that short fiber content is measured and to verify if damage is caused by the fiber individualizer. Therefore, research was conducted to determine if three specimens of cotton fibers with different micronaires, which were hand sorted into known length groups, were susceptible to damage by the fiber individualizer. Damage would be determined by reporting short fiber content in the samples, which did not contain short fiber before testing, after testing using AFIS. In addition, the amount of current required by the fiber individualizer to open these different fiber specimens, the frictional properties of the fibers in each specimen, and the image crimp in individual fibers of each specimen were measured to better understand some of the underlying issues that might contribute to fiber damage during mechanical separation.

MATERIALS AND METHODS

Three bales of upland cotton were chosen to provide fiber with micronaire values of 3.7, 4.3, and 5.4 that were designated as low, medium, and high, respectively. The official High Volume Instrument (Uster Technologies, Knoxville, TN) measurements for each bale were made by Agricultural Marketing Service's Cotton Division office in Memphis, Tennessee (Table 1). Samples were taken from four points around each bale to obtain a representative sample. Fibers from each bale were comb-sorted using the AL-101 method (ASTM, 2001a), so that the different length groups could be removed by hand. Beginning with the longest fibers in a sample, a length group was pulled every 2 cycles of the comb sorter. The individual length group from each sorting was then placed in a sealed container until 40 g of each length group had been collected from each bale. The length groups and measured lower limits (mm) were as follows: 7 - 9.53 mm; 9 -12.70 mm; 11 - 15.88 mm; 13 - 19.05 mm; 15 - 22.23 mm; 17 - 25.4 mm. The length

Table 1. Fiber properties using high volume instrumentation of the three test bales

Bale/ micronaire	Strength (g/tex)	Rd	+b	Upper half mean length (mm)	Uniformity index	Classer color grade
Low / 3.7	**26.0**	**73.5**	**8.9**	**25.15**	**79**	**41**
Medium / 4.3	**25.7**	**74.3**	**9.5**	**26.16**	**80**	**41**
High / 5.4	**27.6**	**72.5**	**8.9**	**26.67**	**81**	**41**

groups collected are consistent with those listed in the standard work sheet for the Suter-Webb Array method and verified by the same method (ASTM, 1997a). Once all specimens for each length group per bale were collected, the individual specimens were tested for strength (3.18 mm or 1/8 inch gauge) on the Stelometer (Spinlab, Knoxville, TN; ASTM, 1995) and for micronaire with a Fibronaire (Motion Control, Inc., Dallas, TX; ASTM, 1997b) (Table 2). Individual specimens were then tested on AFIS using the Multidata option (Uster Technologies, Knoxville, TN). In conjunction with testing on AFIS, an amp meter (Model 22-601, Radio Shack, Fort Worth, Texas) was connected to the drive motor of the fiber individualizer in order to observe a digital readout of the electrical current consumed by the motor during the testing process. For each specimen, 30 replications were conducted on AFIS for a total of 90,000 fibers. The AFIS testing consumed 15 g from each 40-g specimen.

A portion of each specimen was tested by the Institute of Textile Technology (ITT; Charlottesville, VA) using the RotorRing (ITV, Denkendorf, Germany) to get a measure of the frictional properties for each specimen. A minimum of 2 and 3 g, respectively, is required for testing fiber-to-fiber and fiber-to-metal friction of each test specimen on the RotorRing (Watson, 1987). A total of four replications were processed for each specimen, consuming 20 g for each specimen. Remaining individual fibers from three specimens and length groups were sampled, and the image crimp determined on a Favimat Single Fiber Tester (Textechno, Monchengladbach, Germany). A total of 50 fibers per length group were tested on the Favimat.

In each case, testing was performed in a conditioned laboratory at 21 ± 2°C and 65 ± 2% relative humidity according to the ASTM standard D-1776 (ASTM, 2001b). Simple statistics, as well as Pearson correlation matrix and analysis of variance (ANOVA), of the data was analyzed utilizing SYSTAT (SYSTAT, Inc., Version 5, Evanston, IL, 1992).

RESULTS AND DISCUSSION

Tests on the length groups by AFIS provided some interesting, although not surprising results as indicated by the literature (Bragg and Shofner, 1993 and Cui et al., 1999). Short fiber content was reported in all length groups (Table 3). The fibers longer than 12.7 mm (groups 9 and higher) averaged across all three test bales ranged from approximately 19% short fiber content for group 9 to 0.99% for group 17. For the three individual bales, the low-micronaire bale had the highest short fiber content in each length group compared with the medium- and high-micronaire bales. The medium-micronaire bale had higher short fiber content than the high-micronaire bale. In each case, length group 7 (fibers <12.7 mm) for each bale did not test close to the 100% short fiber content that the samples contained prior to testing. In fact, the highest level of short fiber content reported in group 7 is 41.92% for the low-micronaire

Table 2. Stelometer fiber strength and fiber micronaire measurements of specimens from individual length groups from cotton bales with low, medium, and high micronaire

Micronaire[y]	Length groups[z]					
	7	9	11	13	15	17
			Strength (g/tex)			
Low	23.4	22.7	23.7	22.1	23.8	23.9
Medium	19.8	22.6	21.4	21.0	19.7	21.5
High	30.6	22.1	27.4	19.1	22.7	26.4
			Micronaire			
Low	3.1	3.4	3.8	4.0	4.1	4.0
Medium	3.6	3.9	4.3	4.4	4.5	4.4
High	5.1	5.6	5.7	5.8	5.7	5.6

[y] Cotton bales with micronaire values of 3.7, 4. 3, and 5.4 were designated as low, medium and high, respectively.

[z] The length groups and their measured lower limits (mm) were as follows: 7 - 9.53 mm; 9 -12.70 mm; 11 - 15.88 mm; 13 - 19.05 mm; 15 - 22.23 mm; 17 - 25.4 mm.

Table 3. Short fiber content measured by AFIS of specimens from individual length groups from cotton bales with low, medium, and high micronaire

Micronaire[y]	Length groups[z]					
	7	9	11	13	15	17
			Upper quartile length (mm)			
Low	19.86	22.20	25.10	26.72	29.31	32.72
Medium	21.44	23.72	25.96	27.03	29.01	30.38
High	23.42	25.20	26.31	27.48	28.91	30.53
			Mean length (mm)			
Low	15.19	17.88	21.34	23.62	25.86	29.72
Medium	17.42	18.95	21.74	23.62	26.06	27.84
High	17.73	20.78	22.81	24.49	26.47	28.19
			Short fiber content by weight (%)			
Low	41.92	24.96	9.02	3.48	1.92	1.42
Medium	40.90	20.36	8.76	3.24	1.60	0.90
High	30.44	12.04	4.20	1.36	0.82	0.64

[y] Cotton bales with micronaire values of 3.7, 4. 3, and 5.4 were designated as low, medium and high, respectively.

[z] The length groups and their measured lower limits (mm) were as follows: 7 - 9.53 mm; 9 -12.70 mm; 11 - 15.88 mm; 13 - 19.05 mm; 15 - 22.23 mm; 17 - 25.4 mm.

bale. At the long end of the length groups tested, length group 17 from the low-micronaire bale had 1.42% short fiber content. These results are in agreement with the results of Bragg and Shofner (1993) that longer fibers are susceptible to damage by the fiber individualizer of AFIS. It is curious that the high micronaire fibers had less short fiber content (0.64%) in length group 17 than the low micronaire fibers. This suggests that some function or interaction of fiber maturity and fiber diameter plays a role in the determination of the short fiber content measurement by the AFIS instrument, as discussed by Cui et al. (1999).

In addition to measuring fiber properties during AFIS testing, an amp meter was used to monitor the current consumption (in amps) of the drive motor of the fiber individualizer. Five readings on the amp meter were taken for each replication. There were significant (P = 0.05) coefficients of determination (R^2) of 0.553 for micronaire (Figure 2) and of 0.358 for fiber strength with amp meter readings (Figure 3). This indicates that higher micronaire and stronger cottons will consume more current to operate the fiber individualizer of AFIS. If this is true, then the energy consumed to individualize or open the fibers in a sample increases as micronaire and strength increase.

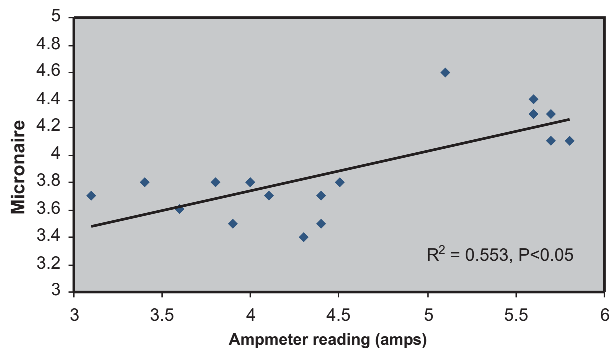

Figure 2. Correlation between fiber micronaire measured with a Fibronaire and current consumption of the drive motor of the fiber individualizer.

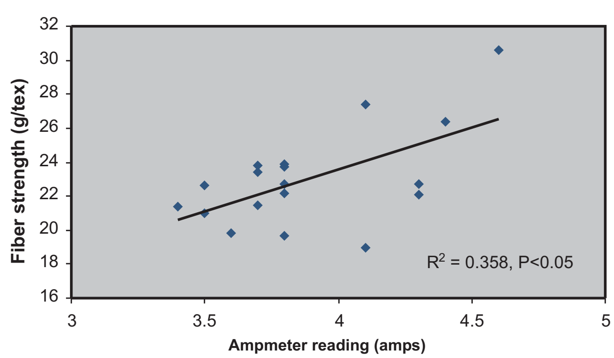

Figure 3. Correlation between fiber strength measured with a Stelometer and current consumption of the drive motor of the fiber individualizer.

To verify the observations by the amp meter on AFIS, a RotorRing was employed to measure the frictional properties (fiber-to-fiber and fiber-to-metal) of the fibers in each specimen. There was a trend of increasing friction (measured in joules) generated by the longer fiber specimens in each bale group (Table 4). The longer fiber specimens of each bale group exhibited higher micronaire values than their shorter counterparts (Table 3), but the coefficients of determination (R^2) of the upper quartile length (UQL) and mean length (ML) to micronaire measured by AFIS were 0.181 and 0.176, respectively (Figures 4 and 5). The literature indicates that in addition to length, micronaire and strength, convolutions in the fiber play an important role in the frictional properties of a fiber (Basu et al., 1978).

To quantify the number of convolutions (crimp) in each specimen, a Favimat was employed. The results indicate that higher micronaire cottons have a higher number of convolutions than the lower micronaire cottons (Table 5). For upland cottons, it is generally accepted that higher micronaire equals greater maturity. If so, then more mature fibers would exhibit more fiber convolutions, thereby making them harder to individualize or separate mechanically. The correlation (r) of crimp (convolutions) to micronaire was 0.778. Analysis of variance of the data indicated a relationship between crimp (convolutions), mean length, upper quartile length (UQL) and fiber-to-fiber friction (joules). The model below is significant ($P = 0.05$) and has a coefficient of multiple determination (R^2) of 0.899.

$$Joules = -2488.729 + (47006.040 \times UQL\ (in)) + (-20028.041 \times mean\ length\ (in)) + (-1362.978 \times crimp)$$

There is clearly a significant influence of cotton fiber properties on the measurement of length (mean length, short fiber content) by AFIS. The correlations

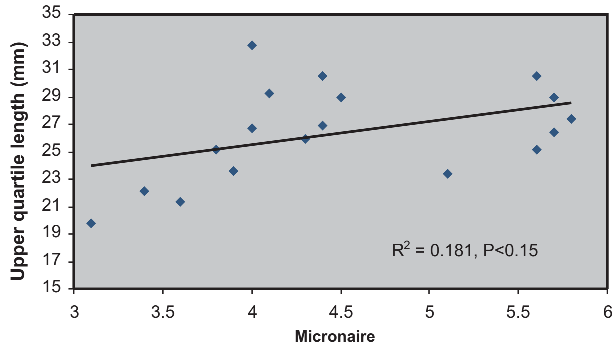

Figure 4. Correlation between upper quartile length measured by AFIS and micronaire measured on the Fibronaire.

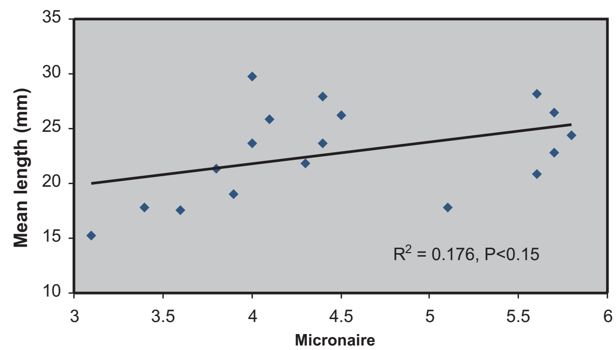

Figure 5. Correlation between mean length measured by AFIS and micronaire measured on the Fibronaire.

Table 4. Rotor ring friction measurements of specimens from individual length groups fr om cottn bales with low, medium, and high micronaire cotton bales

Micronaire[y]	Length groups[z]					
	7	9	11	13	15	17
			Strength (g/tex)			
Low	23.4	22.7	23.7	22.1	23.8	23.9
Medium	19.8	22.6	21.4	21.0	19.7	21.5
High	30.6	22.1	27.4	19.1	22.7	26.4
			Micronaire			
Low	3.1	3.4	3.8	4.0	4.1	4.0
Medium	3.6	3.9	4.3	4.4	4.5	4.4
High	5.1	5.6	5.7	5.8	5.7	5.6

[y] Cotton bales with micronaire values of 3.7, 4. 3, and 5.4 were designated as low, medium and high, respectively.

[z] The length groups and their measured lower limits (mm) were as follows: 7 - 9.53 mm; 9 -12.70 mm; 11 - 15.88 mm; 13 - 19.05 mm; 15 - 22.23 mm; 17 - 25.4 mm.

Table 5. Favimat crimp measurements of individual length groups from low, medium, and high micronaire cotton bales

Micronaire[y]	Length group[z]					
	7	9	11	13	15	17
Low	11.23	11.66	10.95	11.29	11.51	11.63
Medium	11.71	12.15	12.83	12.22	12.62	12.40
High	12.37	12.60	12.62	12.40	13.02	13.02

[y] Cotton bales with micronaire values of 3.7, 4. 3, and 5.4 were designated as low, medium and high, respectively.

[z] The length groups and their measured lower limits (mm) were as follows: 7 - 9.53 mm; 9 -12.70 mm; 11 - 15.88 mm; 13 - 19.05 mm; 15 - 22.23 mm; 17 - 25.4 mm.

(r) of short fiber content to micronaire and to mean length are -0.514 and -0.893, respectively. Through analysis of variance, a regression model based on the data collected in this study was developed:

$$\text{Short fiber content} = 86.47 + (\text{micronaire} \times -2.73) + (\text{mean length (mm)} \times -2.75)$$

This regression has an R^2 of 0.822 at a confidence level of 99% and a standard error of 6.302. This standard error would suggest that the prediction of short fiber content is +/- 6% at best, and that the differences in energy required to individualize fibers of different length and number of convolutions (crimp) may influence the measurement of short fiber. Remember these samples were pre-sorted before testing on AFIS, which align the fibers better than samples typically tested in industry. Even with better aligned samples, AFIS reported lower than expected short fiber content for samples that were known to contain only fibers less than 12.7 mm in length (group 7). It seems reasonable that fibers of different mean lengths may need to be treated differently in the fiber separation function of AFIS. If fibers are not individualized properly, measurement errors of short fiber content will persist.

As a matter of design, the two opening rollers of the AFIS fiber individualizer (Figure 1) operate at the same rpm. This requires that the fiber being fed be pulled from the grip of the feed roll and because the two rollers of the individualizer are operating at the same rpm, the fibers are not individualized further by a combing action. This is a result of a 1:1 transfer ratio between the two opening rollers. In carding, when the differences in surface speed between the cylinder and the licker-in decreases, more tufts will appear on the cylinder than individual fibers (Szaloki, 1977). It is theorized that a similar event is occurring at the fiber individualizer of AFIS. The optimal transfer ratio of the cylinder and the licker-in at carding is 1.8-2:1 as a result of their different surface speeds (Szaloki, 1977). Given the influence of fiber properties on the results of measurements by AFIS and the work measurements (joules) at the RotorRing, it seems plausible that a similar principle as that applied to the carding process could benefit the results of AFIS length measurements.

CONCLUSION

Previous work has indicated that the potential for fiber damage by the opening rollers in the fiber individualizer of AFIS exists. Although work has been done to explain the variability of AFIS measurements of short fiber content, we have taken a different approach. By sorting fibers from varying upland cotton bales to obtain a range in fiber length and micronaire, it was possible to observe some of the effects of the damage inflicted on the fiber specimens by the fiber individualizer. This damage was manifested in the reporting of short fiber (fibers <12.7 mm) in the specimens that contained only fibers which were longer than 12.7 mm in length prior to AFIS testing. Cottons with low micronaire also exhibited a higher level of short fiber content than their high micronaire counterparts. In addition, longer and higher micronaire fibers required more current by the fiber individualizer motor to separate the fibers. The need for more current (amps) by the individualizer motor is supported by the fact that the higher micronaire specimens exhibited a higher number of image crimps, which are known to play a role in fiber friction. This was evident in the higher fiber-to-fiber friction measurement of the high micronaire cottons.

Given the relationship of micronaire and length to the AFIS short fiber content measurement, it seems necessary to make some feasible improvements to the instrument in order to better measure short fiber content. It makes good sense to explore the lessons that have been learned in the carding of cotton and apply these same theories to AFIS instrument in order to improve fiber individualization and reduce fiber damage, thereby providing a more accurate measurement of fiber length.

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