RELATIONSHIP AMONG IMAGE ANALYSIS ON COTTON FIBER CROSS SECTIONS, AFIS MEASUREMENTS AND YARN QUALITY

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Abstract

Image analysis of the cross section of cotton fibers constitutes an excellent reference method for maturity and fineness measurements. Nevertheless, this technique is too slow to be of practical use in commercial operations or plant breeding programs. The AFIS data could provide the industry with a very powerful tool if it relates well with the image analysis data.

The results obtained show that the AFIS is giving very good correlation with the image analysis, especially for the perimeter. They also show that a re-evaluation of the AFIS algorithm is necessary to obtain the same levels than image analysis. This task should be very straightforward and quite simple to achieve. Furthermore, the perimeters estimated with the AFIS and the perimeters measured with image analysis are giving very good correlations with yarn strength.

Introduction

The AFIS is one of the instruments of choice for the cotton breeders because it provides them with both average fiber values and distributions. In a previous work we demonstrated the usefulness of fiber length distribution data (Hequet et al., 2000) for yarn quality predictions. In the experiment related below the relationships among the fiber measurements obtained with the AFIS multidata and those obtained with image analysis of the cotton fiber cross-sections were investigated.

Image analysis of the cross section of cotton fibers constitutes an excellent reference method for maturity and fineness measurements (Thibodeaux et al., 2000). Nevertheless, this technique is too slow to be of practical use in commercial operations or plant breeding programs. The AFIS data could provide the industry with a very powerful tool if it relates well with the image analysis data.

Procedures

Variety evaluation tests were performed at the International Textile Center (ITC), Texas Tech University during the 1999-2000 crop year. Nine Upland cotton varieties were selected. Each variety was represented by 6 independent samples grown in different locations. Therefore, a total of 54 cotton samples were collected.

The cotton fibers from each variety were processed through the Short Staple Spinning Laboratory at the ITC and were made into both ring-spun (36 Ne carded) and rotor-spun yarns (36 Ne carded). Table 1 provides an outline of the mechanical process for all the cottons included in the analysis.

The following measurements were performed on fiber and yarn:

Fiber Tests

- Zellweger Uster HVI 900A: 4 mike measurements, 4 color-grade measurements, 10 length and strength measurements.
- Zellweger Uster AFIS Multidata: 5 replications of 3,000 fibers
- Image analysis: 1 replication of 500 fibers. The method used here was developed at the Southern Regional Research Center in New Orleans, Louisiana, USA (Boylston, et al., 1995). It uses a methacrylate polymer to hold the cotton fibers in order to cut them with a rotary microtome into 1-micron slices, then mounting on glass slides for observation. Approximately 500 fibers are captured in each sample.

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The prepared glass slides were viewed with a computerized video microscope, which captures the magnified images and stores them in computer files. These images then remain available for use in measuring area and perimeter of the fibers.

Alternative software packages were used to take the computerized measurements of the fiber cross-sections. Ultimately, a software package developed by Bugao Xu, University of Texas at Austin, was determined to be the best one for our purposes.

Yarn Tests

- Zellweger Uster Tensorapid: 10 breaks per bobbin and 10 bobbins
- Zellweger Uster UT3: 400 yards per bobbin and 10 bobbins

Results and Discussion

A brief statistical summary of fiber and yarn properties are given in Tables 2 and 3, showing the mean, minimum and maximum values for each characteristic. An examination of these data reveals that all of the cottons exhibit relatively good fiber properties, with low short fiber content, good length and maturity, and high strength levels.

Relationship Image Analysis of Cotton Fiber Cross-Section – AFIS Measurements

Table 2 shows that the samples selected represent a good range for the main fiber properties. The micronaire ranges from 3.3 to 4.6 with tenacities from 28.7 to 36.3. The AFIS maturity ranges from 0.85 to 0.97 and the AFIS fineness from 157 to 180 millitex. The image analyses of the fiber cross-sections show a proportionally wider range for maturity than the AFIS, with theta ranging from 0.393 to 0.564.

The gravimetric fineness is expressed as the mass per unit length of a fiber. Estimates of gravimetric fineness are provided by the AFIS fineness (expressed in millitex) and the HVI micronaire (arbitrary scale of relative values). The lower the fineness or the micronaire, the higher the number of fibers in the yarn cross-section will be. We have shown earlier (E. Hequet, 1999) that neither micronaire nor fineness alone is good predictors of yarn strength.

Gravimetric fineness can be related to standard fineness or biological fineness if the wall thickness or maturity is known. With the AFIS the ratio fineness/maturity ratio gives an estimate of the standard fineness.

Figure 1 shows cotton fiber cross-section schematic, from it we can deduce the following equations:

$$\begin{aligned} A_w &= \pi R_2^2 - \pi R_1^2 \\ &= \pi \left(R_2^2 - R_1^2 \right) \end{aligned} \quad (1)$$

With:

A_w = cell-wall area (cross-sectional area minus lumen area) in microns
R_1 = inside diameter
R_2 = outside diameter

Then,

$$\theta = \frac{\pi\left(R_2^2 - R_1^2\right)}{\pi R_2^2} = \frac{A_w}{\pi R_2^2} = \frac{A_w}{\pi\left(\frac{P_2}{2\pi}\right)^2} = \frac{4\pi A_w}{P_2^2} \qquad (2)$$

With:

θ = degree of secondary wall thickening (no unit)
P_2 = outside perimeter of the fiber in microns

Also,

$$A_w = \frac{H}{\rho} \qquad (3)$$

With:

H = fineness in mtex
ρ = cell-wall density in g/cm^3 = 1.52g/cm^3

$$H_s = \frac{H}{M} = 0.577\frac{H}{\theta} = \frac{0.577 A_w \rho}{\theta} = \frac{0.577 A_w \rho P_2^2}{4\pi A_w}$$
$$H_s = \frac{0.577\rho}{4\pi} P_2^2 \qquad (4)$$

With:

H_s = Standard fineness in mtex
M = Maturity ratio = θ/0.577

Then,

$$P_2 = \sqrt{\frac{4\pi}{0.577 \times 1.52} H_s} = 3.7853\sqrt{H_s} \qquad (5)$$

This means that:

- Area should correlate well with AFIS fineness
- Perimeter should correlate well with the AFIS standard fineness
- Theta should correlate well with AFIS maturity ratio.

For practical reasons it was impossible to examine the same number of fibers by image analysis and by AFIS. We examined, as stated above, 500 fibers per field replication with image analysis, totaling 3,000 fibers per variety, when we did 5 replications of 3,000 fibers per field replication with the AFIS totaling 90,000 fibers per variety.

Figure 2 shows the relationship between Area estimated with image analysis and Area estimated with the AFIS (Fineness divided by the average cell-wall density: 1.52 g/cm^3). The correlation coefficient of 0.83 is highly significant but slope and offset are far from the expected levels (1 and 0). If we consider image analysis of fiber cross-section to be the reference, it means that the AFIS underestimates the Area. It should be noted that Area and HVI micronaire do not correlate (r = 0.303, non-significant).

Figure 3 shows the relationship between Perimeter estimated with image analysis and Perimeter estimated with the AFIS using the equation 5. The coefficient of correlation is very highly significant (r = 0.93) but again slope and offset are far from the expected levels (1 and 0). The AFIS underestimates the perimeter.

Figure 4 shows the relationship between theta estimated with image analysis and theta estimated with the AFIS. The coefficient of correlation is significant (r = 0.81) but again slope and offset are far from the expected levels (1 and 0). The AFIS overestimates theta.

These results are extremely encouraging because they show that the AFIS is giving very good correlation with the image analysis, especially for the perimeter. These results also show that a re-evaluation of the AFIS algorithm is necessary to obtain the same results as image analysis. This task should be very straightforward and quite simple to achieve. However, it will be time consuming due to the necessity to reference the AFIS with image-analysis of cotton fiber cross-section.

Relationship Among Image Analysis on Cotton Fiber Cross-Sections, AFIS Measurements and Yarn Quality

Table 4 shows the correlation coefficients obtained using the averages per variety. First, the HVI micronaire readings (average of 24 readings: 4 replications per sample and 6 samples) do not correlate with the strength for this set of samples. Both image analysis of the cross-sections and the AFIS are giving much more useful information. The perimeters estimated with the AFIS and the perimeters measured with image analysis are giving very good correlations with yarn strength. The correlations obtained are as good as the correlation HVI strength – yarn strength. In a previous experiment (Ethridge et al., 1998), AFIS standard fineness was also found highly correlated with yarn strength for both ring and rotor spinning.

Fiber perimeter or Standard Fineness are highly heritable (Hequet, 1988). Therefore, targeting of these fiber properties by cotton breeders could result in improved cotton fibers.

Conclusions

In conclusion, both the correlations between AFIS standard fineness and fiber perimeter and AFIS standard fineness and yarn strength are extremely encouraging. A larger set of cottons needs to be evaluated in order to be able to re-evaluate the AFIS algorithm for both maturity and fineness. The same set of cottons could be spun to derive yarn strength prediction based on the AFIS measurement.

Acknowledgment

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References

Boylston, E. K., J.P. Evans and D.P. Thibodeaux. 1995. A quick embedding method for light microscopy and image analysis of cotton fibers. *Biotechnic and Histochemistry* 70 (1):24-27.

Hequet E. 1988. Influence of soil type and planting date on yarn quality in Chad. Proceedings International Cotton Conference, Bremen, 9pp.

Hequet E., Ethridge D. 2000. Impacts on yarn quality of AFIS measurements of cotton fiber length distributions. Textile Topics, Winter 2000:2-12

Ethridge D., Hequet E. 1998. Fineness/maturity results from the latest generation of AFIS. Proceedings International Committee on Cotton Testing Methods, Bremen: 73-76

Thibodeaux D., Rajasekaran K., Montalvo J.G., Von Hoven T. 2000. The status of cotton maturity measurements in the new millennium. Proceedings International Cotton Conference, Bremen: 115-128.

Table 1. Outline of the mechanical process.

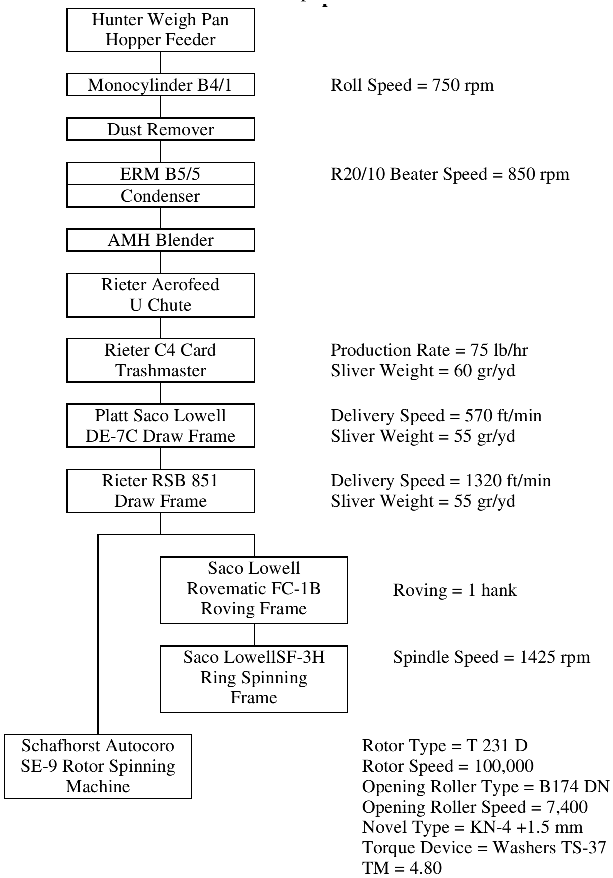

Table 2. Raw Fiber Data for 54 Cotton Samples.

Instrument & Measurement	Units	Mean	Min	Max
Zellweger Uster HVI 900A				
Micronaire		4.1	3.3	4.6
Leaf Grade		3.4	1.0	5.0
Reflectance	%	75.0	72.0	77.3
Yellowness		7.6	6.8	8.4
Upper Half Mean Length	in	1.18	1.10	1.24
Uniformity	%	83.0	81.3	85.2
Strength	g/tex	32.9	28.7	36.3
Elongation	%	6.1	5.5	6.9
Zellweger Uster AFIS Multidata				
Mean Length (w)	in	1.05	0.97	1.13
Short Fiber Content (w)	%	6.2	3.2	8.7
Upper Quartile Length (w)	in	1.26	1.17	1.33
Maturity Ratio		0.92	0.85	0.97
Immature Fiber Content	%	6.7	5.3	9.1
Fineness	mtex	170	157	180
Standard Fineness	mtex	185	174	197
Neps	cnt/g	250	174	436
Seed Coat Neps	cnt/g	30	13	58
Cross Section Image Analysis (Bugao Xu Software)				
Perimeter	μ	55.9	47.7	62.5
Perimeter CV	%	16.1	12.3	20.4
Area	μ^2	117.1	97.5	145.2
Area CV	%	31.7	26.0	40.4
θ		0.486	0.393	0.564
θ CV	%	31.1	25.4	39.4

Table 3. Yarn Data for 54 Cotton Samples.

Instrument & Measurement	Units	Mean	Min	Max
Rotor-spun Yarn Carded 36Ne				
Count Strength Product	.	1971	1663	2277
Tensorapid Tenacity	cN/tex	12.9	10.9	14.9
Tensorapid Elongation	%	5.6	5.2	6.0
UT3 CV%	%	17.7	16.7	18.4
UT3 Thin Places	cnt/km	168	90	254
UT3 Thick Places	cnt/km	333	259	423
UT3 Neps	cnt/km	102	54	155
Hairiness		3.48	3.11	3.79
Ring-spun Yarn Carded 36Ne				
Count Strength Product		2405	1694	2997
Tensorapid Tenacity	cN/tex	15.2	12.3	18.4
Tensorapid Elongation	%	5.2	4.7	5.8
UT3 CV%	%	22.8	20	26.2
UT3 Thin Places	cnt/km	702	222	1374
UT3 Thick Places	cnt/km	1408	787	2117
UT3 Neps	cnt/km	903	662	1461
Hairiness		4.50	3.84	5.16

Table 4. Correlation matrix.

	Ring spun yarn 36Ne		Rotor spun yarn 36Ne	
	Tensorapid Tenacity	Scott Tester CSP	Tensorapid Tenacity	Scott Tester CSP
Image analysis				
Perimeter	-0.81**	-0.82**	-0.83**	-0.87**
Area	-0.56ns	-0.56ns	-0.53ns	-0.59ns
Theta	0.79*	0.80**	0.83**	0.86**
AFIS multidata				
Perimeter	-0.95***	-0.95***	-0.95***	-0.97***
Area	-0.74*	-0.72*	-0.72*	-0.74*
Theta	0.61ns	0.63ns	0.63ns	0.63ns
HVI 900 A				
Micronaire	0.11ns	0.15ns	0.15ns	0.18ns
Strength	0.89***	0.85**	0.92***	0.87**

ns: not significant, *: significant at 95% confidence level, **: significant at 99% confidence level, ***: significant at 99.9% confidence level.

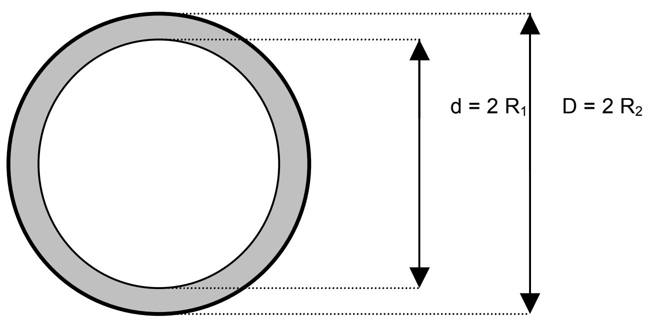

Figure 1. Cotton Fiber Cross-section Schematic.

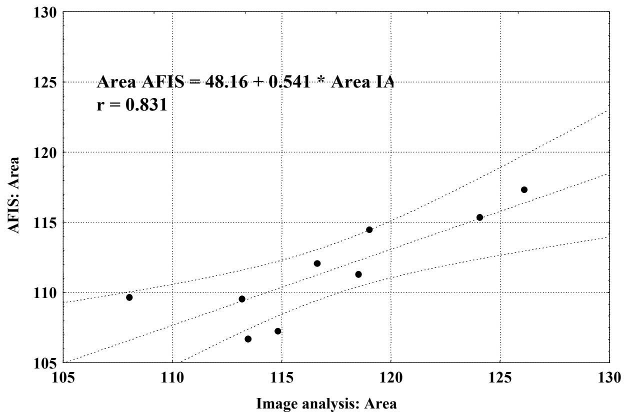

Figure 2. Relationship between Area estimated with image analysis and Area estimated with the AFIS.

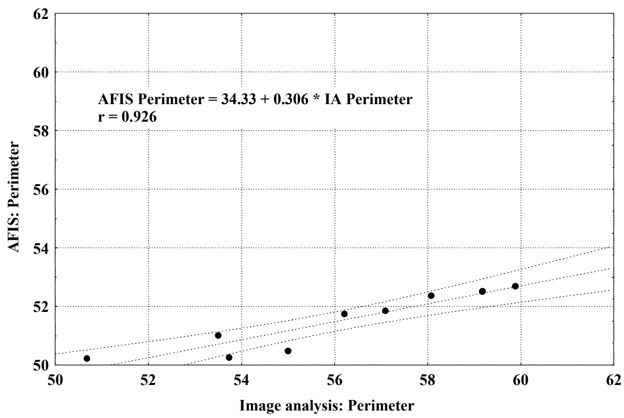

Figure 3. Relationship between Perimeter estimated with image analysis and Perimeter estimated with the AFIS.

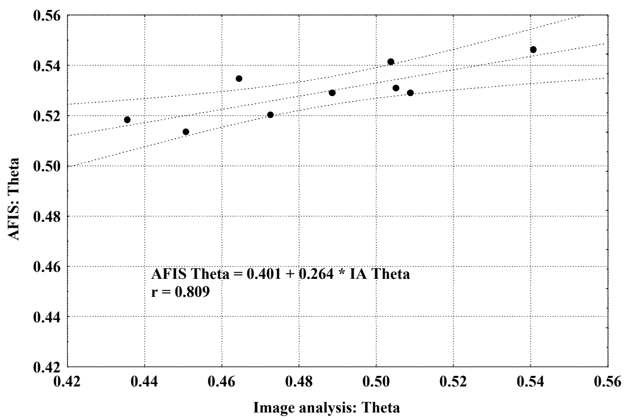

Figure 4. Relationship between Theta estimated with image analysis and Theta estimated with the AFIS.