Simultaneous measurements of cotton fiber mass and moisture content

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Introduction

Fiber tensile strength has long been recognized as an important characteristic when reporting the quality of cotton. Strength affects processing performance and the quality of garments produced. High speed instruments now measure and report the quality of approximately 20 million bales of cotton produced each year in the United States. A premium price is paid to farmers producing high strength cottons.

Cotton strength is measured by collecting an array of fibers into a parallel specimen which is placed between two pair of clamping jaws (Figure 1). Force signals are recorded while one set of jaws is displaced (Figure 2). The maximum force is divided by the total mass density of fibers held between the jaws and reported as strength in grams force per tex (i.e. *gf*/tex).

Various methods have been used to measure cotton strength. All early methods used cut-and-weigh procedures to determine the mass density of each specimen.[1(a),2] The first indirect measurements of mass, based on air flow and visible light transmission, were developed for the new high volume instrument (HVI) fiber testing program. However, both methods are influenced by cotton fiber size (i.e. fineness or micronaire) and fiber crimp (i.e. the degree of straightness).

The main purpose of this research was to evaluate the influence of fiber fineness and fiber crimp on indirect measurements of specimen mass using near infrared (NIR) light. Since we had already demonstrated that NIR reflectance using large compressed samples could be used to normalize strength measurements for changes in moisture,[3] we also included an examination of NIR moisture measurements for optically thin fiber specimens.

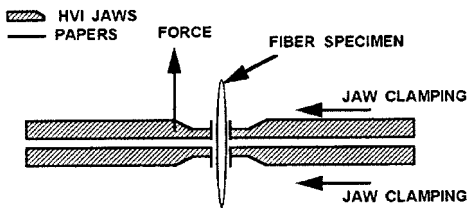

Figure 1. Sketch of the cotton fiber strength measurement.

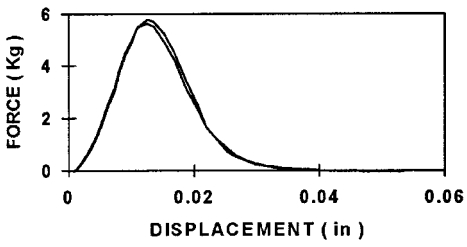

Figure 2. Typical HVI force signals during cotton strength measurements.

Experimental program

Two fiber optic probes were designed to attach at the source and detector locations on our NIRSystems 6500 spectrometer. One probe, with its fiber arranged in rows, provided a light source along a thin narrow line (Figure 3). Both outside layers of fibers were combined and connected to the spectrometer's detector port. All optic fibers in the second probe were randomized and bifurcated for visible and NIR detection (Figure 4). The sensing end of both optic probes was designed to fit between the fiber clamping jaws in the HVI strength testing instrument (Figure 5).

Three light transmission experiments were conducted using cotton fibers on the optic probes. Two were conducted with the probes installed between the HVI strength testing jaws. One of these experiments involved direct transmission measurements of a fiber specimen loaded at different levels of tension. The second used a small piece of white reference material (i.e. Spectralon) instead of the second detector probe. This experiment was designed to record transflectance spectra for a series of fiber specimens from different cottons. A third experiment used the same transflectance configuration (removed from the strength testing instrument) to evaluate moisture measurements in thin layers of fibers.

Cotton fiber transmissivity

A typical cotton was used to prepare a fiber specimen to investigate the influence of fiber crimp (i.e. straightness) on the amount of NIR light transmitted through the fiber bundle. To prepare this

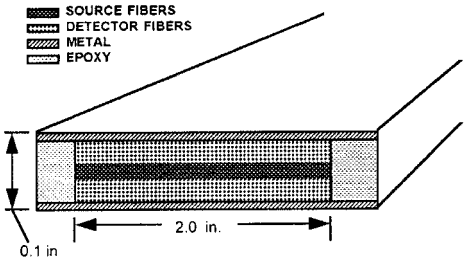

Figure 3. Sketch of optic fiber probe source.

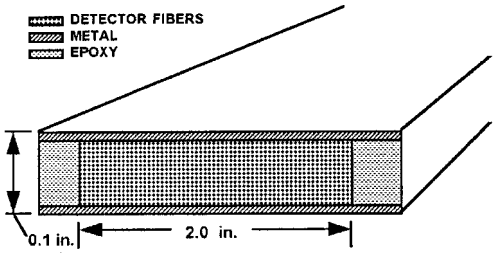

Figure 4. Sketch of optic fiber transmission detector probe.

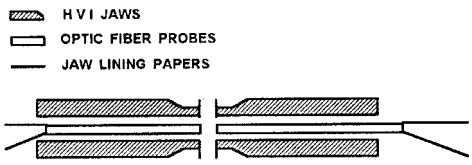

Figure 5. Sketch of optic fiber probes installed in the HVI strength tester.

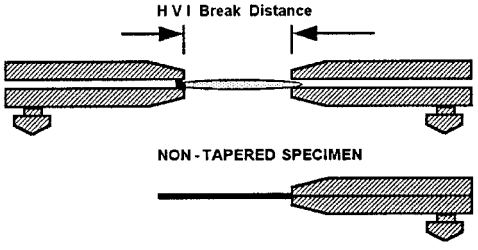

Figure 6. Sketch of non-tapered cotton fibre specimen preparation procedure.

specimen, non-tapered fiber specimens were made by clamping tapered specimens, in a second clamp, at the strength testing point. The first clamp was then removed and the fibers were combed in the opposite direction to form the non-tapered specimen (Figure 6). Therefore, non-tapered specimens do not include short fibers or fiber ends between the two clamping points. Four of these specimens were combined and glued to tension tabs (Figure 7). This entire assembly was positioned between the two optical probes and loaded in tension. Measured transmission showed that absorbance systematically increased, at all wavelengths, as fiber tension was increased (Figure 8). Whereas, the reflectance spectra, recorded at the same time, were influenced by the distance between the optical probe and the cotton specimen (Figure 9), transmissivity and absorbance changes were not linearly related to bundle tension (Figure 10). Because the NIR spectra did not give a strong cellulose absorbance, it was not possible to eliminate the light scattering effect caused by tension changes when predicting specimen mass (Figure 11).

Results from the above experiment suggest the following:

1. Normal strength bundles are optically very thin when observed with NIR light.
2. Increased fiber tension decreased light transmission at all wavelengths. Tension increased fiber straightness and the amount of the detector surface covered by fibers.
3. Reflectance was not a reliable indicator of specimen mass.

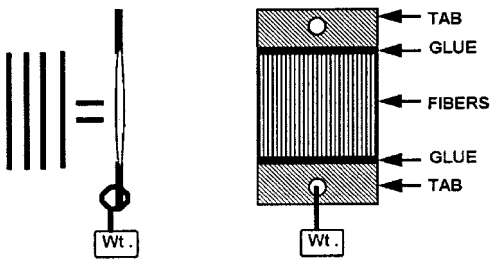

Figure 7. Sketch of cotton fiber tension experiment.

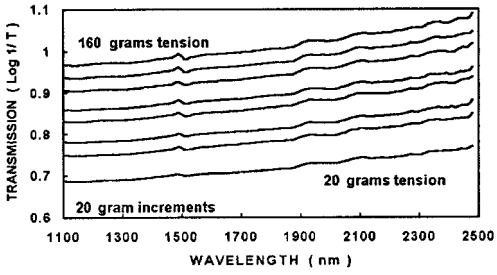

Figure 8. Cotton fiber transmission spectra at different levels of bundle tension.

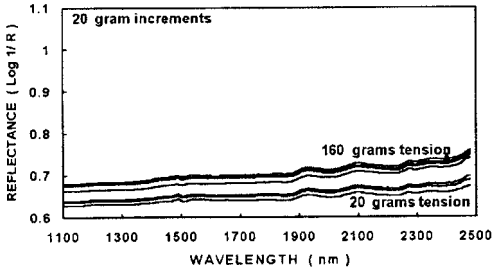

Figure 9. Reflectance spectra of a thin cotton fiber specimen at different bundle tensions.

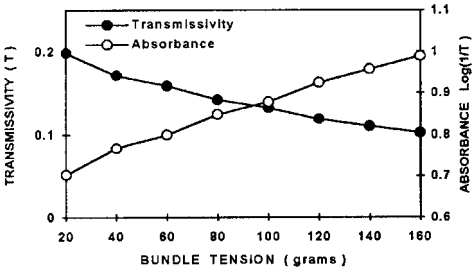

Figure 10. Light transmission data at 1550 nm.

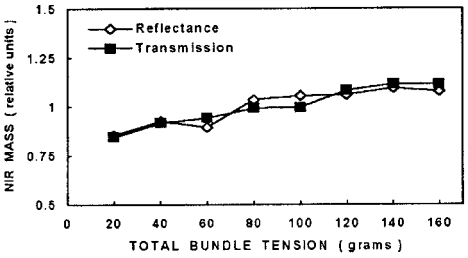

Figure 11. Predicted bundle mass using absorbance at two NIR wavelengths.

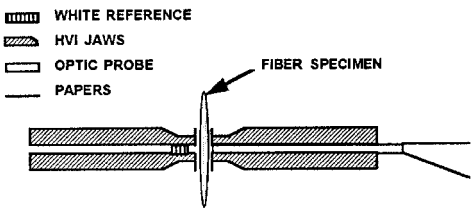

Figure 12. Sketch of the optic fiber probe for thin cotton specimen transflectance measurements.

Cotton fiber transflectance

Because the cotton fiber transmission signals were dominated by light scattering, we investigated a two-pass type of light measurement. To make these measurements, one optic fiber probe was replaced with a small piece of white NIR reference material (Figure 12). Only the optic probe shown in Figure 4 was used for the transflectance detection. Low, medium and high micronaire cottons were used to prepare a series of non-tapered cotton bundles. Transflectance spectra for these samples showed a systematic increase in the strength of both water and cellulose absorption as the bundle mass was increased (Figures 13 and 14). When we compared the spectra from three bundles with the same density from different cottons, we could immediately see the effect of fiber size on transflectance spectra (Figure 15). All three samples showed a cellulose absorption band (i.e. near 2100 nm) that was the same strength. Additionally, since all testing was performed in a humidity controlled laboratory, all moisture absorption bands were also identical (i.e. near 1900 nm).

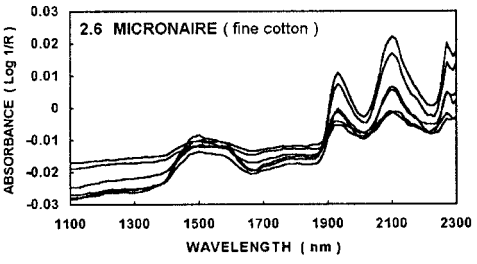

Figure 13. Transflectance spectra for different bundle thicknesses using a fine cotton.

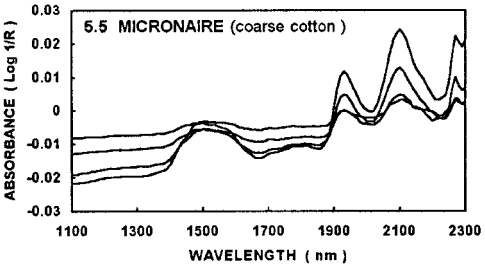

Figure 14. Transflectance spectra for different bundle thicknesses using a coarse cotton.

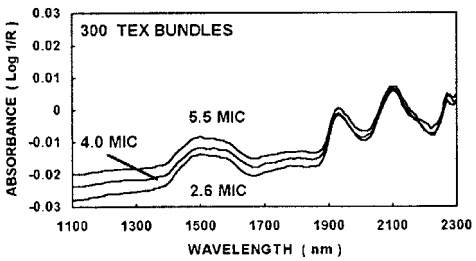

Figure 15. Comparison of transflectance spectra for three different fineness cottons.

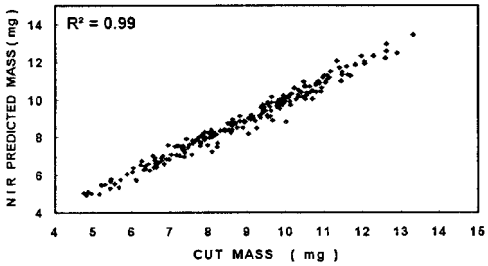

Figure 16. Mass comparison for 12 varieties of cotton using a three wavelength model.

Bundle mass

Fiber samples from twelve different varieties of cotton, grown locally in experimental plots, were used to evaluate the accuracy of estimating linear density from transflectance (Table 1). Each cotton was grown on four replicate plots to provide a good average quality. Thus, a total of 48 fiber samples were available for NIR testing. We made four non-tapered fiber specimens from each. After recording the transflectance data, a 15 mm section of each specimen was cut and

Table 1. Fiber strength results.

		Stelometer	HVI		Universal	NIR mass
	Variety	T1	MCI	Zellweger	U1	N1
1	Georgia King	20.5	28.4	29.0	20.6	21.1
2	DPL Acala 90	20.8	29.7	31.1	21.2	19.9
3	DPL 50	20.1	26.9	26.0	18.9	17.5
4	DPL 5415	19.9	30.0	30.1	18.9	19.0
5	Coker 315	21.0	26.1	27.5	20.7	22.1
6	Coker 320	21.7	25.7	27.3	21.0	21.6
7	PD 3	21.3	27.3	27.4	21.2	21.1
8	PD 5363	21.8	29.5	30.0	21.6	23.4
9	PD 5529	22.4	27.1	26.4	21.7	20.0
10	DES 119	20.8	28.3	26.0	19.3	19.1
11	Acala 1517-88	23.4	31.0	31.4	23.7	25.4
12	HS 46	20.9	30.7	30.2	21.3	20.4

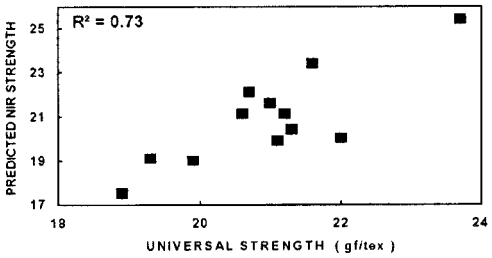

Figure 17. Strength comparison for 12 varieties of cotton using a three wavelength model.

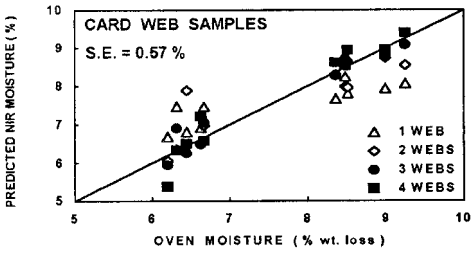

Figure 18. Moisture comparison with four cottons and four fiber web thicknesses.

weighed to determine its linear density gravimetrically. Thirty NIR spectra were measured and averaged to reduce the spectrometer signal noise. Each specimen was displaced lengthwise by approximately 6 mm during spectral testing to provide a component of averaging along the fibers. Stepwise linear regression methods, using the NSAS software (purchased with the spectrometer) were used to predict linear density values for each specimen (Figure 16). The statistical results for fiber mass were better than expected ($R^2 = 0.99$). However, fiber strength values (recorded by breaking identically prepared non-tapered bundles) using the NIR transflectance calibration were more variable than expected ($R^2 = 0.73$; Figure 17).

Moisture content

To evaluate the accuracy of measuring the moisture in thin cotton fiber layers using transflectance, we prepared 32 thin webs of approximately the same fiber mass density measured in the strength bundles. Four cottons (differing in micronaire) were used to include the influence of fiber fineness. Four web thicknesses were prepared from each cotton to provide a range of mass. To force a range in moisture content values, half of the samples were stored in a laboratory at 70°F and 80% RH while the other half were conditioned at 70°F and 55% RH. Reference moisture values were measured by oven dry method.

The calculated NIR moisture values were quite variable (Figure 18). The standard error was 0.57 percent. Using NIR surface reflectance with compressed cotton samples, we were able to produce an accuracy of 0.2%.[3]

Summary

The following observations are reported:

- Cotton fiber transmissivity gave high scatter—low absorption spectra.
- NIR transflectance measurements of cotton fibers provided accurate estimates of bundle mass.
- NIR strength and moisture values on HVI bundles were slightly irregular.

References

1. American Society for Testing and Materials, (a) ASTM D1445-75, “Breaking Strength and Elongation of Cotton Fibers”; (b) D3818-79, “Linear Density and Maturity Index of Cotton Fibers.”

2. K.L. Hertel and C.J. Craven, *Textile Res. J.* **26(6),** 479 (1956).
3. R.A. Taylor, “Moisture in Cotton and its Contribution to Fibre Strength Changes”, in *Proc. 6th INIRS Conference*. Lorne, Australia (1994).