2004 BELTWIDE COTTON CONFERENCES, SAN ANTONIO, TX – JANUARY 5-9

OBJECTIVE EVALUATION OF FABRIC SMOOTHNESS

E.F. Hequet and N. Abidi
International Textile Center
Texas Tech University
Lubbock, TX
C. Turner and H. Sari-Sarraf
Dept. of Elec. and Comp. Engineering
Texas Tech University
Lubbock TX

Abstract

In this research, we have validated an imaging system for automatic grading of fabric smoothness that was developed at Texas Tech University. This system consists of a sheet-of-light, laser-line projector; a smart CMOS camera; a moving platform; and a PC. Its purpose is to provide the textile industry with a tool for rapid, objective evaluation of fabrics' smoothness after home laundering. The validation study involved two cotton fabrics that were treated with increasing amounts of a textile-finishing agent to impart durable press properties. The UATR-FTIR was used as a rapid and precise technique to determine the amount of the cross-linking agent linked to the cellulose after the required laundering cycles. To demonstrate the potential of our newly developed imaging system, we have extracted five features from the acquired images and have related them to AATCC grading and to the amount of finish as evaluated by FTIR. The results obtained demonstrate that this new wrinkle measurement technology has the potential of discriminating between different levels of fabric treatments and different fabrics.

Introduction

Durable press - referred to as smoothness - is a term used for apparels that require little or no ironing after home laundering and have wrinkle resistance properties during daily wear. These garments are becoming a prominent consumer item. The protocol for ascertaining a smoothness grade of a fabric is outlined in the American Association of Textile Chemists and Colorists (AATCC) Test Method (TM) 124 (AATCC, 1991). This standard test is designed to evaluate the smoothness of fabric specimens after five cycles of repeated home laundering. Once three specimens per fabric have been through 5 standard washing-drying cycles, three technicians visually evaluate their appearance. For these evaluations, the specimen is laid on a solid surface that stands at an incline of 5 degrees from vertical under specified lighting conditions. The specimen is then compared to six standard replicas, which are 3-D plastic models, showing varying degrees of smoothness and having grades 1 (very wrinkly), 2, 3, 3.5, 4, and 5 (very smooth). The specimen is assigned the grade of the replica it most closely resembles (Figure 1). Beside exhibiting inter- and intra-subject variability and being an expensive process, this system is very inadequate in providing a true surface description of the fabric. Therefore, a system is needed that can accurately quantify surface smoothness in a practical and repeatable manner.

In this work, we have used the Universal Attenuated Total Reflectance-Fourier Transform Infrared (UATR-FTIR) to assess the chemical finishing of cotton and evaluated, on treated and untreated fabric, the proposed imaging system for the automatic grading of fabric smoothness.

Experimental

Materials

Desized, scoured, and bleached 100% cotton fabric was used throughout this study. The fabric is identified as C1. The fabric characteristics were 100 ends, 85 picks, yarn count 16.4x14.8 tex (36 x 40 English count), and its weight was 118.7 g.m^{-2} (3.5 oz.yd^{-2}). The cross-linking agent used was Dimethylureaglyoxal (DMUG), commercially known as Permafresh ULF. It is a glycoxal based textile-finishing resin ($C_5H_{10}N_2O_3$) with Ultra Low Formaldehyde content. A magnesium chloride solution (catalyst 531) was used to catalyze the cross-linking reaction.

Fabric Treatment

The fabric specimen (52 cm x 52 cm) was immersed in an aqueous bath treatment containing x% of DMUG, x/4% of catalyst 531, and 1% of wet aid (Tergitol). All the concentrations are expressed as a percent weight of the bath. The concentration, x, of the cross-link agent was varied between 1% and 20% on the weight of the bath with 1% increment from 0% to 12%, then 15% and 20%. Then, the impregnated fabric was passed through a two-roller laboratory padder at a fabric speed of 4 yards/min and an air pressure of 2.76 x 10^5 Pa. The weight pick-up was in the range of 90% - 106%. Then the sample was dried in a Benz Dry-Cure Thermosol oven at 100°C for 190 seconds. Finally, the fabric was cured in the same oven at 150ºC for 90 seconds. For each % of DMUG, three specimens were treated. Two replications were performed totaling 90 fabric specimens (1 fabric x 2 replications x 3 specimens x 15 treatments).

Standard Test Method for Smoothness Appearance

The treated fabrics were stitched to prevent unraveling and washed according to AATCC test method 124 (AATCC, 1991). This test method consists of 5 subsequent laundering and tumble-drying cycles. Laundering was conducted at a wash temperature of 41±1°C for 10 minutes, with 66±0.1g of AATCC standard detergent without optical brighteners. Tumble-drying was set for durable press conditions (30 minutes). At the end of the washing cycles, the individual samples were placed on perforated screen for conditioning at 65 ± 2%RH and 21 ± 1°C for 24 hours, as directed by ASTM D1776 (Standard Practice for Conditioning and Testing Textiles). Three trained observers, using AATCC standard replicas, performed the smoothness appearance grading (referred also as Durable Press rating). All AATCC grading and laser-camera image acquisitions were performed before the FTIR measurements.

Laser-Camera Image Acquisition System for Fabric Smoothness Evaluation

The image acquisition system (Figure 2-a) consists of a sheet-of-light, laser-line projector; a smart CMOS camera; a moving platform; and a PC. The laser is a 600-700 nm, 5 mW solid-state device with a line generation optic. The laser line is projected at a low angle (around 5 degrees) onto the moving platform where a fabric sample is placed. The camera is positioned directly above the platform so that its line of sight is perpendicular to the plane of motion. As the fabric sample is moved across the laser line, the camera records the location of the line on the sample. Bumps, wrinkles, and creases in the fabric distort the laser line, Figure 2-b. Obviously, tall wrinkles may occlude the laser line (i.e., the beam of light will be stopped by the wrinkle). During each time step, the camera records these distortions by sensing the row location of the center of the laser line in each column. These values are combined to produce a range image of the fabric sample. Using this system, we image a 20.32cm x 20.32cm (8in. x 8in.) section from the center of a 38.1cm x 38.1cm (15in. x 15in.) swatch at approximately 40 µm per gray level range resolution and 400 µm per pixel resolution in the *x*- and *y*-directions.

Thus far, we have examined two aspects of the wrinkle profiles that are found as the perpendicular cross sections of the wrinkle edges, as detected by the algorithm described in (Turner et al., 2002 ; Turner et al., 2003). The first is a profile's maximum amplitude, which is calculated as the difference of the maximum and the minimum gray values of the profile. This is an obvious choice for a feature, as it shows the height differences among the wrinkles. The second feature is a measurement of the shape or transition of the profile. First, to remove any height information, the profile is normalized so that the minimum value is zero and the maximum value is one. Next a derivative, or discrete difference, operator is applied to this normalized profile. Wrinkles with sharp transitions will produce high responses or spikes while smooth wrinkles will produce a relatively 'flat' response. The measurement is then taken as a difference between the maximum and the minimum values of this derivative. Figure 3 shows an example of these two measurements. Figure 3-a shows an adaptively smoothed (Turner et al., 2002 ; Turner et al., 2003) gray-scale range image of a fabric swatch with the detected edge map overlaid. Figure 3-b is a close-up of the area indicated in Figure 3-a showing the location of a profile (black line) with respect to the edge (white line) at one particular edge point. From this profile (Figure 3-c), the maximum amplitude is calculated to be 34 gray levels (rounded to the nearest integer), and the corresponding maximum amplitude of the derivative, shown in Figure 3-e, to be 0.68 (rounded to the nearest hundredth). Figures 3-d and 3-f show the profile amplitude and its derivative for a smoother wrinkle than that shown in Figure 3-c.

After acquiring profiles at every edge point and calculating the two measurements for each profile, the results are examined using histograms. Figures 4-a and 4-b show these histograms for fabrics with AATCC grades of 1 and 3. The examination of these histograms shows a drastic difference between AATCC grade of 1 and AATCC grade of 3 for both features (profile amplitude and derivative of the normalized profile amplitude). The peak located after 100 in Figure 4-b for the AATCC grade of 1 is characteristic of an occlusion phenomenon, which occurs in the presence of large wrinkles.

FTIR Measurements

Perkin-Elmer Spectrum-One spectrometer equipped with a Universal Attenuated Total Reflectance Fourier Transform Infrared (UATR-FTIR) was used to record the FTIR spectra of the control and the treated fabrics. The UATR-FTIR consists of a ZnSe crystal that allows collecting the FTIR spectra directly on sample without any special preparation. The cotton fabric samples were placed on top of the ZnSe crystal. Pressure was applied on the sample to ensure a good contact between the sample and the incident IR beam, preventing loss of the IR incident radiation. The IR spectra were collected at a spectrum resolution of 4 cm^{-1}, 32 scans, over the range of 4000 cm^{-1} - 650 cm^{-1}. The FTIR measurements were performed on each specimen after 5 successive washing and tumble-drying cycles (9 readings per specimen x 3 specimens for each concentration = 27 FTIR spectra for each concentration). The objective is to evaluate the quantity of DMUG effectively cross-linked to the cellulose chains.

Results and Discussion

FTIR Integrated Intensity vs. %DMUG

The comparison between the FTIR spectra of untreated and treated cotton fabric shows the presence of an additional peak around 1710 cm^{-1} for treated fabrics. This band is attributed to –C=O stretching vibrations and is indicative of the presence of the DMUG on the treated fabric. It should be pointed out that the FTIR spectra were recorded without any sample preparation.

The vibration located around 1710 cm^{-1} was integrated from 1750 cm^{-1} to 1670 cm^{-1} to obtain the integrated intensity (I_{1710}) for each DMUG concentration. The non-linear relationships show high degrees of correlation between the concentration of the cross-linking agent DMUG in the solution and the concentration of the DMUG effectively establishing a cross-link between cellulose chains (I_{1710}= 458.2*(%DMUG)^2 + 0.73, Adjusted R^2=0.96). The decreasing slopes of the curves may be due to the unavailability of cellulosic OH groups for cross-linking with the OH groups of the DMUG (saturation phenomenon). The FTIR measurements of the quantity of cross-linking agent were performed after the required 5 laundering and tumble-drying cycles. Therefore, the effect of the chemical treatment on fabric appearance as well as on fabric properties will be correlated with these measurements and not with the percentage of the cross-linking agent in the formulation.

AATCC Grades

The relationship between the integrated intensity I_{1710} as measured with FTIR and the AATCC grades is: AATCC = 0.0922*I_{1710} - 0.1231, Adjusted R^2=0.96. As expected, there is an increase of AATCC grades, i.e., smoother fabrics with increasing DMUG concentrations. The range of AATCC grades obtained on these fabrics is large enough so that they can be evaluated with the laser-camera image acquisition system.

Laser-Camera Image Acquisition System for Fabric Smoothness Evaluation

After acquiring profiles at every detected edge point and calculating the two measurements described above for each profile, the results are examined using either 2-D histograms or 1-D histograms of the 2 features separately. In this work, to illustrate the potential of this system for fabric smoothness evaluation, we chose to extract five primary attributes from the histograms shown in Figures 4-a and 4-b. The first attribute studied is the Average Profile Height (APH), which is a simple arithmetic average of the profile heights.

The second attribute studied is called the Profile Amplitude Maximum Location (PAML), which is the point at which the profile amplitude has the maximum frequency. Larger PAML values imply more wrinkled fabrics.

The third attribute studied is called the Derivative Amplitude Maximum Location (DAML), which is the point at which the derivative of the normalized profile amplitude has the maximum frequency. Higher DAML values imply smoother fabrics. This concept may not be intuitive and, thus, needs some explanation (Figure 3). In general, tall wrinkles are wide and the slope between the top and the bottom of a wrinkle is not abrupt (Grade 1 fabrics); thus, the derivative is relatively small. On the other hand, creases, as found in grade 3 fabrics, have small amplitude and are narrow. For this type of wrinkles the slope between the top and the bottom of the crease is quite abrupt; thus, its derivative is relatively large. This is the reason why higher values of DAML correspond to smoother fabrics.

The fourth attribute is the Derivative Amplitude Fall-Off (DAFO), which is 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 feature allows us to discriminate between levels of wrinkling but cannot be used for grade 5 fabrics, as the histogram of the derivative of the normalized profile amplitude will be nearly flat.

The fifth attribute is the Derivative Amplitude Occlusion Line Sum (DAOLS), which represents the area under the curve of the occlusion peak (peak situated after 100 on Figure 4-b). This feature should be very effective to discriminate very wrinkly fabrics (grades 1 and 2) from smoother fabrics, as fabrics having grades 3 or above should not have many wrinkles that are tall enough to cause occlusion of the laser line.

In addition, the cross entropy against the control was computed from the 2D histograms. Cross entropy (CE) measures how good a distribution approximates another distribution. It is used in reconstructability analysis as a distance measure between reconstructed hypotheses compared to the original distribution. Thus, it is necessary to minimize the following function:

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

With q(x,y) is the 2-D frequency distribution of fabric A and p(x,y) is the 2-D 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. CE calculation is simple and easy to use. In this study, we choose to calculate CE against the control, but we could also calculate CE against the AATCC replicas or any other internal company standard. The objective is to match an unknown sample to the replica or the internal company standard it most closely resembles.

These five parameters were correlated to the corresponding standard AATCC smoothness grades and the FTIR measurements of the fabrics (Table 1). All coefficients of determination are very highly significant. It should be pointed out that there are excellent relationships between fabric strength loss, as measured with both the strip and the Elmendorf test, and the features extracted from the range images. For example, the correlation between the Elmendorf test (fill direction) and DAOLS is 0.97 (Elmendorf Fill direction = 0.35 + 0.0061 DAOLS). Thus, lower DAOLS, indicating a smoother fabric, implies higher resin content and lower fabric strength. 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.

Table 1 shows 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. Table 3 shows that 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 0 and 0.09, which corresponds to 4% resin, and then there is no further improvement with higher resin percentages. Table 1 shows that the Derivative of the profile Amplitude Maximum Location (DAML) relates quite well to the FTIR measurement and the AATCC grades. As explained above, 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 then there is no further improvement with higher resin percentages. Table 1 shows that the Derivative of the profile Amplitude Fall-Off (DAFO) relates quite well to the FTIR measurement and the AATCC grades. As explained above, a lower DAFO implies a higher AATCC grade (i.e., a smoother fabric). It should be pointed out that the intra-fabric coefficient of variation (CV%) of DAFO is the lowest of all the fabric smoothness parameters measured. To evaluate the intra-fabric CV%, fifty swatches of untreated fabric C1 were cut, then washed following the AATCC procedure. The washed fabrics were evaluated for fabric smoothness using both AATCC and our system. The CV% of the AATCC grade among the 50 swatches was 23.6%, while it was only 6.7% for DAFO. For C1 the decrease of DAFO is linear between 0 and 0.17, which corresponds to 12% resin, and then there is a sudden drop for 15% and 20% resin. For this reason we decided to apply 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 as follows:

$$y = (b_{01} + b_{11} * x_1 + ... + b_{m1} * x_m)*(y = b_n) + (b_{02} + b_{12} * x_1 + ... + b_{m2} * x_m)*(y > b_n)$$

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.

Table 1 shows that the surface under the curve of the occlusion peak (DAOLS) relates very well to the FTIR measurement and the AATCC grades. As explained above, smaller DAOLS means smoother fabrics, as very smooth fabrics (AATCC grade of 4 or 5) will not produce any occlusion of the laser beam. DAOLS shows first a steep decrease between 0 and 0.11, which corresponds to 7% resin, and then the occlusion phenomenon nearly disappears.

Table 1 shows that for both fabric types the cross-entropy against the control increases with higher resin percentages and does not reach a plateau even for high resin percentages (15% and above). Cross-entropy could be a strong candidate for fabric classification, whereby an unknown fabric is matched to the AATCC grade or an internal company standard it most closely resembles.

These preliminary results demonstrate that this new wrinkle measurement technology has the potential of discriminating 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.

Conclusions

An imaging system for automatic grading of fabric smoothness was developed and validated. The validation study involved 100% cotton fabric that was treated with increasing amounts of a textile-finishing agent to impart durable press properties. The UATR-FTIR was proven to be a fast technique to determine the amount of the cross-linking agent linked to the cellulose after the required laundering cycles. The potential use of our newly developed imaging system was shown by highly significant correlations between the standard AATCC grades, the FTIR measurements, and the extracted features from the acquired images.

Acknowledgement

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

References

AATCC Technical Manual of the American Association of Textile Chemists and Colorists 1991, p 288.

Turner, C., Sari-Sarraf, H., Zhu, A., Hequet, E., and Lee, S., Automatic Assessment of Fabric Smoothness, *45th IEEE Midwest Conf. on Circ. and Syst.*, Tulsa, OK, 2002.

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.

Table 1. Prediction equations: APH, PAML, DAML, DAFO, DAOLS and CE *vs.* AATCC grade and FTIR.

Fabric ID	Prediction Equation	Adjusted R^2
C1	*Image analysis vs. AATCC grade*	
	APH = -2.937*AATCC + 13.629	0.93
	PAML = $1.102*AATCC^2$ - 6.042*AATCC + 9.196	0.94
	DAML = $-0.912*AATCC^2$ + 5.579*AATCC + 4.766	0.93
	DAFO = 5.968 + 0.079*AATCC if DAFO = 7.0 DAFO = 13.337 – 1.483*AATCC if DAFO > 7.0	0.93
	DAOLS = $36.667*AATCC^2$ - 243.67*AATCC + 405.53	0.93
	CE = $508.57*AATCC^2$ - 1487.04*AATCC + 1796.4	0.89
C1	*Image analysis vs. FTIR*	
	APH = $-31.081* I_{1710} + 9.628$	0.92
	PAML = $135.24* I_{1710}^2 – 34.07* I_{1710} +3.04$	0.91
	DAML = $-110.31*I_{1710}^2 + 34.01* I_{1710} +10.66$	0.91
	DAFO = $5.969 + 1.448*I_{1710}$ if DAFO = 7.0 DAFO = $11.368 – 16.144*I_{1710}$ if DAFO > 7.0	0.96
	DAOLS = $4292.6*I_{1710}^2 – 1548.5* I_{1710} +141.9$	0.92
	CE = $53842.0*I_{1710}^2 + 648.2$	0.91

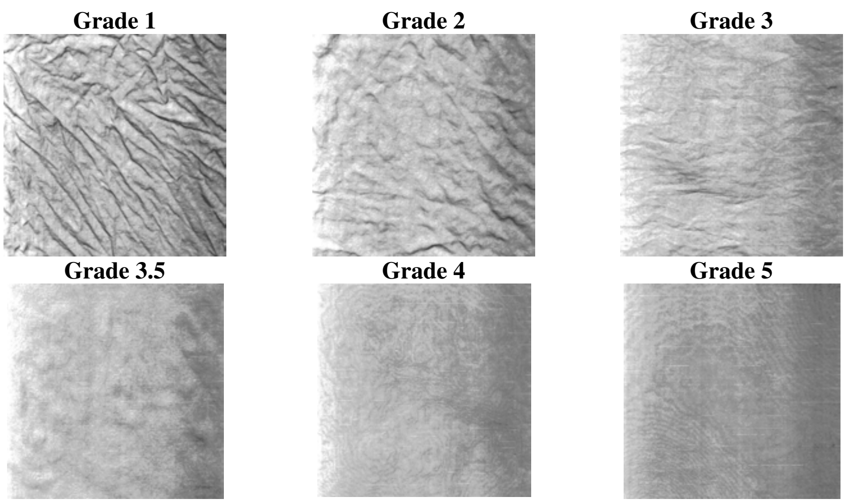

Figure 1. Images of the six AATCC replicas with their respective grades.

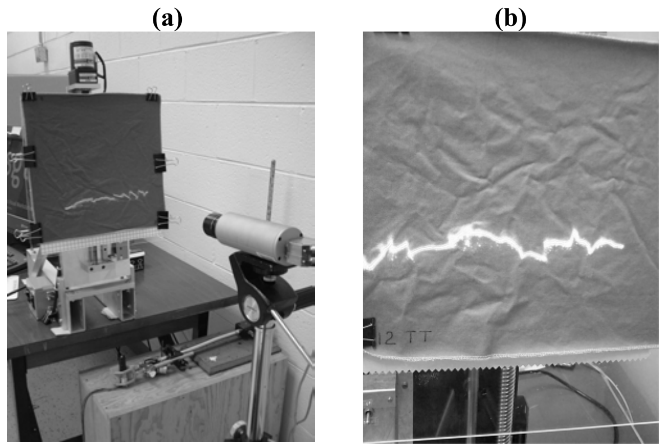

Figure 2. (a) Overall view of the laser-camera image acquisition system. (b) Laser line being projected onto a sample fabric.

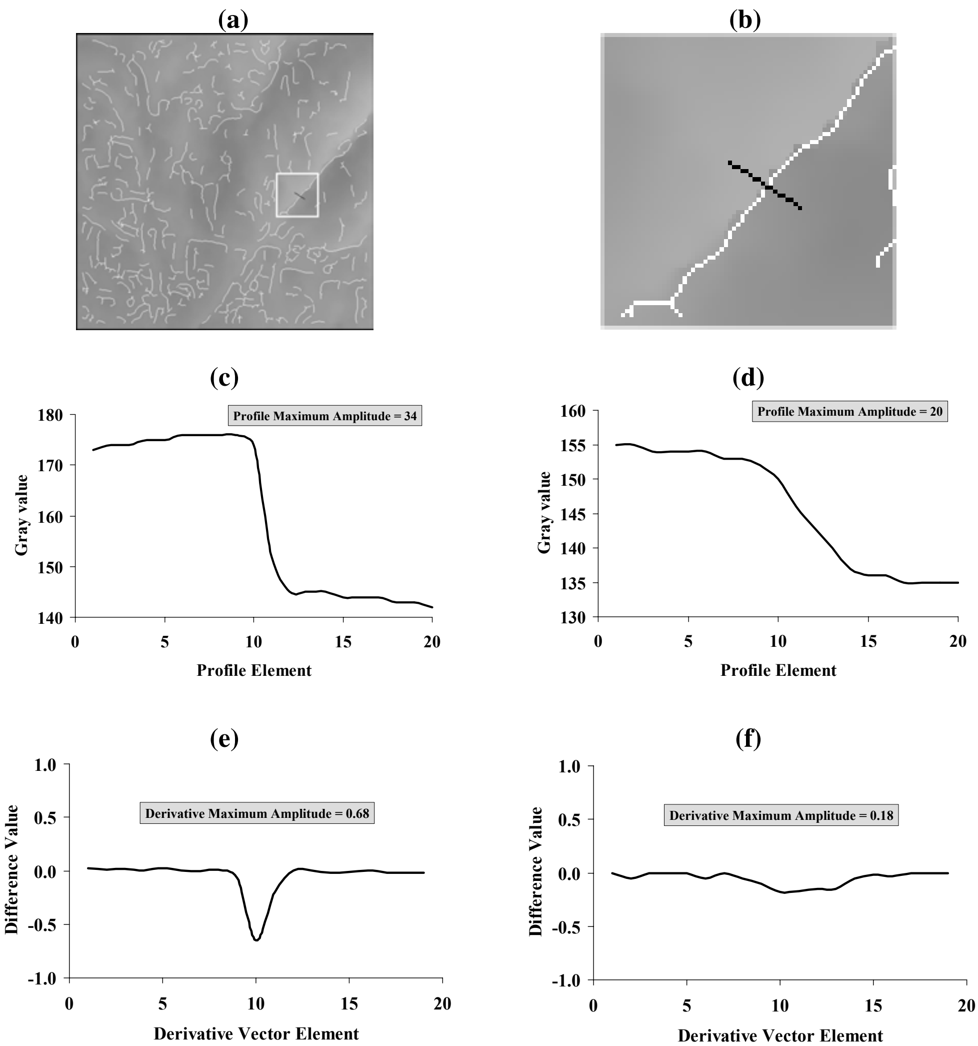

Figure 3. (a) Adaptively smoothed grayscale range image with edge map overlaid. (b) Close-up of area indicated in (a) showing the location of a profile (black line) with respect to the edge (white line) at one particular edge point. (c) Plot of a profile from a tall wrinkle with an abrupt transition. (d) Plot of a profile from an average wrinkle with a smooth transition. (e) Plot of the derivative of the *normalized* profile in (c). (f) Plot of the derivative of the *normalized* profile in (d).

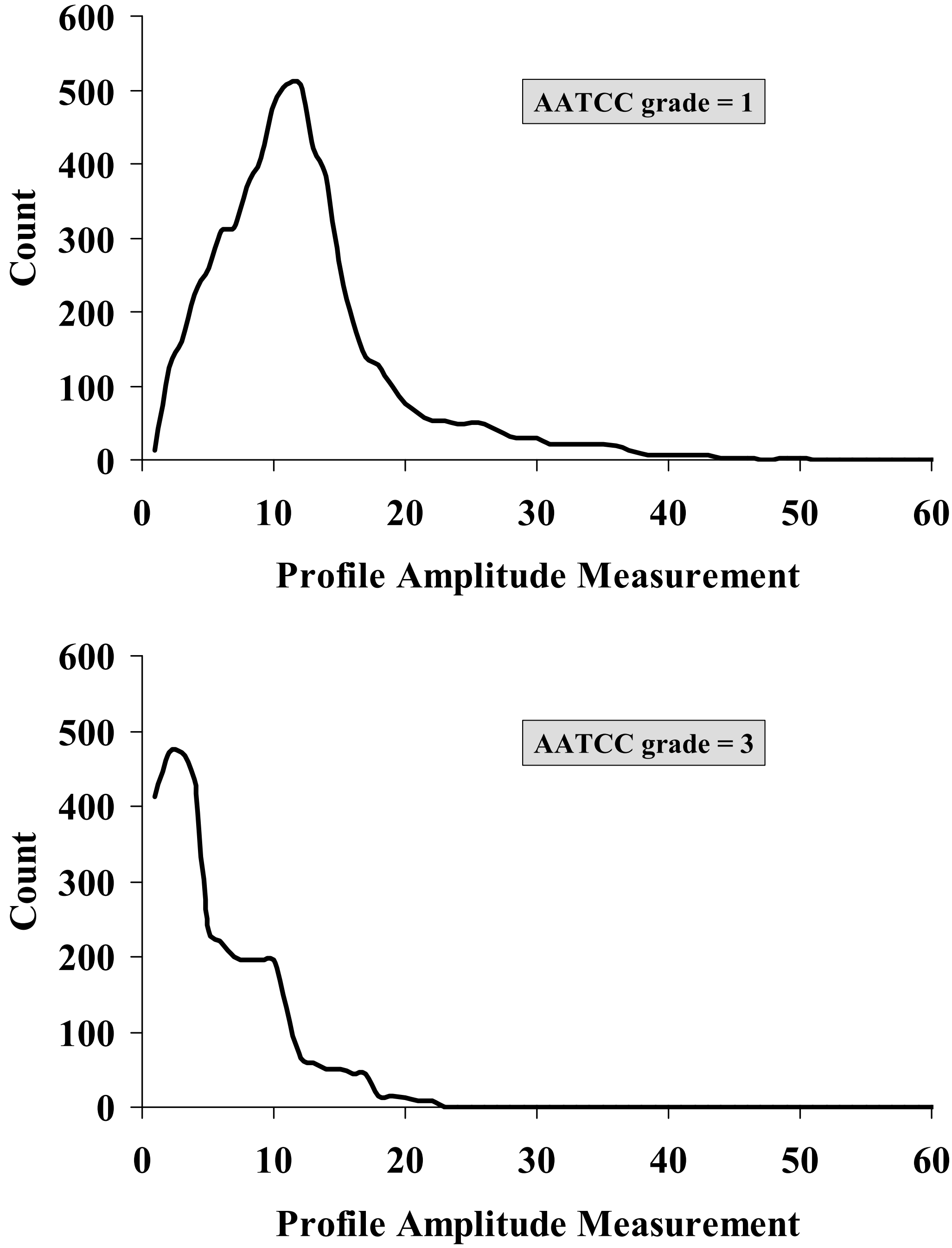

Figure 4-a. Histograms of the profile amplitude measurement.

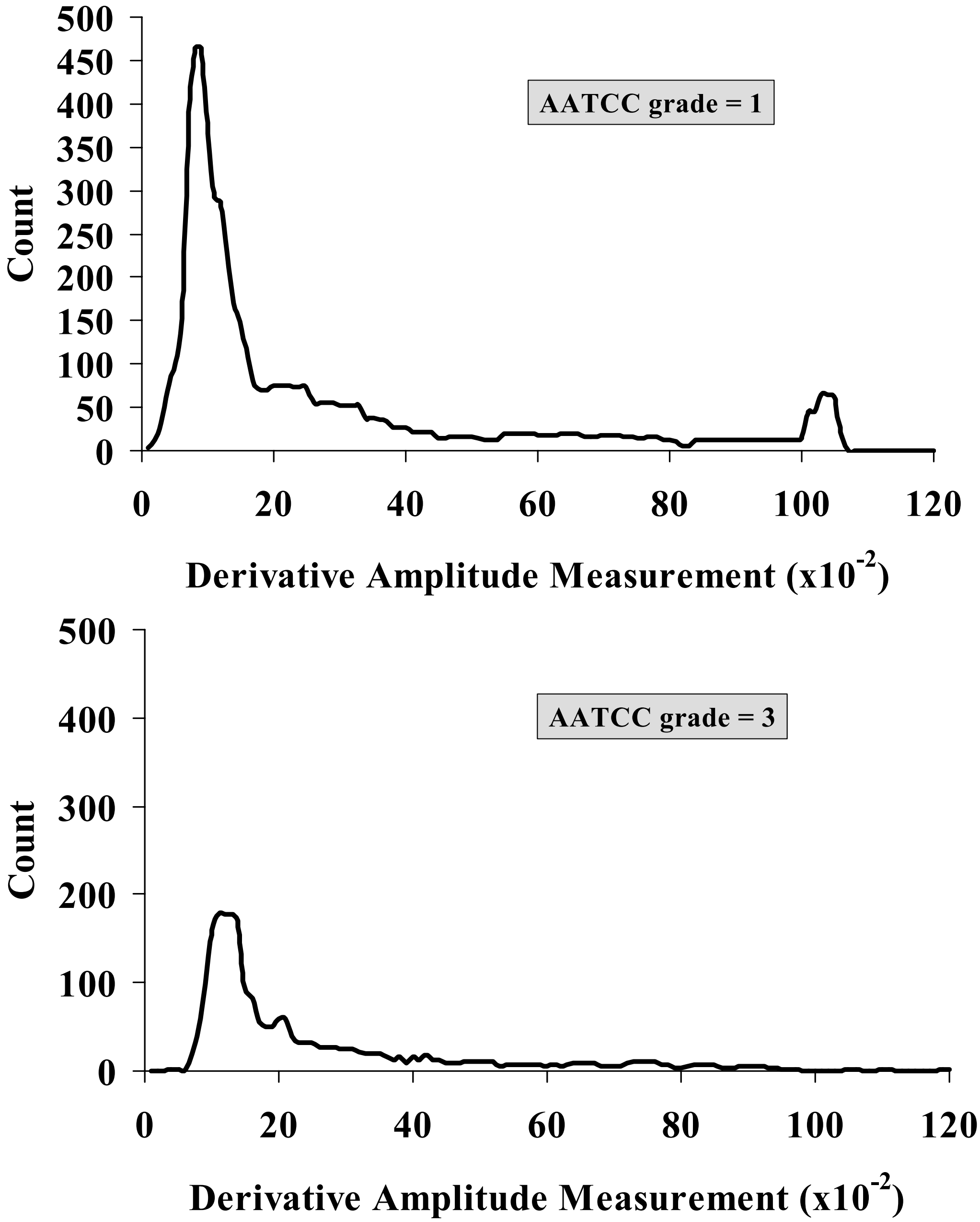

Figure 4-b. Histograms of the derivative of the normalized profile amplitude measurement.