A REFERENCE TEST FOR HVI STRENGTH MEASUREMENTS - IMPLICATIONS FOR HVI TESTING

C. K. Bragg, J. D. Wessinger and L. C. Godbey
USDA-ARS-CQRS
Clemson, SC, USA
J. P. Gourlot
CIRAD-CA
Montpellier, France
A. Drieling
Faserinstitut e.V.
Bremen, Germany

Abstract

Fibrograms were obtained for cotton beards used in HVI testing after conditioning the beards in two different relative humidity environments, 30% and 65%, where the temperature was controlled to a nominal 70 degrees F. The differences in optical mass measurements for the fibrograms were negligibly small and close to the resolution of the optical system of the instrument. From these results it was concluded that the optical measurements used as indirect indicators of mass for HVI strength measurements are relatively invariant to moisture content.

HVI test specimens from several cottons were tested at three different rates of loading, 13, 34, and 214 cm/min, in two different relative humidity environments, 30% and 65%, where the temperature was held to a nominal 70 degrees F. At the standard 13 cm/min rate of loading, the difference between the normalized force measurements for the two relative humidity environments was 45%. At the two other rates of loading the differences were reduced significantly(to 20% for 214 cm/mn) , indicating that it might be possible to select a rate of loading for HVI systems that would reduce the variations in HVI strength measurements due to moisture content variations.

Using a cut-and-weigh procedure that was developed previously for the ReferenceTest Method for HVI Strength Measurements, it was shown that fiber surface characteristics have a significant effect on optical mass determinations in HVI strength tests. The optical mass determination was also shown to be sensitive to the distributions of the micronaire/fineness of the fibers in the test specimens. Scouring to remove or reduce surface constituents was used to demonstrate that natural waxes, which do not contribute to cellulose mass, can cause errors in mass determination made by optical methods. Swelling of the fibers, which does not change their linear density, causes significant changes in optical mass measurements, indicating that fiber surface smoothness affects the reflectance properties.

International interlaboratory test results show significant fiber color effects on differences in strength measurements using Stelomer and HVI. Dyed fibers were used to evaluate the effect of fiber color on the optical mass measurements made by HVI systems. Cottons were dyed to within the Rd and +b ranges of the cotton colorimeter chart. Significant correlations were found between color parameters (Rd and +b) and weight estimations based on optical readings. Corrections are possible to minimize the effect of color on optical mass measurements.

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 2:1599-1609 (1998)
National Cotton Council, Memphis TN

Introduction

Length is one of the most important of all fiber properties. Its influence on processing machinery settings and yarn formation has been pointed out by scientists over many years (Frydrych, 1993; Gutknecht, 1984; Lord, 1961). Many technical developments have been made since the beginning of length characterization to ensure the accuracy and precision of its measurement. Hertel (1964) designed a system to measure the optical mass at different positions along tapered beards of randomly selected fibers. Calculations from these measurements give useful information, such as span lengths or mean lengths, for use in research, trade and industry. This optical system was used in Fibrograph instruments for measuring fiber length and was the basis for the HVI systems produced by Spinlab. HVI systems use the same tapered beard that is used for the length measurement to determine HVI strength. For length and strength characterizations, a comb is used to select a suitable test specimen from a fiber mass protruding through holes in a perforated metal plate. The fibers in a beard specimen are selected randomly along their lengths. A carding and brushing sequence aligns the fibers prior to testing and removes loose fibers.

Then, light from an LED source (Figure 1) is passed through the fiber beard to a detector and converted to a voltage that is proportional to the beard mass at that position. The beard is moved so that it is exposed to the light beam in regular steps from its tip to its base. At each of these steps, the system records the detector voltage corresponding to a precise position on the beard. This voltage is translated into a digital, optical amount(OA) reading by a converter. When there is no fiber, all of the light reaches the detector and an OA reading of zero is produced. When all the light is blocked by the specimen, no light reaches the detector and the OA is 1000.
The curve showing the relationship between OA and beard position, or fiber length, is called a fibrogram (Figure 1). Previous work has demonstrated that the following factors affect this measurement method and its precision:

-- Sampling methods (Chanselme, 1996 ; Gourlot, 1994, 1996)
-- Clamp design (Hertel, 1964)
-- Sample conditioning history
-- Tapering of fibers near their ends (Hertel, 1964)
-- Residual crimp after brushing (Hertel, 1964; Taylor, 1990)
-- Maturity/fineness (Duckett, 1991 and 1993; Taylor, 1990)

All these factors seem to affect the light penetration of the fiber beard and the amount of light reaching the detector. A correction for the effect of maturity/fineness by micronaire has been an integral part of HVI systems since their initiation. Light scattering, absorption, and/or diffraction seem to be induced by the number and transverse and longitudinal shape of the fibers, and/or their external surface characteristics (Figure 2). Some of these characteristics result from the way fibers are produced on the cotton seed.

During the time the cotton boll is developing on the plant, fibers growing on the seeds increase in their diameter, length, and wall thickness. The wall thickness develops from successive, cellulosic deposits inside the lumen of the fibers depending on external factors such as plant nutrition, diseases or insect attacks (Parry, 1982). Thus, the cellulosic deposits are not regular and form fibrils having different lengths and structures (Palmer, 1960). These differences in structure cause tensions which equilibrate due to the moisture conditions in the boll. At the end of the plant growing cycle, the boll opens and the excess moisture is dried out by atmospheric conditions and the sun. The accumulated tensions due to internal structure find another equilibrium by twisting the fibers and creating convolutions, reversals, crimp, etc.

Length distribution and micronaire are required to calculate HVI strength; and, as mentioned earlier, the length distribution is measured by optical methods. It is widely known that variations in moisture content significantly affect cotton fiber bundle strength measurements. As part of an ongoing study to develop a Reference Test Method (RTM) for HVI strength, close study is being given to: (1) the effects of fiber surface irregularities, moisture content and color on optical mass readings and (2) the effects on bundle strength of rate of loading at different moisture contents. The results of part of this work are reported here for selected cotton samples.

Methods and Materials

The cooperative work on the development of the RTM has been reported previously (Bragg, 1996 and 1997). A number of experiments have been performed in the course of development of the RTM. For all experiments, cotton samples and other test materials were analyzed in closely controlled atmospheric conditions that were different for specific experiments. The RTM method uses a standard, Model 900 HVI (Zellweger Uster Spinlab) where specimens are selected and prepared manually with a fibrosampler and processed through the machine. The normal HVI software was modified to provide more detailed information than is available during the standard operation of the instrument. In all other respects the instrument conforms to manufacturers' specifications, settings and operational procedures. A brief outline of the RTM procedure follows:

-- Measure fiber length distribution (fibrogram) by the optical system of the instrument. OA readings are obtained exactly as they are in standard operation of the instrument. Optical measurements corresponding to regular positions at 0.025-inch intervals along the fiber beard are recorded.

-- Choose specific point where fibers in the beard will be broken. In the RTM method this point corresponds to the 30% span length (Figure 3).

-- Clamp the fibers so that a line across the beard corresponding to the 30% span length point on the fibrogram is positioned at the middle of the 0.125-inch-wide rear breaker jaws of the instrument. (Note: In standard HVI operation, the 30% SL line would be placed at the front edge of the back jaw. For a better estimation of broken fiber weight, the RTM method places this line at the middle of the back jaw.)

-- Break the fibers by increasing the distance between the fixed front jaw and the movable rear jaw in increments (steps) of 1/1200 inch. Nominal rate of increase is about 13 centimeters per minute. During the break, the system records the force for each incremental step of the rear jaws.

-- Obtain optical measurement of length distribution of the broken beard as represented in the fibrogram (Figure 3).

-- Export data to an external computer for summary and analysis.

The clamp containing the fiber beard is then placed in a holding device where the beard is separated from the clamp by cutting at a precise position corresponding to a selected optical reading (Figure 4). The fibers are then placed manually on a precision balance and the weight (WGT) in mg is recorded for entry into the external computer.

Specific software is then used to edit the data and for each beard calculates:

-- Peak force (PF) in kg from a quadratic fit in the region of maximum force measurements obtained during the breaking cycle.

-- Elongation as a percentage of the 0.125-inch gauge.

-- The area (TMT) under the broken fibrogram curve which is to be related to WGT (Figure 4).

-- The estimated weight (BKMT) of the broken fibers which are held in the rear jaws during the test.

-- The strength expressed in g/tex by the formula:

$$RTM\ \ Strength = 3.175 * \frac{PF}{BKMT}$$

Where: PF is the peak force, in kg, from a quadratic fit in the region of maximum force in the breaking cycle,

BKMT is the estimated weight, in mg, of the broken fiber beard held in the rear breaker jaws, and

the constant, 3.175, is the width of the rear breaker jaws in mm.

Determining Bundle Elongation

Flexing of the mechanical members of the breaker mechanism of the Model-900 HVI during the breaking cycle has been demonstrated (Taylor, 1990). To overcome the effects of this flexing on elongation measurements, a procedure was devised which allows calculation of the amount of flexing as a function of the force applied during the breaking cycle for each HVI. Flexing is estimated by operating the instrument in the breaking cycle using an ordinary paper index card covered with fiberglass tape. When the covered card is grasped by the breaker jaws, no rear jaw displacement is possible. Force measurements are then saved for different positions of the bottom member of the mechanism that displaces the rear jaws. From these measurements, the position that the rear jaws should occupy during the normal breaking cycle is calculated as a function of lower member position and the corresponding force.

Calibration software corrects for the flexing and provides a precise estimate of the position of the rear jaw if no flexing had occurred. The bundle modulus is then used as an estimate of elongation.

Relationship Between Optical Amount and Weight

A typical relationship between measurements of TMT and WGT for broken beards is shown in Figure 5. WGT can be closely estimated by a quadratic function of TMT as illustrated by the regression equation and corresponding R-square shown. The coefficient has been forced to zero, since a zero amount reading is expected when no fibers are inside the optical device. All cottons tested by the RTM method have exhibited similar--but different--relationships.

A major factor in these different relationships is micronaire reading. Figure 6 shows the relationship between WGT and TMT for seven cottons with different micronaire readings. Using the regression equations for these curves, the TMT for a constant WGT was estimated. Figure 7 shows the relationship between micronaire reading and this estimated TMT for seven cottons. The point furthest from the regression line is for a Pima cotton. This illustrates the need for a different correction for the effect of micronaire on the HVI strength of Pima cottons. This implies that more general corrections for HVI strength could be made with maturity measurements, if such a measurement were available on HVI systems.

The Effect of Moisture Content on Optical Amount

Variation in moisture content is widely known to be a major contributor to the variation in bundle strength measurements of cotton fibers. In the RTM (and indirectly in commercial HVI testing), OA readings are used to estimate the linear density of broken fiber beards. To determine the effects of moisture content on HVI OA readings, several cottons were tested at two widely differing levels of relative humidity (RH). In two adjacent laboratories connected by a well sealed door, temperature was controlled between 68 and 72 degrees F. In one of the laboratories the RH was controlled to a nominal 30%; and, in the other laboratory, it was controlled to a nominal 65%. Using groups of four clamps for each cotton, specimens were prepared in the 30% RH environment, combed and brushed once using the standard HVI procedure and allowed to remain in the laboratory 24 hours before testing on the HVI to obtain fibrograms. The specimens were never brushed again. Several fibrograms were obtained for each specimen. The HVI and the specimens were then moved to the adjacent room where the RH was 65%, and the specimens were allowed to condition in a closely controlled stream of air from the room environment. Several fibrograms were then obtained for each specimen after conditioning to the 65% environment. This process was repeated so that two sets of fibrograms were obtained for each environmental condition.

Figure 8 shows fibrograms for one cotton in each RH condition. It is difficult to see differences in the fibrograms. Figure 9 shows differences between fibrograms for the two RH conditions. The resolution of the optical measurement system is approximately two units. Figure 9 shows that there are differences in the OA readings in the two environments, but the differences are so small for such a wide range in RH that it can be concluded that OA readings are relatively invariant to significant differences in moisture content.

Effect of Displacement Rate and Moisture Content

Since it was demonstrated above that variations in moisture content have little or no effect on one of the two measurements, OA, required to determine HVI strength and since moisture content variations are known to be a major contributor, interest is focused on the other component--the force required to break the fiber bundle. In the past, several attempts have been made to compensate for the effect on HVI strength of moisture content variations through measurements of RH or moisture content in test specimens. These efforts have not resulted in a satisfactory method. The most practical method currently available is the use of rapid conditioning units (RCU) developed and implemented by USDA-AMS-Cotton Division for use in cotton classification. Most cotton samples enter the test environment for classification with low moisture contents.

RCU's are used to pull properly conditioned room air through the cotton samples to equilibrate the samples in a very short time. This requires close control of environmental conditions. Previous work (Carmical, 1988) demonstrated that the physical appearance of the ends of fibers that are broken at different rates of loading is dramatically different. At lower rates of loading, the broken ends of fibers appear ragged and frayed as illustrated in Figure 10. As rate of loading increases, the appearance of

the broken ends changes and becomes less ragged as shown in Figure 11--indicating that the molecular forces binding the fibers together are responding differently at different rates of loading. Since moisture affects these molecular bonds, this leads to speculation that testing at a different rate of loading could reduce or eliminate the effect of variations in moisture content on the breaking force of the beards.

To evaluate this concept, a Motion Control Incorporated (MCI) Model-3500 HVI was modified to break bundles at three different rates of loading--13, 34, and 214 cm/min. The MCI instrument was selected for this experiment because changes in rate of loading were simple to implement. The different rates of loading were obtained by changing the size of the orifice which controls the oil flow rate in the hydraulic system that moves the breaker jaws. Several cottons were tested in the two different RH environments, 30% and 65%, using the three rates of loading. In each case, the force required to break the beards was normalized by dividing it by the break amount for the test specimen. Figure 12 shows the percentage change in these normalized force measurements due to changes in RH. At the standard rate of loading, the difference in strength due to RH differences was 45%. At the high rate of loading, the difference dropped to 20%--indicating that a rate of loading might be found to compensate for (or minimize) the effect of differences in moisture content of the specimens.

Effect of Surface Characteristics on Optical Amount

The precision and accuracy of the estimate of BKMT for various cottons depend on how consistently the light penetrates the fiber bundle and reaches the detector. Ideally, this should depend only on fiber mass and be the same for all cottons; however, it is known that factors other than fiber mass affect light penetration. Maturity/fineness as measured by micronaire is an example. Since light is easily scattered by irregular surfaces, it is not difficult to imagine that fibers with irregular surfaces should scatter more light than fibers with smoother surfaces. Several experiments were conducted to determine if surface characteristics affect optical readings.

In experiment 1, two cottons with different micronaire values (Table 1) were used to make four different mixes to determine the effect of maturity/fineness distribution on OA readings. Mixes 1, 2, 3 and 4 contained 20, 40, 60 and 80% by weight, respectively, of 2.8 micronaire cotton. The other component of the mixes was 4.8 micronaire cotton. Initially, each cotton was thoroughly homogenized using a laboratory blender. Then, mixes were prepared by hand blending different percentages by weight of the two cottons. Three passages on the laboratory blender were used to ensure homogeneous blends (doubling of at least 600).

By mixing the two cottons in different percentages, the maturity/fineness distributions of the mixes changed. The resulting micronaire values, using harmonic averages, are given in the column labeled "predicted" in Table 1. A good relationship is observed between predicted and measured micronaire values, indicating that the proportions of each cotton in the mixes correspond to the expected amounts. Optical amounts and corresponding beard weights were measured for these mixes using the RTM.

Again, the relationships between WGT and TMT are curvilinear, with a ranking of the curves dependent on micronaire values (Figure 13). The a and b coefficients are shown in Table 2. The optical system is shown to be very sensitive to changes in the fiber maturity/fineness distribution expressed as micronaire reading.

In experiment 2, ten cottons having different micronaire values (Table 1) were tested by the RTM as raw cotton and then tested again after scouring and after swelling. Scouring was done using a typical formulation for raw cotton, and swelling was done using 18% sodium hydroxide solution. The treated samples were then conditioned in 45% RH and 70 degrees F. atmospheric conditions. One raw subsample per cotton was selected to determine the wax content by the Soxhlet extraction method using trichloroethylene 1,1,1 solvent.

The cottons labeled with five digits are the base cottons used in the RTM project. Those labeled by letters were chosen to represent a range of micronaire values and different wax content levels. This was achieved by choosing cottons from various growing areas within the USA.

Scouring to change the wax content was expected to affect light diffraction, absorption, transmittance, and/or scattering and, consequently, affect the relationship between optical and gravimetric mass of fiber beards. Swelling is known to make the fibers more rod-like (depending on their maturity level), thus introducing changes in external fiber shapes. The linear density was assumed to remain unchanged, and the ratio mass per unit volume to decrease when the fibers were swollen. This is known to induce a higher micronaire reading and was expected to change optical readings. This would indicate an interaction between fiber surface irregularities or fiber shape and optical readings.

Figure 14 shows the relationship between WGT and TMT for swollen fibers (a and b coefficients for raw, scoured and swollen cottons are in Table 2). The general trend to rank the curves by micronaire value is continued, except for some samples (E for instance). After scouring and swelling, it is difficult to perfectly open and mix the fibers. Entanglements persist and give increased importance to fiber sampling and preparation for micronaire and fibrogram measurements. This may affect the ranking of the curves in the charts.

For each cotton, WGT and TMT curves for raw, scoured and swollen can be compared. Three examples are given in Figures 15, 16 and 17 for cottons 28020, 28671 and D, respectively (a, b and R^2 coefficients are in Table 2). Notice that the curves for raw and scoured samples are grouped together, and the curves for swollen fibers are higher in weight. Table 1 gives the wax contents, expressed as a percentage of the dry weight of the samples, and micronaire values for each treatment. Scouring slightly decreased the micronaire of the fibers, and swelling increased the micronaire as expected.

In the previous section, tests showed that as micronaire decreases the curves WGT vs. TMT approach the TMT axis. Comparison of the raw/scoured curves show the reverse situation--the corresponding curves are farther away from the TMT axis. From this several hypotheses can be drawn:

-- Micronaire depends on the ability of air to pass through fiber samples. Thus, depending on fiber preparation, different results can be obtained. Scoured fibers are more difficult to fluff than raw fibers, resulting in differences in air permeability of the fiber samples. This would induce an increased micronaire value, perhaps modifying curve rankings.

-- Scouring removes wax, thus it seems normal to observe a decreased linear density expressed as micronaire values.

-- Scouring was done at a boiling temperature. This can affect the fiber surface irregularities by removing a part of the crimp and can affect optical readings and induce a decreased micronaire value.

-- Chemical treatments remove increasing amounts of wax as micronaire decreases (Table 1).

The comparison of raw/swollen cotton samples shows a significant increase in micronaire value. The curves are placed at their expected places as ranked by micronaire. Again, measurements based on air and light were changed due to external fiber shape modifications induced by chemical treatment.

Effect of Color on Optical Amount

In previous, unpublished work it was observed that cotton which was dyed in red, green and blue colors gave very different HVI strength results compared to the undyed cotton (up to 10g/tex was observed for blue dyed fibers). This is explained by the absorption spectra, which was much higher (600-700 nm range) for the cotton dyed blue than for the other colors. Since these cottons were outside the range of color for raw cotton and HVI systems were designed for use on raw cotton, this difference is understandable because the interpretation of the OA readings for dyed cotton cannot be the same as for raw cotton. However, these observations do raise an important question about the effect of variations in raw cotton color on OA readings and their relationship to the estimated break amount in HVI testing.

If two samples, *A* and *B*, which differ only in color, with *A* having a higher absorption than *B* in the 660 nm wavelength region are tested for HVI strength:

-- *A* has higher optical amount readings than *B*.

-- For fibers in the break zone, the estimated weight of sample *A* is higher than for sample *B*.

-- This would result in a lower HVI strength for *A* in comparison with *B*.

Based on this assumption, differences can be calculated with data from international interlaboratory tests by the formula:

$$DIFF_{CAL} = HVI\ Strength - T1$$

Where: -- CAL describes the calibration type:
-- ICCS = HVI calibrated with International Calibration Cotton Standards and
-- HVICC = HVI calibrated with HVI Calibration Cottons.
-- HVI = HVI strength for each calibration mode, and
-- T1 = Stelometer strength (not affected by light measurement).

If the previous assumption is true, $DIFF_{CAL}$ should be related to color measurements as expressed by reflectance, Rd, and yellowness, +b, for a wide range of cotton color.

Supporting this:

--Data for 22 cottons from the Bremen interlaboratory check-test program show a significant, positive correlation between the average results for all participants for Rd and DIFF (Figure 18). With the same samples, no correlation between Rd and $DIFF_{HVICC}$ can be demonstrated (Figure 18).

-- 107 cottons from the USDA, HVI check-test program since 1986 were retested for Stelometer (calibrated with International Calibration Cotton Standards) at CIRAD. A highly significant, positive correlation was observed between Rd and $DIFF_{HVICC}$ (Figure 19).

In both cases, no significant correlation was found with yellowness, +b. These differences in HVI results, depending on the calibration mode, could be related to differences in OA readings for the calibration samples. This may be related to fiber maturity/fineness, surface characteristics effects on optical readings, or a color effect as hypothesized above.

To provide a more specific test of this hypothesis, samples from a uniformly blended cotton were dyed to nine different colors by combining yellow and black pigments in a solution of 40 ml/gram of fiber and 20% of NaCl salt. One sample was scoured as mentioned in the previous section and used as a control. Color measurements were obtained using a Spinlab colorimeter and a BYK Gardner spectrophotometer. The spectrophotometer was used to

obtain reflectance measurements at wavelengths in the range of 380-720 nm by steps of 10 nm.

Using the RTM, optical amount, TMT, and corresponding weight, WGT, were obtained as described above. Colorimeter measurements are shown in Table 3 and represent a wide range of color on a standard cotton colorimeter chart. The spectral information is given in terms of Hunter's Rd, a and b, where: a negative indicates a greener color, and a positive indicates a redder color; and, b negative indicates a bluer color and b positive indicates yellowness.

Figure 20 shows the curvilinear relationships between TMT and WGT for all nine samples. Table 4 shows the regression coefficients of the equation. Micronaire determinations (Table 4) show no difference due to the dyeing process. The observed differences in curves should be caused by other fiber characteristics.

In Figure 20, a ranking of the curve positions is possible using reflectance, Rd--showing the effect on the optical mass measurement. A similar ranking cannot be done using yellowness. Figure 21 shows the effect of reflectance on the WGT estimation. For a TMT = 200, WGT varies from 1.35 to 1.65 mg.

$$WGT_{TMT_i} = d_i * Reflectance + e_i$$

Figure 22 shows the correlation coefficients from the relations:

$$WGT_{TMT_i} = f_i * Yellowness + g_i$$

Where: - WGT_{TMT} was estimated with the coefficients shown in Table 4 using each TMT_i in a range of 20 to 1600 by steps of 20.

The correlation coefficients in Figure 22 are r = 0.51 (NS) for Rd, and r = 0.61 (NS) for +b when TMT = 200. Using the same nine colored cottons, correlation coefficients were calculated at each TMT step and are plotted in Figure 23. When a fiber beard goes into the optical device, the first readings are not significantly influenced by the color of the fibers (the beard is very thin here). In this case, it seems to be a "transmission" measurement. The number of fibers increases as the beard continues to go in, and an increasing interaction between light and fibers appears. Some scattering, absorption and/or diffraction seems to occur, showing the increasing importance of fiber color in the optical mass estimation. In this case, correlation coefficients become significant as shown in Figure 23.

A correction is needed to remove the effect of color on the optical mass determination, since significant correlations are observed in some specific TMT areas between WGT and Rd and +b. This correction should use yellowness and reflectance in different coefficient weightings depending on the amount of fibers in the beard. Figure 23 shows that spectrophotometer yellowness, +b, is more correlated to the estimated weights than the colorimeter. For improved precision and accuracy of the BKMT estimates, a correction equation could be developed using a large number of cottons representing the entire color range.

A correction for color should improve the precision and accuracy of HVI strength measurements for cottons with low grades, cottons retested after lengthy storage, or naturally colored cottons where great differences in absorption can be seen in the range 650-660 nm light wavelengths. Figure 24 compares a commercial Mali and three naturally colored cotton samples.

Conclusions

Based on detailed analysis of a limited number of samples with a wide range in fiber properties the following conclusions can be drawn about HVI strength measurements:

-Optical mass measurements of cotton beards are relatively invariant to moisture content.

-Variations due to moisture content can be reduced by selecting a higher rate of loading than the currently used rate.

-Optical mass measurements are affected by fiber surface smoothness and wax content.

-An HVI measurement of wax content is needed to correct for errors in optical mass measurements.

-Optical mass measurements are affected by fiber color.

-Correction factors for errors in mass measurements can be developed using current HVI color measurements.

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Table 1. Wax content and measured and predicted micronaire values depending on sample preparation.

			Micronaire			
Cotton		Wax %	Raw	Scoured	Swollen	Predicted
27992		0.608	3.8	3.6	4.8	
28020		0.844	2.8	2.7	3.9	
28671		0.440	4.8	4.5	5.7	
1	20%/80%		4.1			4.2
2	40%/60%		3.6			3.8
3	60%/40%		3.3			3.4
4	80%/20%		3.0			3.1
A		0.439	4.6	4.5	5.5	
B		0.415	4.8	4.6	6.0	
C		0.660	3.1	3.0	4.7	
D		0.480	4.0	4.0	5.4	
E		0.644	3.2	3.0	4.5	
F		0.544	4.2	4.0	5.2	
G		0.680	3.1	3.1	5.1	

Table 2. Coefficients in the equation WGT = a * TMT² + b * TMT for the experimental cottons.

Exp.	cotton	treatment	a	b	R²
raw	22636	raw	2.23E-06	0.005800	0.993
raw	27742	raw	2.65E-06	0.007862	0.998
raw	27992	raw	3.50E-06	0.006083	0.996
raw	28020	raw	2.20E-06	0.005527	0.997
raw	28463	raw	1.94E-06	0.006928	0.998
raw	28671	raw	2.77E-06	0.007295	0.995
raw	28764	raw	2.06E-06	0.005237	0.995
1	1**	20%/80%	2.78E-06	0.006044	0.998
1	2**	40%/60%	2.68E-06	0.005722	0.998
1	3**	60%/40%	2.75E-06	0.005196	0.998
1	4**	80%/20%	2.38E-06	0.005390	0.997
1	28020	raw	2.20E-06	0.005527	0.997
1	28671	raw	2.77E-06	0.007295	0.995
2	27992	raw	3.57E-06	0.005456	0.996
2	27992	scoured	5.54E-06	0.004334	0.989
2	27992	swollen	6.68E-06	0.005651	0.996
2	28020	raw	2.27E-06	0.005239	0.996
2	28020	scoured	3.83E-06	0.004344	0.994
2	28020	swollen	3.77E-06	0.006235	0.996
2	28671	raw	2.69E-06	0.006697	0.996
2	28671	scoured	5.48E-06	0.005371	0.993
2	28671	swollen	5.88E-06	0.006865	0.995
2	A	raw	2.86E-06	0.006588	0.997
2	A	scoured	5.55E-06	0.005325	0.988
2	A	swollen	6.09E-06	0.006894	0.983
2	B	raw	2.45E-06	0.006508	0.996
2	B	scoured	3.94E-06	0.006294	0.989
2	B	swollen	4.72E-06	0.007686	0.996
2	C	raw	2.18E-06	0.005100	0.996
2	C	scoured	3.42E-06	0.004833	0.995
2	C	swollen	4.03E-06	0.006273	0.996
2	D	raw	2.12E-06	0.006186	0.998
2	D	scoured	3.93E-06	0.005085	0.994
2	D	swollen	3.59E-06	0.006952	0.997
2	E	raw	2.59E-06	0.005756	0.996
2	E	scoured	4.10E-06	0.006253	0.992
2	E	swollen	4.23E-06	0.008298	0.992
2	F	raw	2.00E-06	0.006060	0.993
2	F	scoured	3.89E-06	0.005319	0.998
2	F	swollen	3.77E-06	0.006848	0.996
2	G	raw	2.28E-06	0.005496	0.997
2	G	scoured	4.91E-06	0.004233	0.994
2	G	swollen	3.96E-06	0.007305	0.994

* * The first percentage concerns cotton 28020, Micronaire=2.83
The second percentage concerns 28671, Micronaire=4.84.

Table 3. Color measurements for dyed samples.

	Spectrophotometer			Spinlab Colorimeter	
Sample	Rd%	a	b	Rd%	+b
D0	77.8	0.5	7.3	78.6	6.5
D2	77.3	0.6	9.8	79.0	9.5
D3	73.1	0.9	13.6	76.2	14.0
D8	55.4	-3.0	2.8	56.9	3.5
D9	54.3	-3.1	4.5	56.3	5.6
D11	58.4	-2.1	6.9	62.5	7.5
D12	42.3	-4.2	1.4	45.6	5.1
D13	57.0	-2.9	5.8	59.2	6.6
D14	63.1	-2.0	8.4	64.6	8.9

Table 4. Coefficients in the equation WGT = a * TMT² + b* TMT for the cottons that were dyed.

Cotton	a	b	R²	Mike
D0	3.7E-6	0.00646	0.998	4.0
D2	3.7E-6	0.00688	0.995	4.0
D3	2.5E-6	0.00765	0.996	4.0
D8	2.1E-6	0.00739	0.993	4.0
D9	3.0E-6	0.00674	0.996	4.0
D11	3.5E-6	0.00660	0.996	4.0
D12	2.2E-6	0.00632	0.998	4.0
D13	2.4E-6	0.00691	0.997	4.0
D14	2.5E-6	0.00718	0.997	4.0

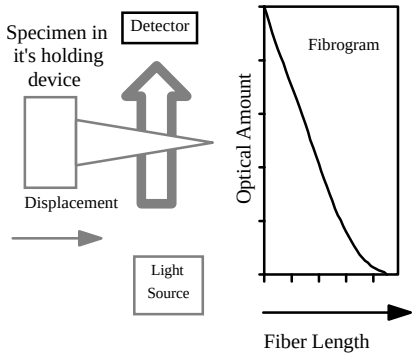

Figure 1. Optical device schematic.

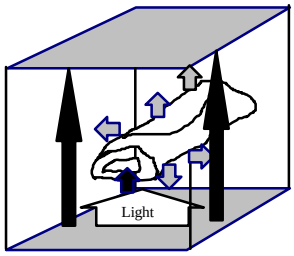

Figure 2. Illustration of light transmission, diffraction, scattering and absorption.

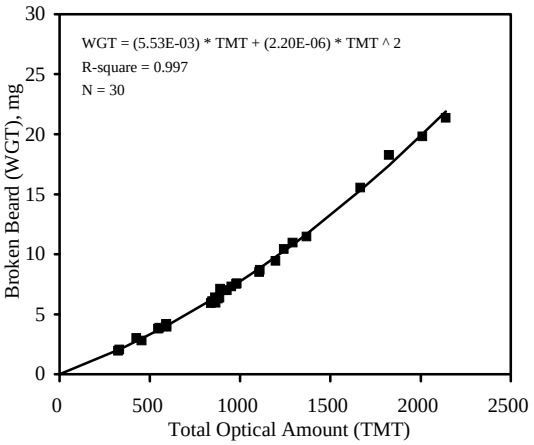

Figure 5. Example of relationship between WGT and TMT.

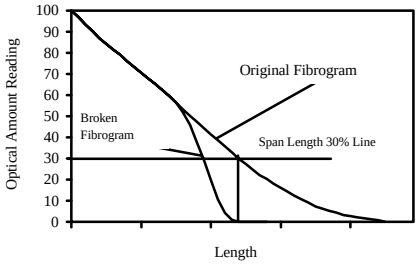

Figure 3. Fibrograms for original and broken beards.

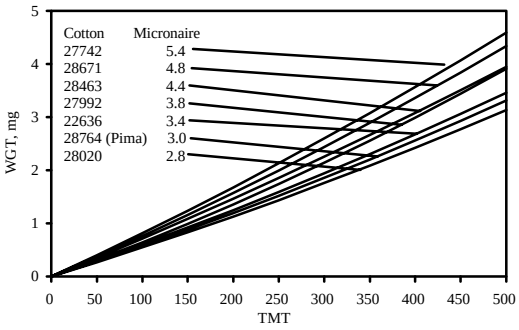

Figure 6. Relationship between WGT and TMT for 7 cottons.

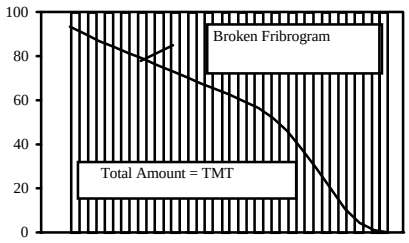

Figure 4. Representation of TMT calculations.

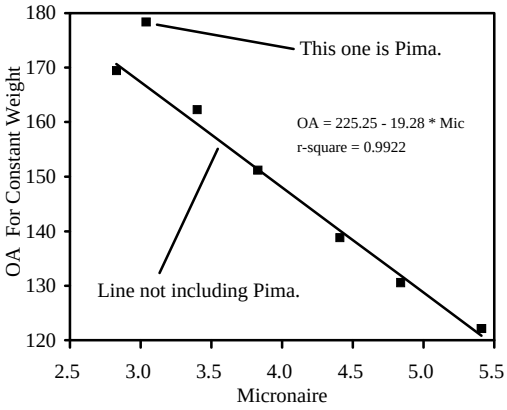

Figure 7. Relationship between optical amount and micronaire for seven cottons.

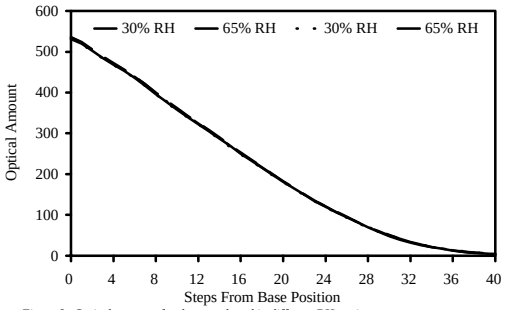

Figure 8. Optical amounts for the same beard in different RH environments.

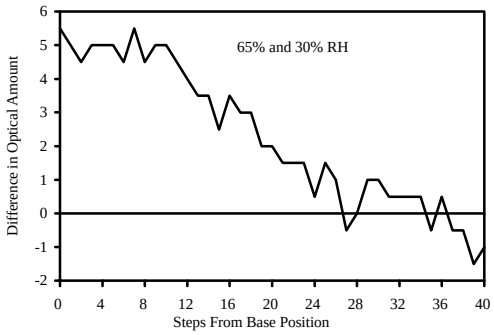

Figure 9. Difference in optical amounts for the same beard in different RH environments.

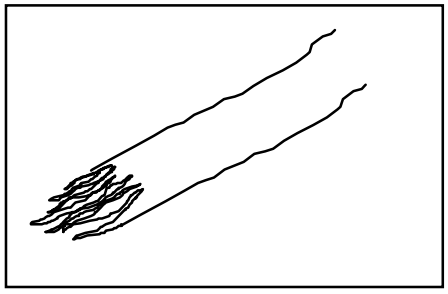

Figure 10. Appearance of a broken fiber at a low rate of loading.

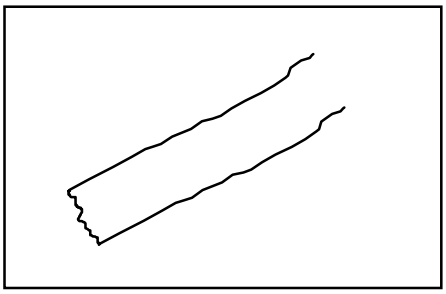

Figure 11. Appearance of a broken fiber at a high rate of loading.

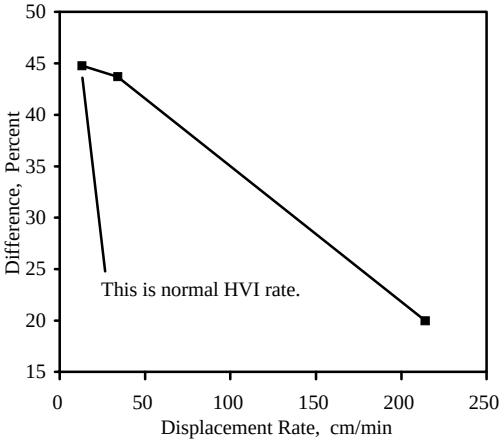

Figure 12. Difference in breaking force ratio for 30% and 65% RH - average of seven cottons.

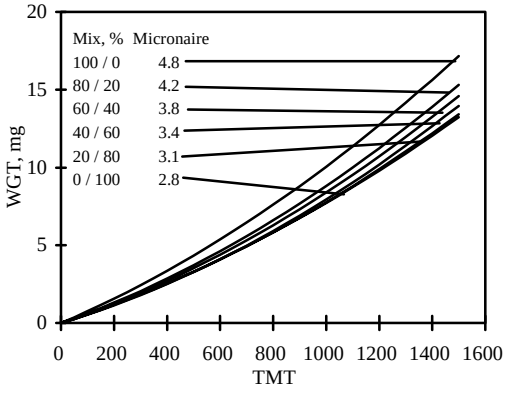

Figure 13. Relationship between WGT and TMT for samples mixed in different percentages.

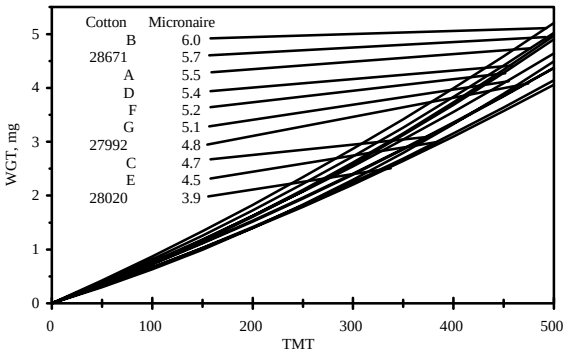

Figure 14. Relationship between WGT and TMT for 10 swollen cottons.

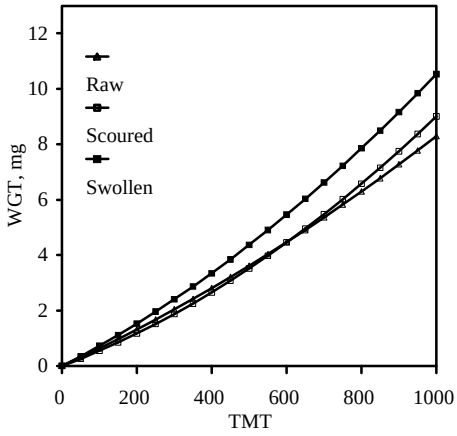

Figure 17. Relationship between WGT and TMT for cotton D.

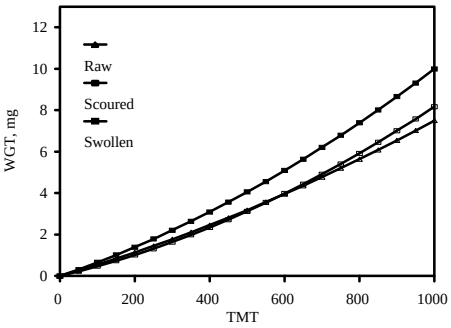

Figure 15. Relationship between WGT and TMT for cotton 28080.

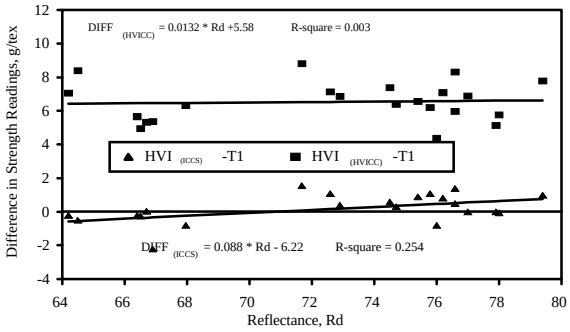

Figure 18. Differences between HVI and Stelometer test results using different calibrations for Bremen Inter1aboratory test cottons.

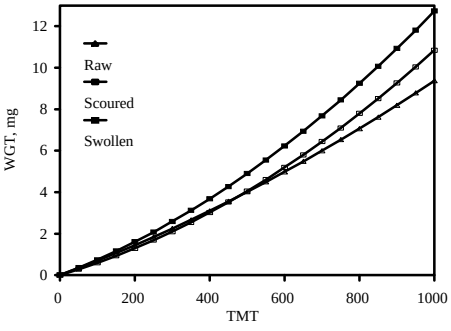

Figure 16. Relationship between WGT and TMT for cotton 28671.

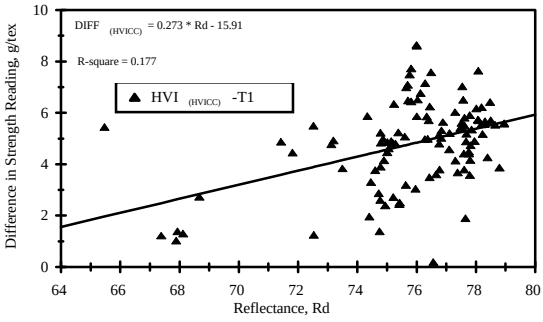

Figure 19. Differences between HVI and Stelometer test results for USDA HVI check test cottons.

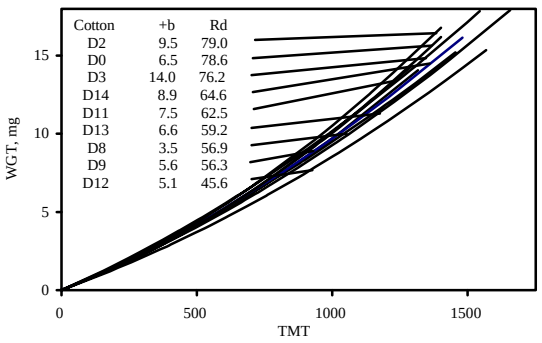

Figure 20. Relationship between WGT and TMT for nine dyed cottons.

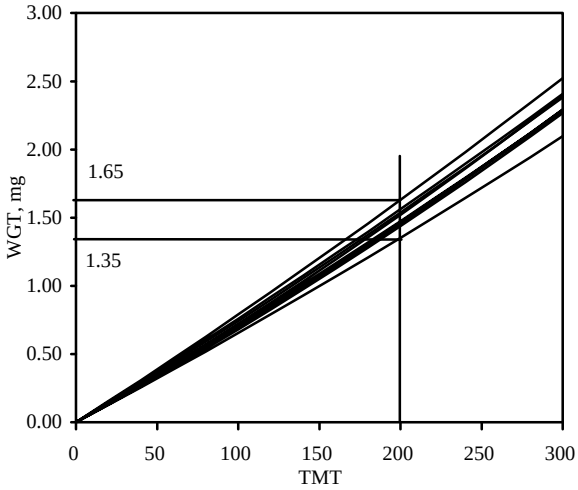

Figure 21. Effect of cotton color on weight estimations.

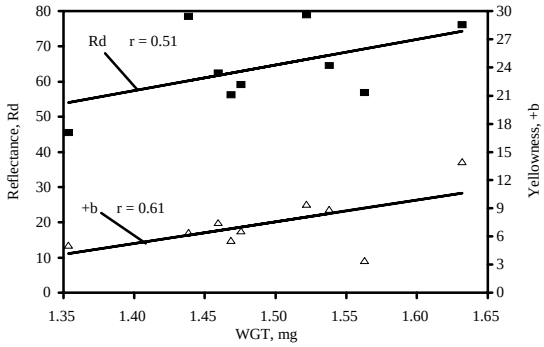

Figure 22. Relationship between estimated WGT and color measurements for TMT = 200.

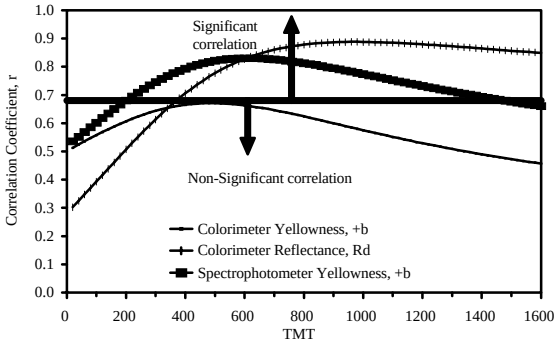

Figure 23. Correlation coefficients between color measurements and estimated weights for nine colored cottons.

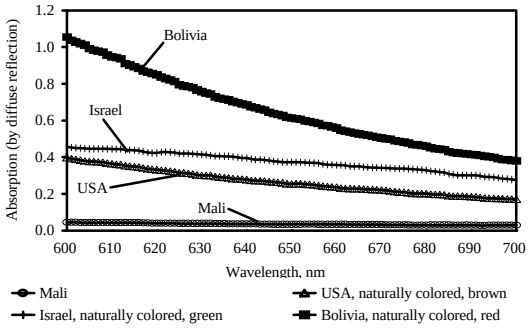

Figure 24. Some examples of naturally colored cotton absorption spectras.