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New Method of Fabric Wrinkle Measurement Based on Image Processing

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Abstract
In this paper, a system of fabric wrinkle measurement was developed which consisted of a fabric wrinkle simulator, scanner and computer. The simulator generated "diamond" wrinkles just like those of the elbow and knee in actual wear. The images of wrinkled fabrics acquired by the scanner were processed with software developed in MATLAB and new characteristics of wrinkle severity (WS) and fabric unevenness (FU) in the warp and weft direction were proposed for the wrinkle characterisation. 15 different fabrics were used to compare the measurement results of the system with those of the AATCC 66-2008 test method. The results showed good agreement of the two methods and at a 45° wrinkle recovery angle, the correlation between the wrinkle recovery angle and WS or FU increased. Therefore it was advised that the wrinkle recovery angle of 45° be measured rather than averaging warp and weft wrinkle recovery angles only when using the AATCC 66-2008 test method. Compared with the AATCC 66-2008 test method, that in this paper can produce more "realistic" wrinkles and measure the wrinkling properties of fabrics in actual wear.

Key words: *fabric wrinkle, actual wear, measuring method, image processing.*

Introduction

Fabric wrinkle, which is caused by crumpling, folding or compressing in the wearing, washing and drying process, is a vital performance characteristic as it influences and decides the visual esthetics of a garment, as well as the appearance quality of textiles. Therefore it is of vital importance to measure and evaluate wrinkling accurately and objectively. AATCC (American Association of Textile Chemists and Colourists) methods are most commonly used in measuring fabric wrinkle performance, which include the AATCC 66-2008 wrinkle recovery angle method and AATCC 128-2004 wrinkle grade subjective evaluation method. In the former method, wrinkles are caused by folding and compressing the fabric, while in the latter, wrinkles are caused by rotating and compressing the fabric. As for the evaluation methods, the wrinkle recovery angle from folding deformations and wrinkle grades from experts by comparing the wrinkled fabrics with standard replicas are used to characterise the wrinkle performance of fabrics, respectively.

As a subjective evaluation method, it is tedious, time-consuming and there are such disadvantages as difficulty in distinguishing between the adjacent grades and constant disagreement concerning the results between trained experts with regard to the AATCC Test Method 128-2004. As a result of this, in the latest two decades, many efforts have been devoted to the measurement of a fabrics ability to resist and recover from wrinkling, especially how to evaluate objectively the grades of wrinkles generated by the AATCC Test Method 128-2004.

In 1995-1999, Xu and Reed defined the surface ratio and shade ratio to characterise wrinkled appearance using computer image analysis techniques based on the analysis of AATCC wrinkle recovery replicas [1]. Na and Pourdeyhimi analysed the degrees of fabric wrinkling of AATCC replicate standards with grey level and surface statistics, co-occurrence analysis, and the power spectral density of image profiles to analyse grades of fabric wrinkle [2]. Kang proposed a new objective method of measuring fabric wrinkles using the 3-D projecting grid technique, and quantified the degree of wrinkling with the roughness ratio, surface area ratio, wrinkle density, and power spectrum density of the fast Fourier transform [3]. Su and Xu suggested a laser line triangulation method to measure the 3D surface data of a wrinkled fabric, and built a neural network to execute wrinkle classification with respect to the visual standard [4]. Kim devised a device for wrinkle recovery measurements involving the installation of a laser sensor and used artificial neural networks for the objective evaluation of wrinkle recovery [5].

In 2000-2003, Kang and Lee used fractal geometry to objectively evaluate the surface ruggedness of fabric wrinkles and seam puckers [6]. Hu and Xin proposed a new method for measuring fabric wrinkling based on integrating photometric stereo and image analysis techniques [7]. Mori and Komiyama used the grey level co-occurrence matrix, fractal analysis and neural networks for visual evaluations of wrinkled fabrics [8]. Yang and Huang proposed a method for fabric 3D surface reconstruction using photometric stereo technology [9].

In 2005, Mohri et al introduced a new quantitative analysis method for fabric wrinkle and developed an image analysis technique using the radon transform and texture analysis to evaluate it [10]. Abidi et al validated an imaging system for the automatic grading of fabric smoothness consisting of laser-line projector [11]. Kang et al proposed a wavelet-fractal method to calculate the fractal dimension for objectively evaluating the surface roughness of fabric wrinkle, smoothness appearance and seam pucker [12].

In recent years, more technology and instrumental equipment have been adopted to develop new methods for more objective and reliable measurement of fabric

Table 1. *Specification of fabrics used.*

Sample	Colour	Weave	Material	Yarn structure
1	white	plain	cotton	staple
2	green	plain	polyester	filament
3	pink	plain	wool	staple
4	grey	satin	polyester	filament
5	yellow	plain	linen	staple
6	black	satin	polyester	filament
7	brown	twill	cotton	staple
8	black	twill	cotton	staple
9	purple	twill	viscose	staple
10	red	plain	cotton	staple
11	cream	twill	polyester	filament
12	light green	plain	polyester	filament
13	light blue	plain	linen	staple
14	ivory	satin	polyester	filament
15	coral	satin	cotton / spandex	staple

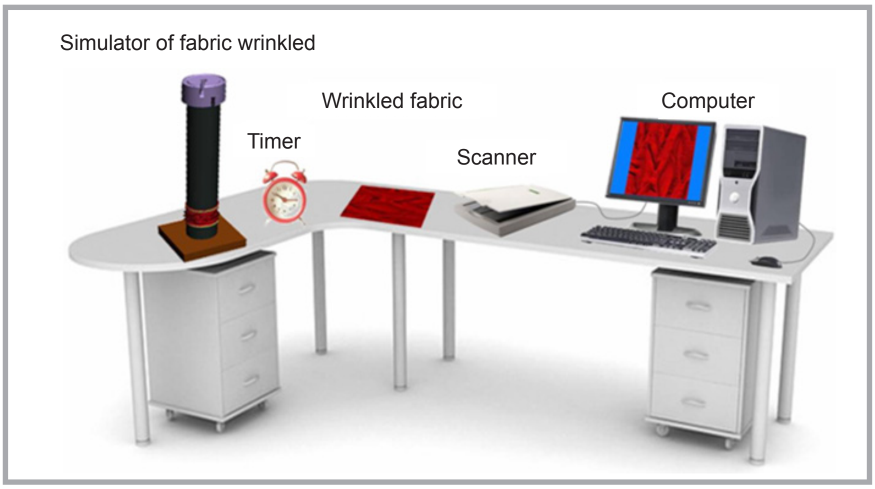

Figure 1. Measuring system of fabric wrinkles.

wrinkling appearance. Zaouali and Msahli proposed a new objective evaluation of multidirectional realistic fabric wrinkling generated by the French method of "cylindre creux" using image processing [13]. Abril et al considered two images of the sample obtained under orthogonal lateral illumination and applied a joint Canny edge detector to integrate information about the wrinkles of both images [14]. Hesarian studied the wrinkle property of fabrics using the projected profile light line technique [15].

All these objective methods use digital image-processing technology based on the AATCC wrinkle recovery test. However, the wrinkles induced in AATCC methods have obvious differences from those in actual wear. In this paper, we proposed a new measurement of fabric wrinkle simulating actual wear using image processing technology.

Experimental

Experimental materials

In order to analyse and compare the measurement results, 15 different fabrics in various colors, weaves, and materials were used, as shown in ***Table 1***. The fabrics used, made from different fibres or a combination of fibres including cotton, polyester, viscose and wool fabrics of solid colour, have different wrinkle appearances.

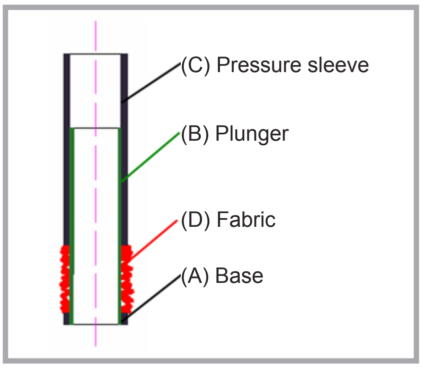

***Figure 2**. Structure of wrinkle simulator.*

Method

The measuring system of fabric wrinkles, shown in ***Figure 1***, consisted of a fabric wrinkle simulator, an Epson scanner with high space resolution for the acquirement of images, and a computer for image processing. The scanner used has a large enough space in the surrounding area without pressure on the wrinkled sample placed on the scanner.

Simulator of fabric wrinkle

To create fabric wrinkles, a mechanical wrinkle simulator was developed on the same lines as that of the AATCC system. The mechanical design of the simulator is shown in ***Figure 2***. The simulator consisted of a base (A), plunger (B) and pressure sleeve (C) for loading the fabric (D) assembled together to introduce wrinkles in the fabric. The heights of the plunger and pressure sleeve are more than 30 cm and their circumferences are about 13 cm. The external radius of the plunger is slightly smaller than the inner radius of the pressure sleeve so that the pressure sleeve would not drop by self-gravity when raised from the plunger.

Standard condition

Temperature: 21 ± 1 °C
Relative humidity: 65 ± 2%
Duration of conditioning: 8 h

Test specimen dimensions

A test specimen of the size 28 × 15 cm was taken from the fabric in both the warp and weft directions, respectively.

Wrinkling process

Raise the pressure sleeve to a distance of 25 cm from the base. Then wrap and fix one long edge (28 cm) of the specimen around the lower edge of the pressure sleeve with the face side of the specimen on the outside. After that, wrap and fix the other long edge around the upper edge of the base. Finally put weights of 3500 grams on the pressure sleeve. The wrinkling process of the fabric is shown in ***Figure 3***. After 20 min, remove the weights and fabric from the wrinkle simulator as gently as possible so as not to distort the winkles. Place the shorter edge (15 cm) under the clips on the clothes hanger and let the specimen hang vertically in the long direction. After 24 h in standard atmosphere, remove the fabric from the hanger gently.

Comparison of wrinkles in actual wear and those generated by the wrinkle simulator is shown in ***Figure 4***. Since the joints of the elbow and knee move frequently in everyday life, the fabrics near them wrinkle most seriously during wear. ***Figures 4.a*** and ***4.b*** were selected and taken from common clothes, and represent the most ordinary and typical wrinkles occurring in wearing. ***Figures 4.d*** and ***4.f*** present wrinkles from in ***Figures 4.a*** and ***4.b*** in a state as the clothes were taken off and spread, respectively. As can be observed from ***Figure 4***, wrinkles generated by the simulator resemble those at the elbow and knee very much. From ***Figures 4.a - 4.c***, we can see that "diamond" wrinkles induced by the simulator looked just like how they were at the elbow and knee during actual wear. ***Figures 4.d - 4.g*** showed that when the fabric was removed from the simulator and spread, the wrinkles in the fabric were also analogous to those at the elbow and knee if the sleeve and trousers were

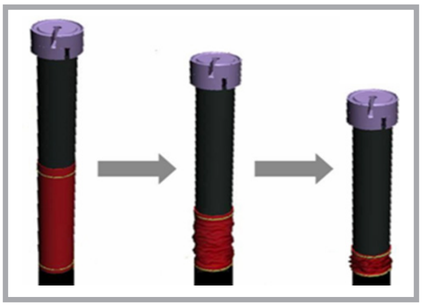

***Figure 3.** The wrinkling process of fabric.*

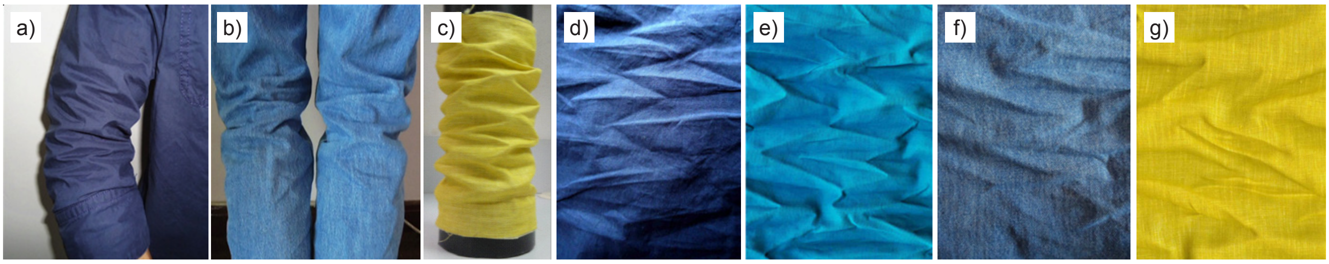

Figure 4. *Comparison of wrinkles in actual wear and those generated by wrinkle simulator; a) wrinkles at the elbow, b) wrinkles at the knee, c) wrinkles in the simulator, d) elbow wrinkles when the coat is spread, e) wrinkles of fabric 3 when it is spread, f) knee wrinkles when the trousers are spread, g) wrinkles of fabric 5 when it is spread.*

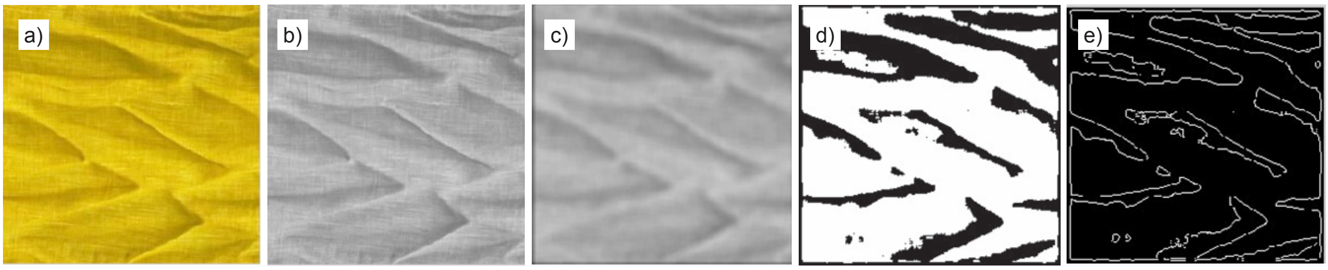

Figure 5. *Image process of wrinkled fabric; a) coloured image, b) grey level image, c) median filtered image, d) binary image, e) edge detected image.*

spread. Simply put, the simulator produced very "realistic" wrinkles.

Image capture

After the fabric was wrinkled with the simulator, the scanner was used to acquire an image of the wrinkled fabric, as shown in ***Figure 1***. We set the area of fabric captured to 100 × 100 mm with a resolution of 300 pixels per inch [13].

Image analysis

After that, the images of wrinkled fabrics were processed with the software developed in MATLAB, as shown in ***Figure 5***. The color image scanned was first converted into a grey-level image. To eliminate disturbance of the fabric texture, the grey-level image was median filtered, which was then converted to a binary image (the area of black and white was caused by the different directions of illumination). The binary image of the wrinkle was finally edge detected (the white lines were the wrinkle edges).

Wrinkle characterisation

Wrinkle severity (WS)

Wrinkle severity was represented by the percentage of white pixels to the total number of pixels in the edge detected image, which was calculated in accordance with ***Equation 1***.

$$WS = \frac{sw}{n} \times 100\% \qquad (1)$$

where, WS was the wrinkle severity, sw the number of white pixels, and n the total number of pixels.

Fabric unevenness (FU)

Based on the principle of the variation in the grey level resulting in different degrees of wrinkling, fabric unevenness can be represented by the standard deviation of grey level intensity of all the pixels, which was calculated in accordance with ***Equation 2***.

$$FU = \sqrt{\frac{\sum_{i=1}^{n}(G_i - \overline{G_i})^2}{n-1}} \qquad (2)$$

where G_i was the grey level intensity at pixel number i, $\overline{G_i}$ the mean of grey level intensity, and n the total number of pixels.

Fabric wrinkle measurement by AATCC test method

As has been mentioned by many experts [10 - 15], the visual evaluation method of AATCC 128-2004 is subjective and the results are mainly dependent on personal views. Besides, as there are six grades altogether, the fabrics which are grouped into the same grade generally have different severity and characteristics of wrinkling. Therefore the AATCC 66-2008 wrinkle recovery angle test method was chosen to measure the wrinkling performance of the fifteen fabrics selected as a comparison with the method proposed in this paper. The wrinkle recovery angle of all fabrics was tested in test direction angles of 0° (weft direction), 45° and 90° (warp direction).

Results and discussion

The new characteristics of wrinkle severity (WS) and fabric unevenness (FU) in the warp and weft directions were calculated based on the image processing method. The regression of the new wrinkling characteristics and wrinkle recovery angle in three directions are shown from ***Figure 6*** - ***Figure 13*** (see page 54). As can be observed from the figures, both the wrinkle severity and fabric unevenness had a good negative correlation with the wrinkle recovery angle. When the 45° wrinkle recovery angle was taken into consideration, it was observed that the correlation between the wrinkle recovery angle and new characteristics of WS or FU increased in both the warp and weft directions.

As shown in ***Figures 6*** and ***8***, the correlation coefficient between the warp wrinkle severity and mean of the warp and 45° wrinkle recovery angle (about 88%) was higher than that of warp wrinkle recovery (about 85%). That is, the wrinkling performance of the fabric in the 45° direction played such an important part in deciding the total wrinkling appearance of the fabric that it could not be included either in the warp or in the weft direction. This can be explained by the anisotropy in the wrinkle properties of woven fabric [16] and by the fact that the "diamond" wrinkles in actual wear consisted of horizontal and diagonal ones, which can be observed in ***Figure 4***. As a result, when

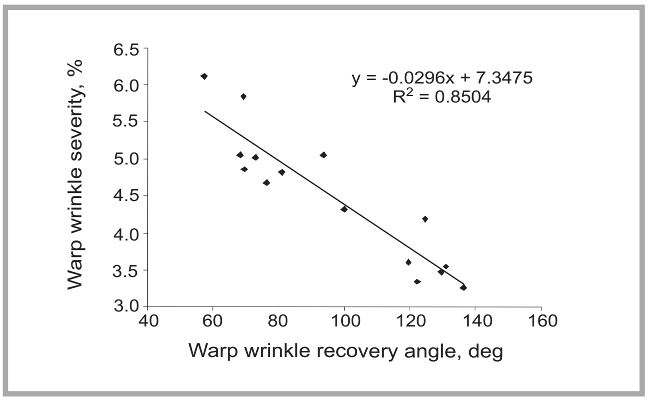

Figure 6. *Regression graph of warp wrinkle severity and warp wrinkle recovery angle.*

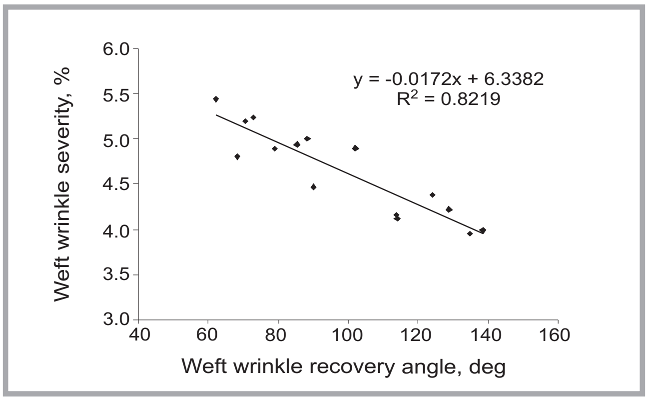

Figure 7. *Regression graph of weft wrinkle severity and weft wrinkle recovery angle.*

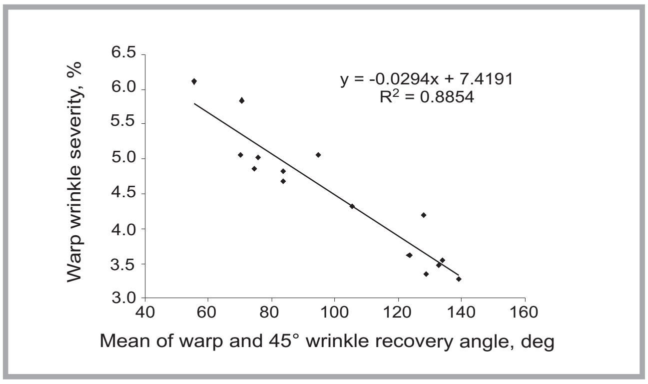

Figure 8. *Regression graph of warp wrinkle severity and mean of warp and 45° wrinkle recovery angle.*

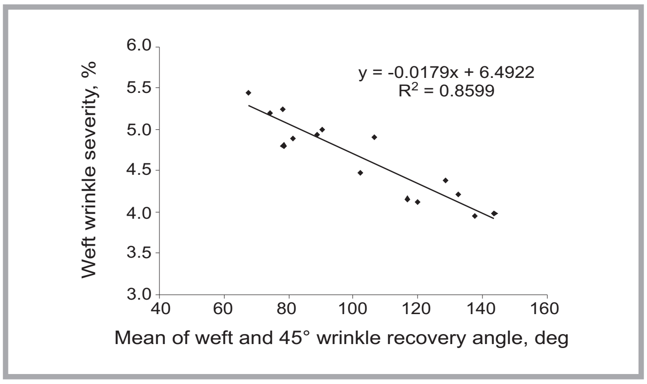

Figure 9. *Regression graph of weft wrinkle severity and mean of weft and 45° wrinkle recovery angle.*

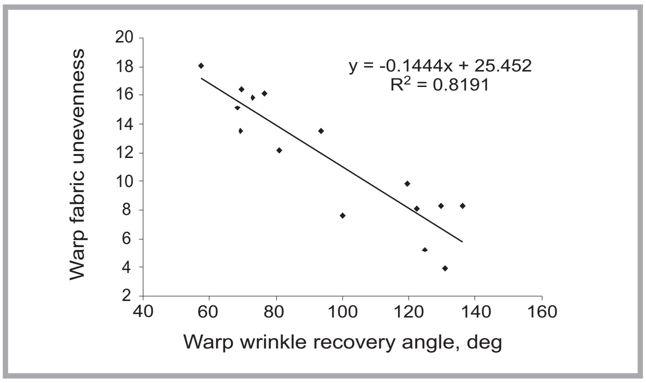

Figure 10. *Regression graph of warp fabric unevenness and warp wrinkle recovery angle.*

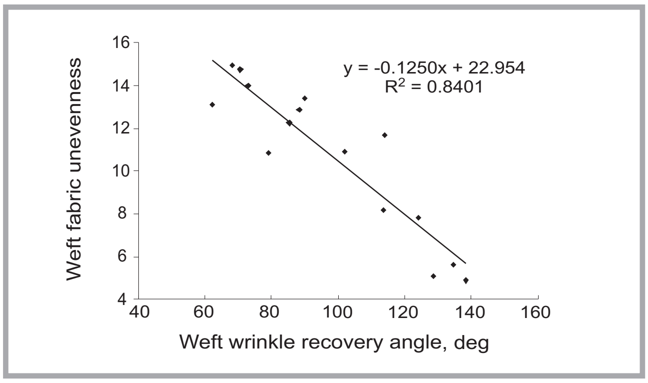

Figure 11. *Regression graph of weft fabric unevenness and weft wrinkle recovery angle.*

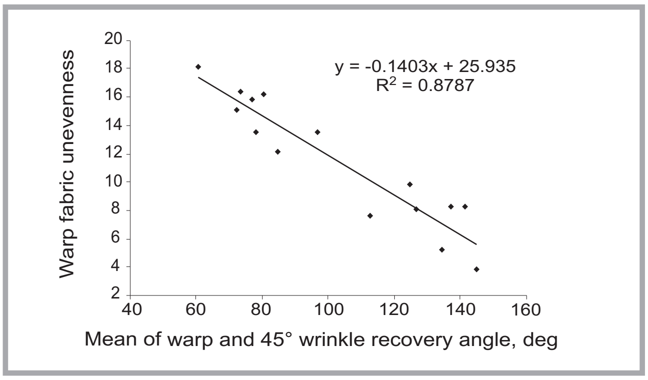

Figure 12. *Regression graph of warp fabric unevenness and mean of warp and 45° wrinkle recovery angle.*

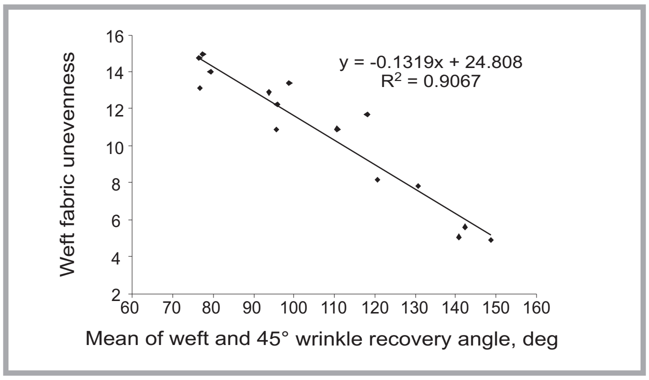

Figure 13. *Regression graph of weft fabric unevenness and mean of weft and 45°wrinkle recovery angle.*

testing the wrinkle properties of woven fabrics according to the AATCC 66-2008 test method, it was advisable that a wrinkle recovery angle of 45° be tested rather than averaging warp and weft wrinkle recovery angles only.

Compared with the AATCC 66-2008 test method, which can only produce a simple, two-dimensional wrinkling line and measure the wrinkling properties of one direction at a time, the method put forward in this paper can produce more complex, three-dimensional, realistic "diamond" wrinkles and measure the wrinkling properties of actual wear.

Conclusion

In this study, a measuring system for fabric wrinkles was developed which consisted of a fabric wrinkle simulator, scanner and computer. The simulator generated realistic "diamond" wrinkles just like those of the elbow and knee in actual wear. Images of wrinkled fabrics acquired by the scanner were processed with software developed in MATLAB and the new characteristics of wrinkle severity (WS) and fabric unevenness (FU) in the warp and weft directions were proposed for wrinkle characterisation. 15 different fabrics in various colours, weaves and materials were used to analyse and compare the measurement results of the system with those of the AATCC 66-2008 test method. It was found that both WS and FU had a good negative correlation with the wrinkle recovery angle and for the 45° wrinkle recovery angle, the correlation between the wrinkle recovery angle and WS or FU increased. It was advised that a wrinkle recovery angle of 45° be measured rather than averaging warp and weft wrinkle recovery angles only when using the AATCC 66-2008 test method. Compared with the AATCC 66-2008 test method, the method in this paper could produce more "realistic" wrinkles and measure the wrinkling properties of fabrics in actual wear.

Acknowledgments

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