EFFECT OF MOISTURE ON COTTON FIBER STRENGTH

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Abstract

A two part study was conducted to investigate and quantify the relationship between cotton fiber moisture, measured by Near Infrared Reflectance (NIR), and High Volume Instrument (HVI) strength. Samples were collected from cotton bales representing growth regions and plant varieties across the United States. The first part of the study established a mathematical relationship between moisture level and strength by equilibrating the samples to different moisture levels followed by strength and moisture testing. The second part of the study applied the formulated relationship to a duplicate set of samples tested several times while in the process of conditioning.

Investigations of the relationship between moisture and strength resulted in several findings. The strength change per unit moisture change was found to increase with increasing cotton strength. Equilibrium moisture contents of the study cottons at 65 percent relative humidity were found to range from just under 6.7 percent to just over 7.2 percent (wet-basis moisture content). The moisture change per unit relative humidity change was found to increase with decreasing equilibrium moisture content.

Several findings resulted from the application of the strength correction equation developed in the first part of the study. Applying the strength correction to samples at the conditioned state decreased the reproducibility by about three percentage points. Results also indicated that strength corrected reproducibility increased the farther (within limits) the moisture level was from conditioned equilibrium. When the sample moisture deviated from standard equilibrium conditions by about one-half percent or more, the applied strength correction produced a reproducibility equal to or greater than the reproducibility obtained under ideal conditioning and testing procedures.

Introduction

The accuracy of HVI strength measurements is largely dependent upon the degree of sample moisture variability. Lawson et al., 1976 studied the effect of changes in relative humidity of the test atmosphere on cotton fiber strength as measured by the Stelometer. They showed that fiber strength responded quickly to changes in relative humidity. More recently, Byler and Anthony, 1994 and Taylor and Godbey, 1994 have continued efforts in this same area as related to the HVI.

The standard practice for controlling the effect of moisture variability is to equilibrate or condition cotton samples to a standard air environment prior to HVI testing. The standard cotton conditioning and testing air environment is 65% relative humidity at a temperature of 70 degrees Fahrenheit (ASTM, 1993). Samples equilibrated to these air conditions present the desired level of moisture to the HVI for strength measurement.

Moisture variability between cotton test samples and between HVI calibration cotton and cotton test samples contributes greatly to the variability in the strength measurement. The USDA, AMS, Cotton Division has invested considerable time and effort in developing and testing new ideas to reduce the effect of moisture on the strength measurement. Improvements in laboratory environmental systems have resulted in air conditions that maintain tighter relative humidity and temperature tolerances (Earnest, 1995). Development of rapid conditioning systems (Knowlton and Alldredge, 1995) has improved sample conditioning in laboratories.

Another approach that has been under investigation for several years is to adjust strength measurements for samples with moistures that deviate from the proper moisture equilibrium. This approach involves obtaining a moisture measurement of the cotton sample at the time of the strength test. Based on a mathematical relationship between strength and moisture, the strength is corrected to the equilibrium moisture strength level.

In 1994, a strength correction study (Knowlton, 1995) was performed under the restraints of normal classing office testing procedures. The 1994 study provided positive results and prompted the development of this study. The primary purpose of this study was to develop a strength and moisture relationship utilizing the best conditioning and measuring equipment available without the restraints of classing office testing procedures. The classing office provides the best setting for evaluation. However, for development and study of the moisture and strength relationship greater flexibility was necessary.

Materials and Methods

Cotton Samples

Cotton samples were collected from 30 bales representing a cross section of varieties and growing regions in the U.S. Two identical sample sets were collected from these bales. Each sample set consisted of six samples from each bale. Six samples from each of the short and long calibration cottons (same cottons used to calibrate the HVI) were included in each sample set. In addition, 18 short and 18 long calibration cotton samples were collected and stored in a separate laboratory that remained at standard

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conditions (65%RH and 70°F) during the entire study. These samples were divided into three sets each containing six short and six long samples. These samples were individually placed into large two gallon zip-lock bags. The bags were left open while being held at standard conditions. The bags allowed the samples to be sealed to avoid moisture changes when the samples were transported to the testing laboratory for testing.

Instruments

Two prototype Near Infrared Reflectance (NIR) moisture measuring instruments were used in this study to measure cotton sample moisture content. These instruments were used in previous moisture studies (Knowlton, 1995; and Knowlton and Grantham, 1995). Prior to the study, the instruments were calibrated to measure wet-basis moisture content as determined by the oven-dry method. Moisture sealed cotton samples, encased in plastic with a quartz window, were measured twice during every test session to verify calibration. Recalibration was not required during the study. Only one NIR instrument was used to provide moisture data for the analysis of this study. The second NIR instrument was used to verify calibration of the primary instrument.

A 900 Automatic Spinlab HVI was used for obtaining HVI measurements. The only HVI calibration performed was at the beginning of the study. The calibration samples, that were held at standard moisture conditions throughout the study, were used to monitor and if necessary adjust the HVI testing level.

Procedure

The HVI and NIR instruments were set up in a conditioning laboratory capable of maintaining different levels of relative humidity. The temperature was maintained at 70° Fahrenheit for the entire study. The study was divided into a part A and a part B. The testing schedule for each part is shown in Table 1. The main objective of part A was to obtain HVI measurements of the samples at five different states of moisture equilibrium. Each moisture equilibrium state was achieved by three to four day conditioning at a specific relative humidity level followed by HVI and moisture tests. The five relative humidity levels utilized were 50, 55, 60, 65 and 70 percent.

Part A began by preconditioning the group of test samples at 45 percent relative humidity for one week. The relative humidity was then raised to 50 percent and the samples were conditioned for approximately three days. The sample set was then HVI and moisture tested. Immediately following testing, the relative humidity was raised to 55 percent. Again the samples were conditioned for approximately three days before testing. This procedure was repeated for the remaining moisture levels. Following each testing, the relative humidity was raised by five percent until the final testing at 70 percent relative humidity was completed.

The three calibration sample sets, being held at standard conditions in the separate conditioning laboratory, were each brought into the testing laboratory during each testing session. The first set was carried into the testing laboratory and tested prior to testing the test samples. The second set was brought in and tested during the middle of sample testing; and the third set was brought in and tested at the end of the test session.

Part B of the study involved bringing the duplicate sample set into the testing laboratory and preconditioning the samples at the driest condition attainable with the conditioning laboratory air. After one week of preconditioning at approximately 35 percent relative humidity, the sample moistures were sufficiently low. On the first day of part B testing, the relative humidity was set from the 35 percent level to 65 percent. Sample testing began immediately. Air conditions were up to 65 percent relative humidity within fifteen minutes. Approximately two and one-half hours were required to complete testing of the sample set. Three hours after completing the first testing, the sample set was tested again. In the morning of the second day and in the afternoon of the third day, testing was again conducted.

Results and Discussion of Part A

The analysis of the first part of the study began by obtaining moisture content and strength versus relative humidity relationships for each of the 30 cotton bales. In addition, the two calibration bales used for calibrating the HVI were also included in the analysis. In Figures 1 through 6 are presented results from six of the 32 bales that have been selected for discussion. The top curve on each graph shows the moisture content versus relative humidity and the bottom curve shows HVI strength versus relative humidity. Each point on the graph is the average of six measured samples taken at equilibrium moisture conditions.

Equilibrium Moisture Contents

Figure 7 shows the equilibrium moisture contents (EMC) of the test cottons after five days of conditioning at 65 percent relative humidity. The range over which the EMCs span is greater than one-half of one percent. By definition (ASTM, 1993), all of the bales represented on Figure 7 are all at the correct moisture level for HVI strength testing (give or take a small degree of variability in conditioning relative humidity from sample to sample). An ideal moisture measurement, for purposes of a strength correction, would show these points over a very narrow moisture measurement range. However, as seen by Figure 7, moisture contents from cotton to cotton vary at any given equilibrium relative humidity state. Figure 7 also gives the relationships of micronaire and strength versus moisture content. There is some correlation between these HVI measurements and EMCs. Strong cottons consistently had relatively high EMCs while high micronaire cottons tended to have relatively low EMCs. A correction for EMC based on strength and micronaire could conceivably tighten the EMC range.

Comparison of Moisture Slopes

The moisture content versus relative humidity curves in Figures 1 through 6 all appear very similar. In order to quantify the curves, the slope of a best fit line through the moisture content points was calculated for each graph. The resulting slope values are found adjacent to the curves. The difference between the slopes is small. However, there is an interesting pattern. The slopes increase from bale to bale as the level of equilibrium moisture content decreases. This implies that a bale with a low equilibrium moisture content will have a wider range of moisture contents over a given relative humidity range than a bale with a high equilibrium moisture content.

Comparison of Strength Slopes

The strength versus relative humidity curves in Figures 1 through 6 illustrate that there is some variation in the slopes from graph to graph. Closer observation reveals that the slopes increase as relative bale strength increases. Figure 8 plots the strength versus moisture content slopes found for each bale. The slopes are taken from a best fit line from each bales strength versus moisture content relation. The slopes are plotted over the strengths found at 65 percent relative humidity equilibrium moisture conditions. A line was then fitted to the slope points. The equation for the line is shown on the graph of Figure 8. The correlation is fairly strong as supported by an R-squared value of 0.78. Given a sample's strength at 65 percent relative humidity conditions, the equation will predict a correction factor that can be used to correct the strength as it deviates from proper moisture equilibrium.

Equation 1 was used as a basis for developing a correction formula. This formula multiplies a correction factor to the amount that a sample's moisture deviates from a predetermined equilibrium moisture content. This product is then added to the measured raw strength.

$$CS = (MB)(CF) + RS \qquad [1]$$

Where: CS = Corrected Strength
MB = Moisture Bias
= Measured Moisture - Equilibrium Moisture
CF = Correction Factor
RS = Raw Strength

Equation 1 by itself assumes that all cottons have the same strength versus moisture content slope. Since Figure 8 shows that this is not true, the correction factor is derived from Equation 2 which is the line fit equation from Figure 8.

Since the strength to moisture equation from Figure 8 is based on strength levels at 65 percent relative humidity equilibrium, Equation 2 will give a correction factor that is slightly incorrect if a strength measurement of non-standard conditions is applied. In order to minimize this effect, the raw strength is first adjusted using the Figure 8 equation before being applied to Equation 2. Equations 3 and 4 accomplish this task. Combining all equations results in the final correction formula given as Equation 5.

$$CF = (0.099)(ARS) - 1.63 \qquad [2]$$

Where: ARS = Adjusted Raw Strength

$$ARS = (MB)(ICF) + RS \qquad [3]$$

$$ICF = (0.099)(RS) - 1.63 \qquad [4]$$

Where: ICF = Initial Correction Factor

$$CS = (MB)[(0.0098)(MB)(RS) - (0.1614)(MB) + (0.099)(RS) - 1.63] + RS \qquad [5]$$

Ideally, the moisture bias (MB) variable in equation 5 is the difference between the measured moisture content and the moisture content at 65 percent relative humidity equilibrium conditions. Since there is a fairly wide range of equilibrium moisture contents across different cottons, as illustrated by Figure 7, using one equilibrium moisture content for all cotton samples will introduce some error into the moisture bias. However, in practical application of a strength correction in a classing office, the range of equilibrium moisture contents would be narrower since there would not be the variety of cottons that are represented in this study.

Equilibrium moisture content should be referenced back to the moisture of the calibration cottons used to calibrate the HVI. An absolute moisture measurement is not necessary as long as the moisture instrument can accurately indicate the moisture difference between the calibration cotton and the test cotton. This would facilitate multiple instrument setups since the instruments would not have to be calibrated to the same exact moisture level. In part B of the study it was found that the best accuracy given by the strength correction formula was given using an equilibrium moisture content of 7.1 percent. This was slightly below the strong calibration cottons equilibrium moisture content. All EMCs of the test cottons were below the EMC of the strong calibration cotton.

Results and Discussion of Part B

The strength correction equation (equation 5) that was developed in part A was applied to the data obtained in part B. Part B of the study was designed to simulate actual sample moisture conditions experienced in classing office testing. Part B differed from Part A in that the samples were presented for testing while in the process of conditioning.

Results for part B are found in Tables 2 and 3. The average moisture content column in Table 2 gives the overall average of the sample moisture for each testing run. Initial moisture content of the samples prior to the first run was approximately 5 percent. However, once the humidity was raised to 65 percent and testing was immediately initiated, the samples began taking on moisture very rapidly. Evidence of this is given by the first average moisture content of 6.29 percent. The moisture contents for the other runs continued to increase as each test run was made. The second column gives the overall average strength readings without the application of the moisture correction. The average strengths for the first three runs continue to increase. However, there was no detected strength change between the last two runs. The fact that moisture changes were still being detected between the last two runs illustrates that the moisture measurement has greater sensitivity to moisture change than does the strength measurement. The last column gives the average of the strength measurements corrected by equation 5 from part A.

Table 3 shows the reproducibility and bias between each run compared to the last run (run 4). Since the last run was very near ideal moisture equilibrium conditions, this run provided the best reference for comparing the other runs. Reproducibility was calculated by taking the two runs being compared and counting the number of samples that were in agreement between the two runs. A sample's two runs were considered in agreement if they were within 1.5 strength units of each other. The number of samples in agreement divided by the total number of samples gives the reproducibility. The bias is calculated by taking the average of the sample differences between the runs.

The uncorrected results in Table 3 show improving reproducibility and a shrinking bias as the runs being compared become closer together in terms of moisture conditions. The reproducibility result best for comparing all others against is the 86 percent reproducibility found between the uncorrected runs of three and four. Runs three and four provided a near ideal moisture situation where two runs were compared with hardly any detectable change in strength or moisture. In other words, decreased reproducibility due to moisture variability was minimal.

The corrected results in the middle columns gave reproducibilities near or better than the uncorrected reproducibility for the ideal moisture situation. Since the reproducibility between the uncorrected runs of three and four are close to strength and moisture equilibrium, application of the moisture based strength correction to any run should not produce a reproducibility greater than 86 percent. However, for the corrected runs of one and four, the resulting reproducibility is 89 percent (3 percentage points higher than the ideal). The reproducibilities are reduced in Table 3 when all runs are corrected except for run four.

Conclusion

The main implication of this study is that a moisture based strength correction can provide accurate strength results without moisture conditioning. However, there remain some questions that need to be answered regarding the accuracy improvement found by the moisture correction. Results indicate that strength accuracy decreases when the strength correction is applied to properly conditioned samples. This seems logical since a moisture correction at best should only be able to improve accuracy to the accuracy level obtained at proper moisture conditioning. In determining fiber strength, there remains other sources of error that contribute to decreased strength accuracy in which the moisture correction is not designed to reduce. Therefore, some question arises when results show corrected strength accuracy for dry cotton at or above strength accuracy for properly conditioned cotton. More analysis of this data is underway to hopefully improve the current level of understanding of exactly how the strength correction is improving accuracy. Given the potential of a moisture based strength correction, it is important that all aspects be clearly understood.

References

1. Alldredge, R.K. and Knowlton, J.L. 1995. Rapid Conditioning of Cotton Samples in Cotton Division Offices. Proceedings of the 1995 Beltwide Cotton Quality Measurements Conference, pp.1271-1274.

2. ASTM. 1993. D1776-90. Standard Practice for Conditioning Textiles for Testing. American Society for Testing and Materials. Philadelphia.

3. Byler, R.K. and W.S. Anthony, 1994. HVI Strength Correction for Measured Moisture Content: Development. Proceedings of the 1994 Beltwide Cotton Quality Measurements Conference, pp.1493-1495.

4. Earnest, D. 1995. Environmental Control in USDA Classing Laboratories. Proceedings of the 1995 Beltwide Cotton Quality Measurements Conference, pp. 1264-1268.

5. Knowlton, J.L. 1995. Strength Correction Using NIR Instruments. Proceedings of the 1995 Beltwide Cotton Quality Measurements Conference, pp. 1225-1228.

6. Knowlton, J.L., and R.A. Alldredge, 1994. A New Method for Accelerating Cotton Sample Conditioning in Cotton Classing Offices. Proceedings of the 1994 Beltwide Cotton Conferences, pp. 582-584.

7. Knowlton, J.L. and S.L. Grantham Evaluation of NIR Moisture Instruments. Proceedings of the 1995 Beltwide Cotton Quality Measurements Conference. pp. 1223-1225.

8. Lawson, Reba, H.H. Ramey, Jr., and R.S. Krowicki, 1976. Cotton Fiber Tenacity and Elongation in Rapidly

Changing Relative Humidity. Textile Research Journal, Vol. 46, Oct. 1976. pp. 715-719.

9. Taylor, R.A., and L.C. Godbey. 1994. Evaluation of High Speed Methods to Measure Cotton Moisture for HVI Testing. Proceedings of the 1994 Cotton Quality Measurements Conference. pp. 1418-1421.

Table 1. Testing Schedules.

Part A:

RH	Week	Day
50	1	Tuesday
55	1	Friday
60	2	Tuesday
65	2	Friday
70	3	Tuesday

Part B:

Run #	Week	Day	Time
1	4	Monday	8:00 am
2	4	Monday	12:30 pm
3	4	Tuesday	8:00 am
4	4	Wednesday	12:30pm

Table 2. Average moisture contents and strengths for Part B.

		Average Strength (gm/tex)	
Run #	Avg. M.C.	Uncorrected	Corrected
1	6.29%	27.88	28.85
2	6.60%	28.04	28.62
3	6.95%	28.97	29.14
4	7.10%	28.97	28.95

Table 3. Strength reproducibilities and biases for Part B.

Runs	Uncorrected		Corrected		All Corrected Except R4	
Compared	Repro.	Bias	Repro.	Bias	Repro.	Bias
R1 to R4	67%	-1.089	89%	-0.103	86%	+0.116
R2 to R4	74%	-0.929	85%	-0.331	81%	+0.345
R3 to R4	86%	+0.004	83%	+0.189	83%	+0.175

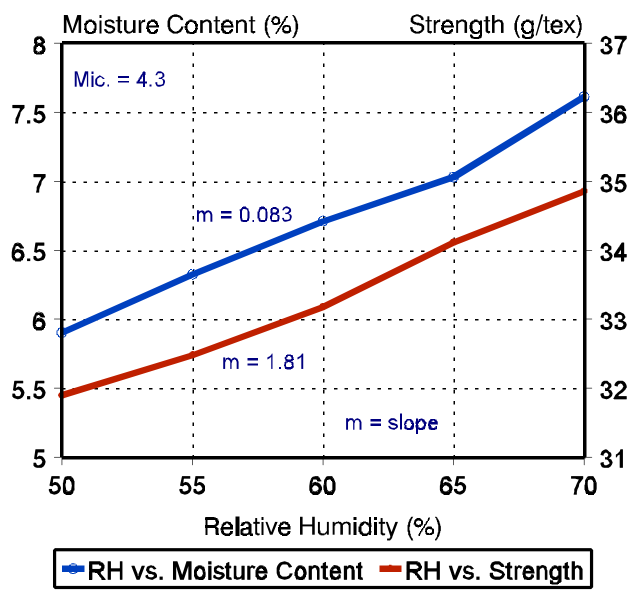

Figure 1. Bale # 521 at Five Equilibrium States.

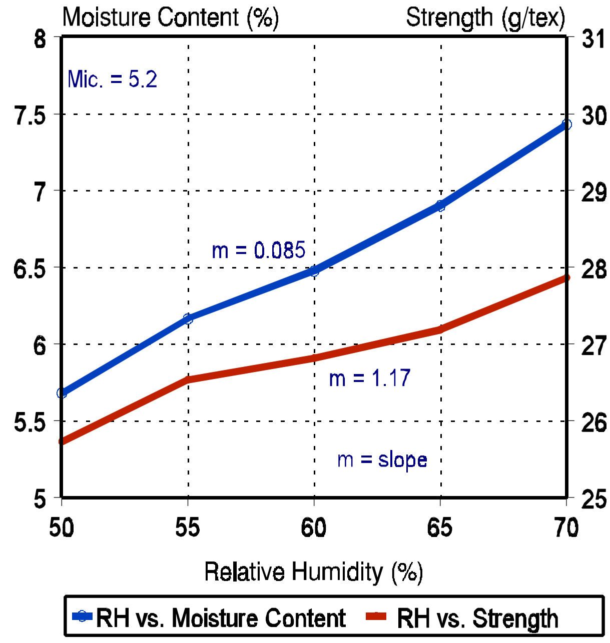

Figure 2. Bale # 007 at Five Equilibrium States.

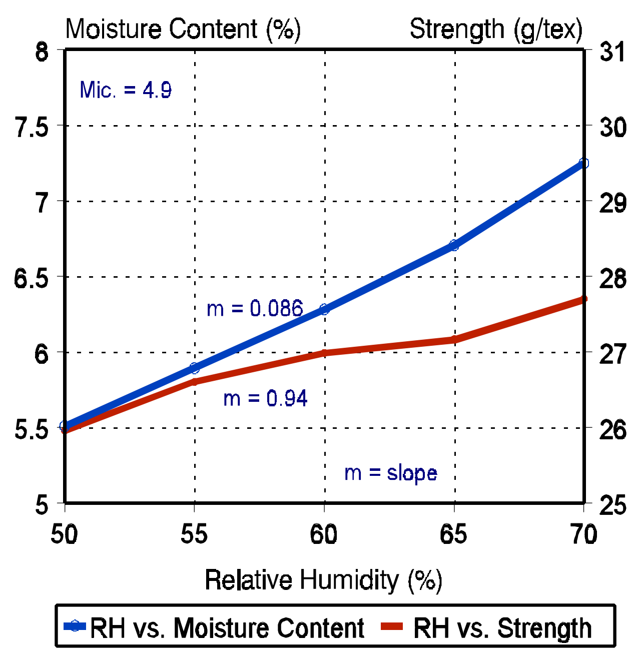

Figure 3. Bale # 134 at Five Equilibrium States.

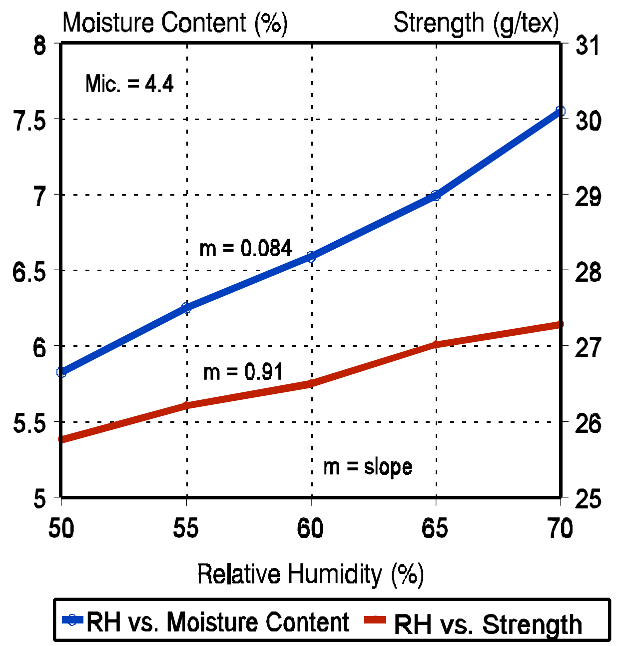

Figure 4. Bale # 064 at Five Equilibrium States.

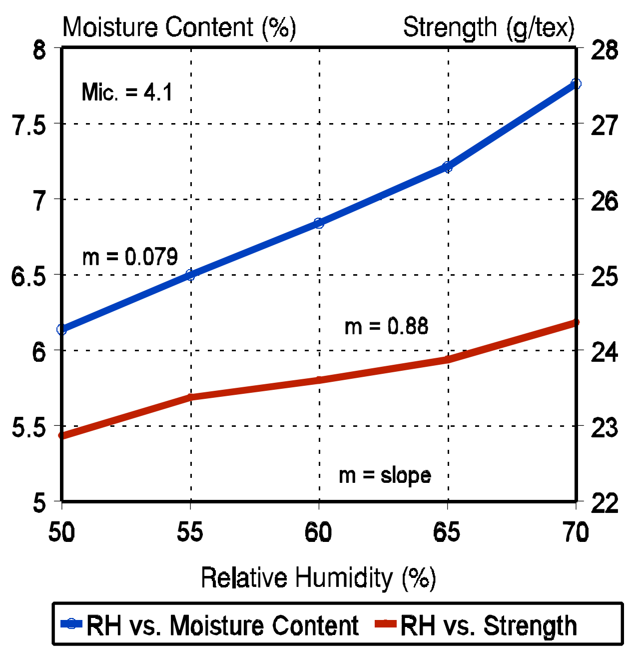

Figure 5. Bale # 392 Cotton at Five Equilibrium States.

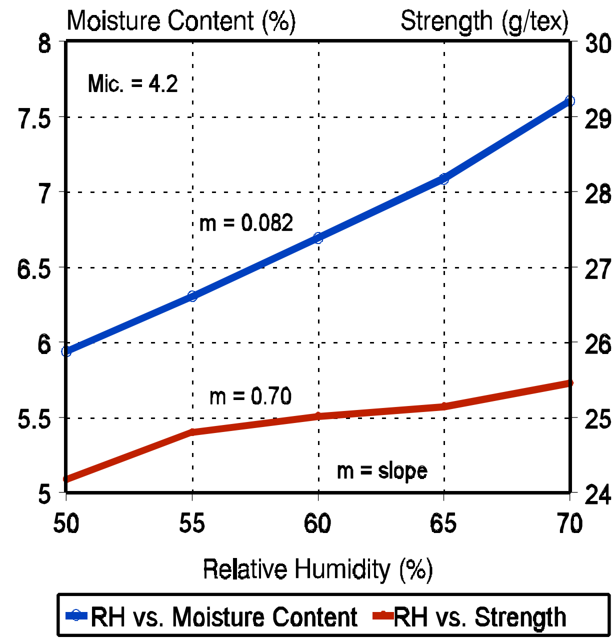

Figure 6. Bale # 083 at Five Equilibrium States.

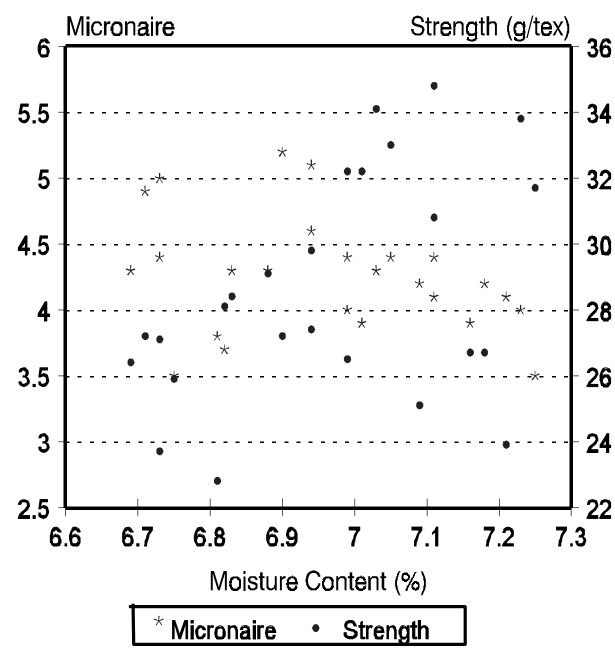

Figure 7. Relationship between strength, micronaire, and moisture content at 65% RH equilibrium.

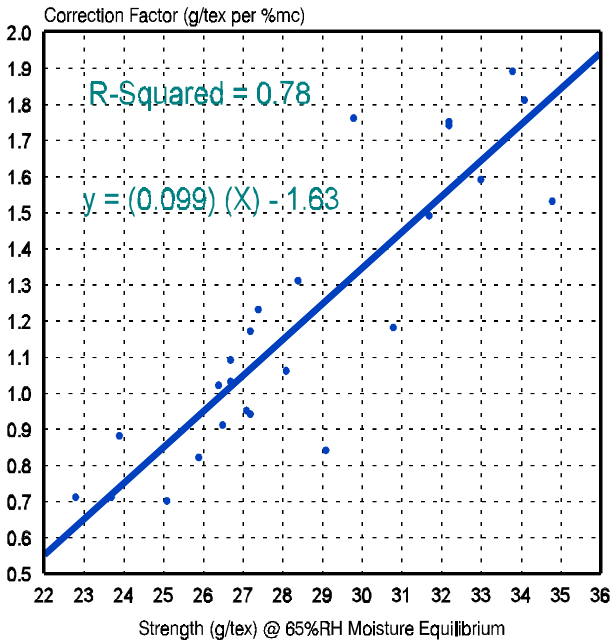

Figure 8. Strength/Moisture-Content Slopes vs. Strength