

TOPICS

International Textile Center

Texas Tech University Lubbock, Texas USA

TEXAS INTERNATIONAL COTTON SCHOOL TO OFFER NEW SESSION

The Texas International Cotton School announced their next session will begin Monday, August 22nd. For almost twenty years, hundreds of students, managers and textile workers from 52 countries have joined top cotton and textile experts for an intensive two-week session of the TICS. The program comprises hands-on instruction of all phases of cotton production, harvesting, ginning, classing, testing, preparation and processing--providing their students with an integrated understanding of the U.S. cotton industry and how it interacts with the global cotton/textile complex.

NEW EQUIPMENT ARRIVES AT INTERNATIONAL TEXTILE CENTER LABS

Through funding from the Higher Education Appropriation Fund (HEAF), the Finishes/Chemical Division of the ITC has acquired a PerkinElmer Pyris 1 Thermogravimetric Analyzer (TGA) with Autosampler. TGA analysis is often used to determine polymer degradation temperatures, residual solvent levels, absorbed moisture content, and the amount of inorganic (noncombustible) filler in polymer or composite material.

TEXAS TECH RESEARCHERS AWARDED PATENT FOR GROUNDBREAKING X-RAY IMAGING SYSTEM

The U.S. Patent office has awarded a patent to two Texas Tech researchers, Dr. Eric Hequet, of the International Textile Center at Texas Tech University and Dr. Hamed Sari-Sarraf of the Electrical and Computer Engineering Department of Texas Tech University. The patent was granted for their new innovative method of analyzing contaminants in cotton.

Because the amount of contaminants (or "trash," as it is commonly called) in a particular bale of cotton has a direct impact on its market value, an accurate measurement of the amount and character of the trash is important. Hequet and Sari-Sarraf (and Tech Masters' student Ajay Pai) developed the first system using X-ray imaging techniques to more completely recognize trash in the cotton sample. This technique could easily prove to be a less invasive and much more accurate way for the cotton industry to grade and price cotton crops.

*Sharing
current research
information
and trends
in the cotton
and textile
industries.*

International
Textile Center
Texas Tech University
Lubbock, Texas
79409 - 5019
phone 806.747. 3790
fax 806.747. 3796
itc@ttu.edu
<http://www.itc.ttu.edu>

OBJECTIVE EVALUATION OF DURABLE PRESS TREATMENTS AND FABRIC SMOOTHNESS RATINGS

Noureddine Abidi and Eric Hequet,
Chris Turner and Hamed Sari-Sarraf

Adapted with permission from an article published in the Textile Research Journal 75(1), 19-29 (2005).

INTRODUCTION

This article discusses the next step in our validation of an imaging system for the automatic grading of fabric smoothness, developed at Texas Tech University, (this research is described in *Textile Topics, Summer 2003*). The system, which consists of a sheet-of-light, laser-line projector; a smart CMOS camera; a moving platform and a PC, was developed to find an inexpensive and objective method of evaluating the smoothness of a fabric after home laundering. This validation study involves two cotton fabrics treated with increasing amounts of a textile-finishing agent to impart durable press properties.

Durable Press (or “smoothness”) is a term used for apparel that requires little or no ironing after home laundering and has wrinkle resistant properties during daily wear. These garments are quite popular with consumers. The USDA reports that durable press fabrics account for the sale of an additional 2.5 million bales of cotton that would have been overlooked and replaced by synthetic fibers [1].

To achieve durable press characteristics, cotton fabric is treated by chemical agents that restrict slippage of cellulose chains. We used N-methylol-based products with very low formaldehyde release as a crosslinking agent. The application method was the pad-dry-cure process, which consists of impregnating the sample in an aqueous solution containing the crosslinking agent and the appropriate catalyst, padding the impregnated fabric to 90-100 % wet pickup, drying and then curing.

MEASURING FABRIC SMOOTHNESS

To properly measure the efficiency of durable press processes, a standard of smoothness had to be established. The American Association of Textile Chemists and Colorists (*AATCC*) determined a standard protocol—graded on a scale ranging from 1 (for very wrinkled) to 5 (for very

smooth)—to evaluate smoothness of fabric, after five cycles of home laundering [2]. In this protocol, compared to standard plastic 3D replicas, a sample will be assigned the grade of the replica it most closely resembles. However, this system proved to be labor intensive and problematic for providing a true objective surface description of fabric.

We developed an instrument using laser triangulation to accurately quantify surface smoothness in a practical and repeatable manner. Other researchers have investigated an automatic wrinkle evaluation system with laser triangulation as well. Xu, *et al.*, [3] used laser profiles acquired from the fabric with a laser line projector and a CCD video camera [3]. Later, Su, *et al.* [4] incorporated a rotating stage and used a neural network classifier in the features they described. Han *et al.* [5] acquired profiles of fabric surface using a slit beam of light projected onto a specimen placed on a translation stage. After extracting such features as the standard deviation of height values, the increasing rate of the surface area and the fractal dimension, the surface is interpolated to fit a profile from an amalgam of 41 different positions.

Some of these approaches use data acquisition techniques similar to our own, but with vital differences. For example, we utilized a structured lighting technique to construct a true 3D representation of the specimen to prevent confusion caused by fabric color and color patterns. In fact, our early attempts did use shallow angle illumination and the facet model. Unfortunately, this method did not perform well on actual fabric samples [6].

Our approach configures the issue of smoothness evaluation as a segmentation problem. Using the algorithm we proposed before (see again, *Textile Topics, Summer 2003*), our technique becomes a topographical analysis to locate the wrinkles, then focuses on the *localized* features of the fabric. With these individual wrinkle measurements, we can obtain a highly detailed quantitative description of the fabric and relate it to the quality measurement of fabric smoothness.

METHOD

Materials, Treatment and Test Method—Two desized, scoured and bleached cotton fabrics (identified as fabrics “C1” and “C2”*) were manufactured at the International Textile Center. Using dimethylureaglyoxal (DMUG)—commercially known as Permafresh ULF-- as the crosslinking agent. A magnesium chloride solution was used to catalyze the crosslinking reaction.

Each fabric specimen, measuring 52×52 cm, was immersed in an aqueous bath treatment containing $x\%$ DMUG, $x/4\%$ catalyst and 1% wet aid (Fergitol). Concentrations are expressed as a percent weight of the bath. The concentration x of the crosslinking agent varied between 1 and 20% on the weight of the bath with one percent increments from 0 to 12%, then 15 and 20%. The impregnated fabric then passed through a two-roller laboratory padder (BTM 6-20-190) at a speed of 4 yards per minute and an air pressure of 2.76

10^5 Pa. The weight pickup was in the range of 90-106 % for C1 and 96-119% for C2. The sample was dried in a Benz dry-cure thermosol oven at 100°C for 190 seconds; then cured in the same oven at 150°C for 90 seconds. Three specimens were treated for each fabric and for each percentage DMUG, with two replications totaling 180 fabric specimens (2 fabric 2 replications 3 specimens 15 treatments). The treated fabrics were stitched to prevent unraveling and washed according to AATCC TM 124 [2], consisting of five subsequent laundering and tumble-dry cycles.

Three trained observers, using AATCC standard replicas, performed the smoothness appearance grading (referred here as durable press rating). All AATCC grading and laser-camera image acquisitions occurred before FTIR measurements and textile performance testing were completed.

Laser-Camera Image Acquisition System for Fabric Smoothness Evaluation

—By combining a smart CMOS camera with a laser-line projector to obtain range images of fabric samples, an excellent depiction of the surface topography of fabric specimens result. With the algorithm described in references [7, 8], we could reliably locate and quantitatively describe various kinds of wrinkles.

* Characteristics of C1: 100 ends, 85 picks, yarn count-16.4 X 14.8 tex (36 X 40 English count), and a weight of 118.7 g.m^{-2} (3.5 oz.yd^{-2}). Characteristics of C2: 40 ends, 56 picks, yarn count-59 X 59 tex (10 X 10 English count), weight of 230.56 g.m^{-2} (6.8 oz.yd^{-2}).

FTIR Measurements— On several occasions, Infrared Spectroscopy has been used to confirm the effectiveness of durable press treatments in other research. Morris, *et al.* used near infrared (NIR) for quantitative determination of polycarboxylic acids in cotton fibers after washing, thus measuring the lasting presence of the durable press treatment. This necessitated grinding the finished fabric in a Wiley Mill [9]. In addition, Wei, *et al.* used infrared spectroscopy as a tool for predicting durable press performance in finished cotton fabric, again grinding the fabric for evaluation [10]. These techniques are destructive, labor intensive and require skilled evaluation, thus rendering them less practical.

In an effort to investigate a more rapid and less destructive technique to determine the amount of crosslinking agent linked to the cellulose on each specimen, we used the Universal Attenuated Total Reflectance-Fourier Transform Infrared (or, **UATR-FTIR**). Measurement was taken after five successive washing and tumble-drying cycles (a total of 27 FTIR spectra were taken for each concentration). UATR-FTIR was used to record the FTIR spectra of control and treated fabrics. The device's ZnSe crystal allows collection of the FTIR spectra directly on the sample without any special preparation. The cotton fabric samples were placed on top of the crystal and pressure was applied to the sample to ensure good contact.

RESULTS AND DISCUSSION

FTIR Integrated Intensity versus %DMUG

—Figure 1 displays representative FTIR spectra of untreated and treated cotton fabric C1. A comparison of the spectra shows the presence of an additional peak around 1710 cm^{-1} for treated fabrics. This band is indicative of the presence of DMUG on the treated fabric. Similar spectra were recorded for treated fabric C2. Note that the FTIR spectra were recorded without any sample preparation.

*The researchers would like to thank
Cotton Incorporated and
the Texas Food and Fibers Commission
for providing financial support for this project.*

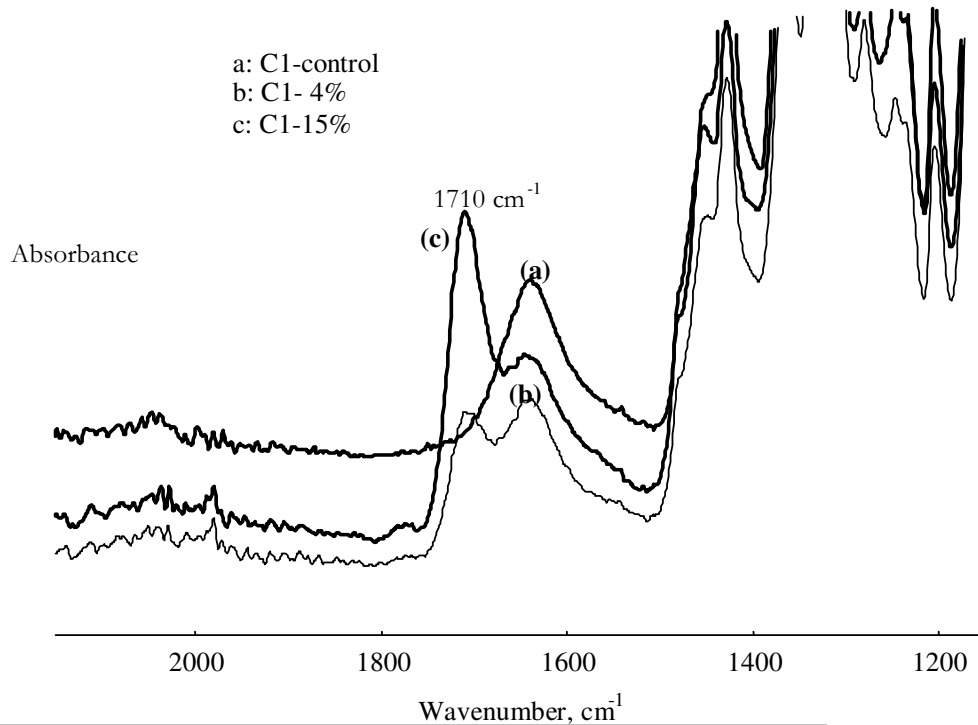


Figure 1. “FTIR spectra of the control and the treated cotton fabric C1.”

Figure 2 shows the plot of the integrated absorption of the vibration 1710 cm⁻¹ (I_{1710}) versus the % DMUG initially in the crosslinking solution. The nonlinear relationships in Figure 2 reveal a high correlation between the concentration of the crosslinking agent DMUG in solution and concentration of the DMUG, effectively establishing a crosslink between cellulose chains (Table I). These results indicate the efficacy of FTIR measurement.

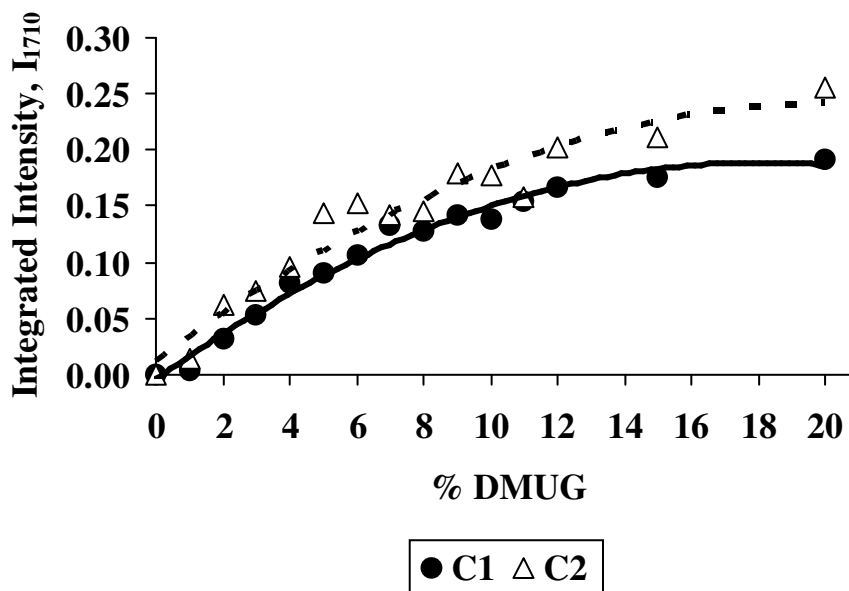


Figure 2. “FTIR integrated intensity I_{1710} versus %DMUG for fabrics C1 and C2”

Table I. Nonlinear regression of FTIR integrated intensity I_{1710} vs. % DMUG for fabrics C1 and C2.

Fabric ID	Prediction Equation	Adjusted R ²
C1	$I_{1710} = 458.2 (\%DMUG)^2 + 0.73$	0.96
C2	$I_{1710} = 294.5 (\%DMUG)^2 + 0.77$	0.95

The decreasing slopes of the curves may be due to the decreasing availability of cellulosic OH groups to crosslink with the OH groups of the DMUG (i.e., saturation phenomenon). Furthermore, the FTIR results show a higher DMUG concentration on fabric C2 than on C1. This is attributed to the light weight of fabric C1 (a characteristic associated with finer yarns) resulting in the lower weight pick-up. On average, weight pick-up was 93.4 % for C1 and 108.1% for C2.

Therefore, the effect of the chemical treatment on both fabric appearance and properties will be correlated with these measurements and not with the percentage of crosslinking agent in the formulation.

AATCC Grades—Figure 3 and Table II show the relationships between the integrated intensity I_{1710} as measured with FTIR and the AATCC grades of the two fabrics. As expected, there is an increase in AATCC grades, i.e., smoother fabrics are a product of increasing DMUG concentrations.

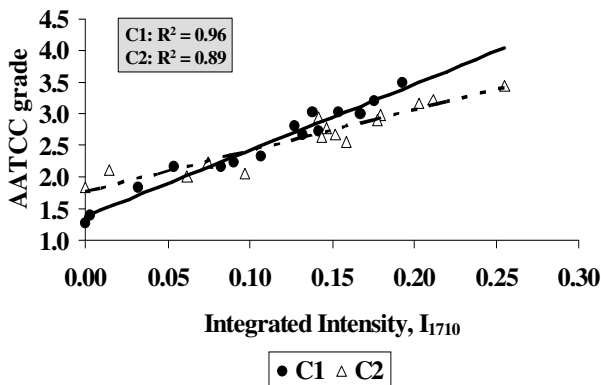


Figure 3. “AATCC grade versus FTIR integrated intensity I_{1710} for fabrics C1 and C2”

Laser-Camera Image Acquisition System for Fabric Smoothness Evaluation—Having acquired profiles at every detected edge point and then calculating the statistical relationships for each profile, we examined the results using either two- or one-dimensional histograms of the two features separately. To illustrate

the potential of this system for smoothness evaluation, we chose to extract five primary attributes from the attributes derived from the histograms borne in our previous research. They are as follows:

1. Average Profile Height (APH)—a simple arithmetic average of the profile heights.

2. Profile Amplitude, Maximum Location (PAML)—the point at which the profile amplitude has the maximum frequency. Larger PAML values imply more wrinkled fabrics.

3. Derivative Amplitude Maximum Location (DAML)—the point at which the derivative of the normalized profile amplitude has the maximum frequency. Higher DAML values imply smoother fabrics.*

4. Derivative Amplitude Fall Off (DAFO)—the “speed” at which the curve falls after the maximum amplitude is reached. First, an exponential distribution is fitted to the observed distribution of the derivative of the normalized profile amplitude, then the fall-off is derived from the fitted distribution. Lower DAFO values imply smoother fabrics. This allows us to discriminate between levels of wrinkling, but it cannot be used for grade 5 fabrics, because the histogram of the derivative of the normalized profile amplitude will be nearly flat.

5. Derivative Amplitude Occlusion Line Sum (DAOLS)—this represents the area under the curve of the occlusion peak, i.e., this feature should be very effective for discriminating very wrinkled fabrics (grades 1 & 2) from smoother fabrics, since fabrics with grades 3 or above should not have many wrinkles that are tall enough to occlude the laser line.

*This concept may not be intuitive and thus needs some explanation. In general, tall wrinkles are wide and the slope between the top and the bottom of a wrinkle is not abrupt (grade 1 fabrics), so the derivative is relatively small. On the other hand, creases, found in grade 3 fabrics have a small amplitude and are narrow. For these wrinkles, the slope between the top and the bottom of the crease is quite abrupt; thus, its derivative is relatively large. This why higher values of DAML correspond to smoother fabrics.

Table II. Prediction equations: APH (average profile height), PAML (profile amplitude maximum location), DAML (derivative amplitude maximum location), DAFO (derivative amplitude fall-off), DAOLS (derivative amplitude occlusion line sum) and CE (cross entropy against the control) versus AATCC grade and FTIR integrated intensity I_{1710} for fabrics C1 and C2.

Fabric ID	Prediction equation	Adjusted R ²
C1	AATCC grade versus FTIR AATCC = 0.0922 x I_{1710} - 0.1231	0.96
C1	Image analysis versus AATCC grade APH = -2.937 x AATCC + 13.629 PAML = 1.102 x AATCC ² - 6.042 x AATCC + 9.196 DAML = -0.912 x AATCC ² + 5.579 x AATCC + 4.766 DAFO = 5.968 + 0.079 x AATCC if DAFO < 7.0 DAFO = 13.337 - 1.483 x AATCC if DAFO > 7.0 DAOLS = 36.667 x AATCC ² - 243.67 x AATCC + 405.33 CE = 508.57 x AATCC ² - 1487.04 x AATCC + 1796.4	0.93 0.94 0.93 0.93 0.93 0.89
C1	Image analysis versus FTIR APH = -31.081 x I_{1710} + 9.628 PAML = 135.24 x I_{1710}^2 - 34.07 x I_{1710} + 3.04 DAML = -110.31 x I_{1710}^2 + 34.01 x I_{1710} + 10.66 DAFO = 5.969 + 1.448 x I_{1710} if DAFO < 7.0 DAFO = 11.368 - 16.144 x I_{1710} if DAFO > 7.0 DAOLS = 4292.6 x I_{1710}^2 - 1548.5 x I_{1710} + 141.9 CE = 53842.0 x I_{1710}^2 + 648.2	0.92 0.91 0.91 0.96 0.92 0.91
C2	AATCC grade versus FTIR AATCC = 0.1382 x I_{1710} - 0.2294	0.89
C2	Image analysis versus AATCC grade APH = -4.573 x AATCC + 19.187 PAML = 0.930 x AATCC ² - 6.201 x AATCC + 11.453 DAML = 2.515 x AATCC + 5.593 DAFO = -2.305 x AATCC + 14.504 DAOLS = 73.83 x AATCC ² - 478.11 x AATCC + 777.07 CE = 314.22 x AATCC ² - 526.36 x AATCC + 659.89	0.85 0.62 0.77 0.86 0.78 0.92
C2	Image analysis versus FTIR APH = -32.116 x I_{1710} + 11.464 PAML = 44.63 x I_{1710}^2 - 21.25 x I_{1710} + 3.62 DAML = 18.248 x I_{1710} + 9.763 DAFO = -16.384 x I_{1710} + 10.636 DAOLS = 2789.2 x I_{1710}^2 - 1379.3 x I_{1710} + 168.3 CE = 30227.7 x I_{1710}^2 + 830.5	0.90 0.86 0.88 0.94 0.97 0.93

Finally, we computed the cross entropy against the control from two-dimensional histograms. **Cross entropy** (or, **CE**) measures how well a distribution approximates another distribution. It is used in reconstructability analysis as a distance measure between reconstructed hypotheses and the original distribution. Thus, it is necessary to minimize the following function: $H_{avg}(p, q)$

$$= \frac{\sum_{x,y} \left[p(x,y) \log \left(\frac{p(x,y)}{q(x,y)} \right) + q(x,y) \log \left(\frac{q(x,y)}{p(x,y)} \right) \right]}{2}$$

Where $q(x,y)$ is the two-dimensional frequency distribution of fabric A and $p(x,y)$ is the two-dimensional frequency distribution of fabric B. When comparing two exactly identical distributions, the CE should be “0.” Higher CE values imply greater differences between the distributions.

In this study, we chose to calculate CE against the control, but one may also calculate CE against the AATCC replicas or any other internal company standard. Thus, industry evaluators could conceivably match an unknown sample to the replica or internal company standard it most closely resembled within these parameters.

After correlating these five parameters to the corresponding AATCC smoothness grades and the FTIR measurements of the fabrics (as seen in Table II), all coefficients of determination are highly significant. Note that there are excellent relationships between fabric strength loss, as measured with both the strip and Elmendorf tests, as measured with both the strip and Elmendorf tests and the features extracted from the range images. For example, for both C1 and C2 fabrics, the correlation between the Elmendorf test (fill direction) and DAOLS is 0.97 (for C1, the Elmendorf fill direction = $0.35 + 0.0061$ DAOLS; for C2, Elmendorf fill direction = $1.84 + 0.0212$ DAOLS). Thus, a lower DAOLS, indicating a smoother fabric, implies a higher resin content and lower fabric strength. Also the effect of the resin treatment is much more drastic on the C2 fabric (read more strength loss, since the slope is 3.5 times higher than on C1). Thus, it is possible to use DAOLS, or one of the other features extracted from the range images of the fabric swatches, to predict strength loss related to the DMUG treatment for a given fabric type.

(Figures 4 through 9 illustrate the relationships derived from the equations of Table II).

Figure 4 illustrates the notion that for both fabric types, there is a linear relationship between the average profile height (APH) and the FTIR measurement. Obviously, high profile amplitude implies more wrinkled fabrics. The wrinkles on fabric C2 averaged about 6.6% taller than those on fabric C1; however, average wrinkle heights with the 20 % resin treatment are nearly identical.

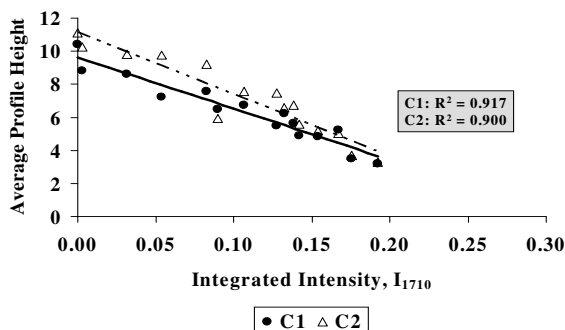


Figure 4. "Average Profile Height (APH) versus FTIR integrated intensity, I_{1710} for fabrics C1 and C2."

In Figure 5, for both fabric types, the profile amplitude maximum location (PAML) relates very well to the FTIR measurement and the AATCC grade. High PAML implies taller wrinkles and lower AATCC grades, i.e., more wrinkled fabrics. For C1 the decrease of PAML is large between the FTIR readings of 0 and 0.09, which corresponds to 4 % resin, and there is no further improvement with higher resin percentages. The behavior of the C2 fabric is quite different; the decrease of PAML is more gradual and the plateau is reached only for high resin percentages (15% or more).

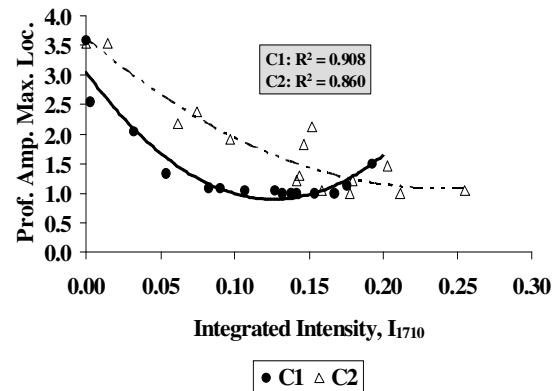


Figure 5. "Profile Amplitude Maximum Location (PAML) versus FTIR integrated intensity, I_{1710} for fabrics C1 and C2."

Figure 6 shows that for both fabric types, the derivative of the profile amplitude maximum location (DAML) relates quite well to the FTIR measurement and the AATCC grades. As we explained earlier, a higher DAML implies a higher AATCC grade (i.e., a smoother fabric). For C1 the increase of DAML is large between 0 and 0.13, which corresponds to 7 % resin, and there is no further improvement with higher resin percentages. The behavior of the C2 fabric is quite different, in that the increase of DAML is linear and the plateau is not reached even for very high resin percentages (15 % or more).

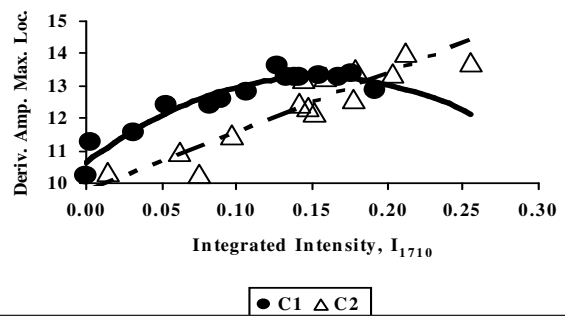


Figure 6. "Derivative Amplitude Maximum Location (DAML) versus FTIR integrated intensity, I_{1710} for fabrics C1 and C2."

Figure 7 shows that for both fabric types, the derivative of the profile amplitude fall-off (DAFO) relates quite well to the FTIR measurement and the AATCC grades. As we explained earlier, a lower DAFO implies a higher AATCC grade (i.e., a smoother fabric).

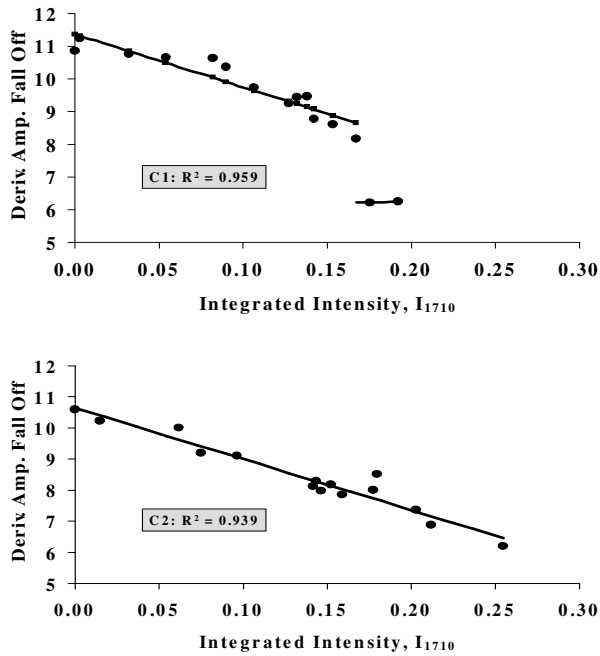


Figure 7. “Derivative Amplitude Fall-Off (DAFO) versus FTIR integrated intensity, I_{1710} for fabrics C1 and C2.”

Note that the intrafabric coefficient of variation (CV%) of DAFO is the lowest of all the fabric smoothness parameters measured. To evaluate the intrafabric CV%, fifty swatches of both untreated fabrics C1 and C2 were cut, washed following the AATCC procedure, then evaluated for fabric smoothness using both AATCC and our system. The CV% values of the AATCC grade of the 50 swatches were 23.6 % and 14.5 % for C1 and C2, respectively, while they were only 6.7 % and 8.9 % for DAFO.

For C1 the decrease in DAFO is linear between 0 and 0.17, which corresponds to 12 % resin followed by a sudden drop for 15 and 20 % resin. For this reason, we decided to use a piecewise linear regression to describe the relationship between DAFO and FTIR as well as DAFO and AATCC grade. The model for such a regression is:

$$y = (b_{01} + b_{11}x_1 + \dots + b_{m1}x_m) (y < b_n) + (b_{02} + b_{12}x_1 + \dots + b_{m2}x_m) (y > b_n)$$

Thus, we estimated two separate linear regression equations: one for the y values that are less than or equal to the breakpoint ($b_n = 7$) and one for the y values that are greater than the breakpoint.

In Figure 8, note that for both fabric types, the surface under the curve of the occlusion peak (DAOLS) relates very well to the FTIR measurement and the AATCC grades. As we explained earlier, a smaller DAOLS means a smoother fabric, since very smooth fabrics (AATCC grade of 4 or 5) will not produce any occlusion of the laser beam. For both C1 and C2, the DAOLS decrease is almost the same. First, there is a steep decrease between 0 and 0.11, which corresponds to 7 % resin, and then the occlusion phenomenon nearly disappears.

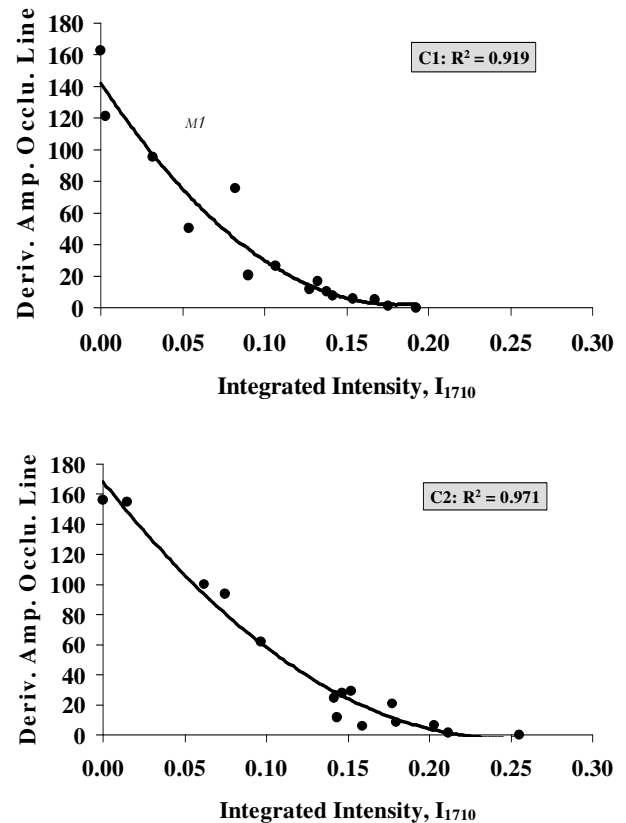


Figure 8. “Derivative Amplitude Occlusion Line Sum (DAOLS) versus FTIR integrated intensity, I_{1710} for fabrics C1 and C2.”

In Figure 9, for both fabric types, the cross entropy against the control increases with higher resin percentages (15 % and above). Cross entropy could be a strong candidate for fabric classification, as an unknown fabric is matched to the AATCC grade or an internal company standard it most closely resembles.

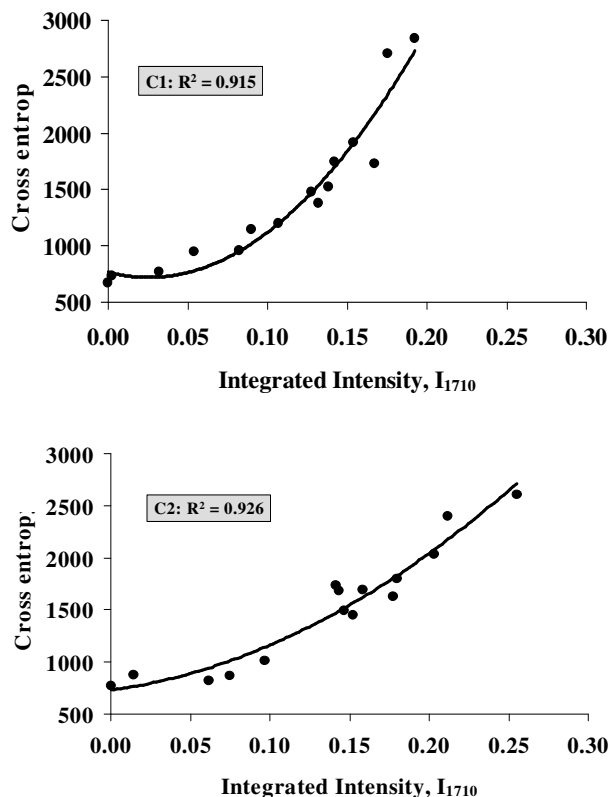


Figure 9. “(Cross Entropy versus the Control) Fall-Off (DAFO) versus FTIR integrated intensity, I_{1710} for fabrics C1 and C2.”

CONCLUSIONS

In order to further develop and validate an imaging system for automatic grading of fabric smoothness, we applied the UTAR-FTIR results on two cotton fabrics treated with increasing amounts of a textile finishing agent to impart durable press properties. Results show the UATR-FTIR to be a fast, non-destructive technique to determine the amount of crosslinking agent linked to the cellulose after the required laundering cycles.

These results suggest that our new wrinkle measurement technology has the potential to discriminate between different levels of fabric treatments and different fabrics. Obviously the features extracted from the histograms could be refined; we are currently working on improving the repeatability of the current features as well as evaluating new features.

Highly significant correlations between the standard AATCC grades, the FTIR measurements, and the features were extracted from the acquired images.

LITERATURE CITED

1. Kaniuka, R. P., "Making Fabrics Friendly" (excerpted from "Milestones in ARS Research," in *Agricultural Research* **32**(4) p. 4-9). March 22, 2005. <http://www.ars.usda.gov/is/timeline/fabric.htm>.
2. AATCC *Technical Manual of the American Association of Textile Chemists and Colorists*. p. 288: 1991.
3. Xu, B., Cuminato, D.F., and Keyes, N.M. "Evaluation of Fabric Smoothness Appearance Using a Laser Profilometer," *Textile Research Journal*. **68** (12), p.900-906 (1998).
4. Su, J. and Xu, B., "Fabric Wrinkle Evaluation Using Laser Triangulation and Neural Network Classifier," *Optic Engineering*. **38**(10), p.1688 (1999).
5. Han, J., Yang, M. and Matsudaira, M., "Objective Evaluation for Wrinkle Appearance of Fabrics by Image Processing and Slit Beam Projecting Technique," *Textile Research Journal*. **49**(1), p. 1-6 (2003).
6. Dai, Y., "Fabric Quality Measurement," Masters Thesis, Texas Tech University, Lubbock, Texas, May 2001.
7. Turner, C., Sari-Sarraf, H., Hequet, E., Abidi, N. and Lee, S., "Preliminary Validation of a Fabric Smoothness Assessment System, in "Proc. Of 6th Quality Control by Artificial Vision," Gatlinburg, TN, May 2003.
8. Turner, C., Sari-Sarraf, H., Zhu, A., Hequet, E. and Lee, S., "Automatic Assessment of Fabric Smoothness, 45th IEEE Midwest Conference on Circ. And Syst., Tulsa, OK, 2002.
9. Morris, N.M., Faight, S., Catlano, E.A., Montalvo, J.G. and Andrews, B.A.K., "Quantitative Determination of Polycarboxylic Acids on Cotton Fabrics by NIR," *AATCC Review*, **26**(11), p. 33-37 (1994).
10. Wei, W. and Yang, C.Q., "Predicting the Performance of Durable Press Finished Cotton Fabric with Infrared Spectroscopy," *Textile Research Journal*. **69**(2), p.145-151 (1999).

Copyright Agreement--

All material included in [this portion of] this .pdf file is the exclusive property of SAGE Publications, or its licensors and is protected by copyright and other intellectual property laws. The download of [this portion of] the file is intended for the User's personal and noncommercial use. Any other use of the download of the work is strictly prohibited. User may not modify, publish, transmit, participate in the transfer or sale of, reproduce, create derivative works (incl. coursepacks) from, distribute, perform, display or in any way exploit any of the content of [this portion of] the file in whole or in part. Permission may be sought for further use from Sage Publications, Ltd., Rights and Permissions Department. By downloading the file, the User acknowledges and agrees to these terms.