NEW METHOD FOR THE EVALUATION OF WOVEN FABRIC UNEVENNESS

Petra Jiraskova, Eva Mouckova

Technical University of Liberec, Faculty of Textile Engineering,
Department of Textile Technologies, Liberec, The Czech Republic
Studentska 2, 461 17 Liberec 1
E-mail: petra.jiraskova@tul.cz, eva.mouckova@tul.cz

Abstract:

Unevenness of woven fabric results from irregularity of the yarn used as well as from the process of its manufacture (weaving). A periodical and non-periodical yarn irregularity shows itself in the flat textile by known effects - the moiré effect, cloudiness, and stripiness. It is possible to predict the appearance of flat textiles from measured values of yarn mass irregularity and their characteristic functions (a spectrogram, a variance-length curve). The evaluation of surface unevenness of woven fabrics is done not directly but by judging their appearance, most often subjectively. For evaluation of flat textile appearance, it is also possible to use a so-called area-variation curve. The curve can be constructed on the basis of analysis of a woven fabric image either by a special program, created by J. Militky (Technical University of Liberec) in the programming environment Matlab, or by means of image analysis. By these methods it is possible to evaluate an image of real flat textile as well as a simulated image from an apparatus for yarn irregularity measurement. The woven fabric image is in grey scale. The variation coefficient of greyness degrees expresses the unevenness of flat textiles. In the experiment both real woven fabric images and simulated appearances of woven fabric, obtained by means of the apparatus Uster Tester IV, are evaluated by the methods mentioned above. The acquired area-variation curves are compared with each other and compared with visual evaluation of the woven fabric image. It was found that area-variation curves show only marked unevenness of woven fabric.

Key words:

Surface unevenness, area-variation curve, woven fabric, image analysis, greyness degree .

Introduction

Unevenness of plain textiles expresses itself not only as a variability of permeability or textiles thickness but also in their appearance. It shows as a fluttering, cloudy appearance with thicker and thinner places. The appearance of the plain textile is influenced by the irregularity of yarns from which the plain textile is made and by the textile manufacturing process, that is by weaving or knitting.

The yarn mass irregularity displays itself in the plain textile in specific known ways. These characteristic effects are stripiness and the moiré effect. They are caused by the periodical irregularity of yarn, which is visible in a spectrogram. The moiré effect is caused by the short-term mass variation (the wavelength λ up to 50 cm). The long-term irregularity (the wavelength λ > 5 m) is the reason for the stripiness. The medium-term periodical irregularity rarely shows itself in the appearance of plain textiles. It is recognizable only after fulfilment of definite conditions. The non-periodical irregularity of yarn expresses itself in plain textiles as an unsettled appearance. Besides this, the appearance of flat textiles is influenced by other casual effects, which are given by the structure of yarn mass irregularity.

The parameter and characteristic functions of mass irregularity are usually used for the evaluation of unevenness of longitudinal textiles (yarns). The parameters indicate a value of irregularity. The characteristic functions describe the structure of irregularity and provide for the localization of their source. Measurement of yarn mass irregularity is done, for example, on Zellweger Uster apparatuses: Uster Tester, Zweigle, and QQM 3. The measurement results obtained by these devices are values of irregularity as well as characteristic functions. On the basis of these functions, we can predict the appearance of future plain textiles. In literature the interrelation between the shape of a spectrogram (the periodical irregularity) and the moiré effect as well as the stripiness [1] and between the shape of a variance-length curve and the unsettled appearance of plain textile is mentioned [2].

The subjective evaluation methods (e.g. visual judgement of the appearance of plain textiles) are generally used for the evaluation of plain textile unevenness. In the 1960s Wegener and Peuker [3] determined formulas for calculation of an area-variation coefficient and for construction of area-variation curves on the basis of mass fluctuation of plain textile samples. Wegener and Hoth [4] put together a formula for calculation of an ideal area variation on the basis of an assumption about random distribution of thick and thin places of the yarn in the plain textile. But these methods are not used in practice because of the difficulty of determining the real area variation of plain textiles and because their calculations are complicated. Next, Militky [5] assigned an ideal value of CV for non-woven textiles.

The surface unevenness of plain textiles is described in the literature by the variation coefficient (CV) of various properties of the plain textile or by derived statistical functions [6,7]. A sample of the plain textile is divided into square fields, where individual properties, for example the variation of greyness degree, are measured. So-called area-variation curves are constructed too, as a parallel of a variation-length curve. The area-variation curve is also constructed in works [8,9] as a quantitative evaluation of the quality of the predicted image of the plain textile. This image is generated with a virtual signal created by combination of two signals. The first is obtained during optical measurement of the yarn diameter by the CCD camera. The second is from the measurement of yarn mass irregularity by a capacitance sensor.

Other statistical functions by means of which it is possible to describe the surface variability use the fact that the magnitude *z(x,y)* is a random function of two variables (a random field). For example, co-variation functions or so-called directional semivariograms belong to these functions [6,10]. The semivariogram describes the spatial dissimilarity between values at the locations x_i and x_j. It is defined as one-half of the variance of differences: $(z(x_i)-z(x_i+lag))$ [6,10]:

$$\Gamma(lag) = 0.5 \cdot D(z(x_i) - z(x_i + lag)) \qquad (1)$$

The magnitude *lag* is a directional vector (0°, 90°, 45°) representing separation between two spatial locations. In literature the lag is also marked as *h*. For uniformly distributed points *x* the values of vector lag express multiples of distance between squares in the directions of columns (0°), rows (90°), and diagonals (45°) [6,10]. The omni-directional semivariogram is obtained by averaging of all three types of semivariograms. For a stationary random field the mean value is constant in individual locations. If $\Gamma(lag) = const$, the magnitude *z(.)* is not correlated in a given direction. When a random field is non-stationary, a centred sample semivariogram is used [6].

Definition and principle of determination of fabric unevenness

The surface unevenness of plain textile expresses itself in the fabric's appearance and is also evaluated according to this appearance. The simulated fabric appearance as well as an image of the real fabric can be used. An instrument for the yarn mass irregularity measurement usually generates the fabric appearance (woven fabric, knitted fabric). The simulated image is created by special software on the basis of irregularity values of measured yarn. The image is in grey scale with various intensities of the greyness according to the yarn irregularity.

The fabric unevenness is converted into the dye (greyness) variation, that is, unevenness of colouration. The variation of the mean greyness degree characterizes deterioration in the surface unevenness of woven fabric. It can be caused by yarn and by negative influences during weaving but also by effects not related to the surface unevenness (fabric crimps).

During the evaluation of simulated fabric appearance, it is not possible to take into account the influence of the fabric manufacturing process on surface unevenness.

It is possible to obtain the real fabric image, for example by scanning the true side of the fabric sample at a resolution of 300 dpi. In the experiment, the real size of the woven fabric image acquired was 15 x 21 cm. On the basis of experiments done by the authors of this article, samples were scanned with a black underlay. The black underlay shows through the fabric and thus accentuates its unevenness (the yarn diameter variation as well as the variation of distance between individual threads in fabric samples are more visible). This enables better identification of surface unevenness.

The obtained plain textile image, in this case woven fabric, can be processed by image analysis using NIS-Elements or by the programme Surface Unevenness created by Militký in the programming environment Matlab. The area-variation curves are the results of both methods of processing.

Area-variation curve

In this article, the area-variation curve is set up as an external variability of greyness degrees in the fabric image in dependence on the square field area:

$$CV(A) = \frac{\sqrt{S^2}}{\overline{\overline{X}}} \qquad (2)$$

where:

CV(A) - the external variation coefficient of average greyness degrees between square fields of the area A in the fabric image,

S - the standard deviation of mean values of greyness degrees in square fields of the area A included in the fabric image,

$\overline{\overline{X}}$ - the mean value of all mean values of greyness degrees in square fields of the area,

A - the square field area of the image.

Experimental determination of area-variation curves

In processing of the plain textile image by image analysis using NIS-Elements, the mean value of greyness degrees and its variation in the image are studied. The variation coefficient is calculated. It expresses the unevenness of greyness degrees, which is analogous to the measured CV-value in yarn. This CV-value is a variation coefficient expressing the yarn mass variation. According to [11], it is appropriate to repeatedly divide the image area into a square net with gradually increasing size of squares. Then the mean value of greyness degrees and its variation are determined in individual fields. It is possible to construct the area-variation curves from the variations of mean values of greyness degrees in squared fields of different areas. Their shape is analogical to that of the variance-length curve: the variation of greyness degrees decreases with increasing square field area. It is also possible to observe the mean value of greyness degrees and its variation in square fields in the directions of rows and columns. The fluctuation of greyness degrees (i.e. the greyness degrees variation) between rows or columns can be expressed.

In processing of the fabric image by the program Surface Unevenness (Militký), the digital fabric image obtained is converted into greyness degrees. The program observes greyness degrees of individual pixels and calculates the variation coefficient of greyness degrees in the whole image of defined size and in square fields of different areas. It constructs the area-variation curve of greyness degrees from calculated values according to Formula (2).

Several experiments were done independently of each other. Their aim was to study the shapes of area-variation curves of greyness degrees in different fabric samples and to verify the suitability of area-variation curves for the evaluation of surface unevenness.

Experiment No. 1

For the experiment, 100% CO, white colour woven fabrics were used. The count of warp and weft yarn was 33 tex. The weft sett used was: 16 threads/cm (the fabric marked B16), 20 threads/cm (the fabric marked B20), and 24 threads/cm (the fabric marked B24). From each woven fabric, 12 samples were taken and scanned with both black and white underlay. By putting the black folder onto the scanned sample the black underlay was created, whereas for the white underlay a sheet of white paper covered the sample. The size of the scanned image was 15 x 21 cm. The influence of the weft sett on the shape of the external area-variation curve was studied. The average area-variation curves from fabrics B16, B20, and B24 were compared with each other (see Figures 1 and 2).

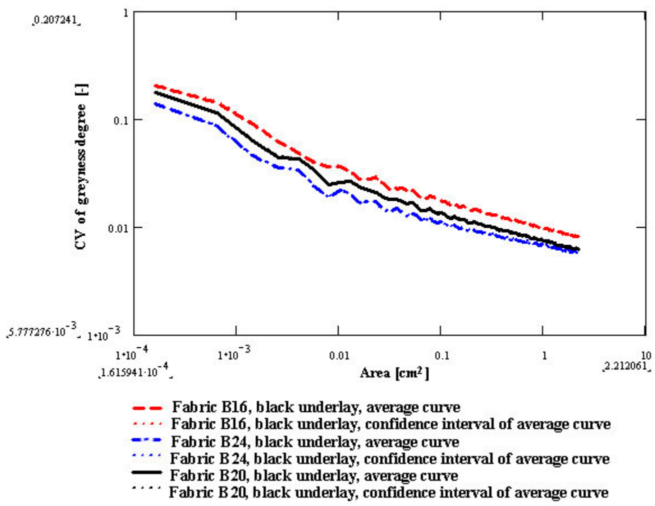

Figure 1. Average external area-variation curves - fabrics B16, B20, and B24, black underlay.

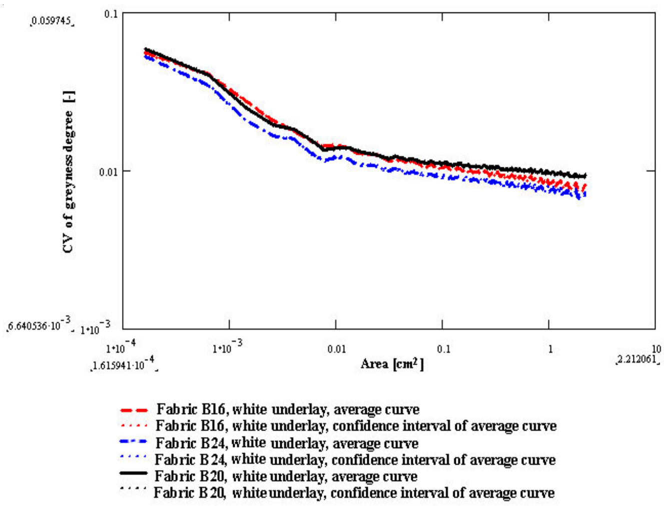

Figure 2. Average external area-variation curves - fabrics B16, B20, and B24, white underlay.

The average area-variation curve of greyness degrees of the fabric with the lowest sett (B16) has the highest CV-values in the case of the image with black underlay. The loose sett of the fabric is the cause of this fact. Due to this, the black underlay strikes more through places among yarns in the fabric during scanning, and thus higher variation in the greyness degrees of individual pixels was recorded. In the case of fabric B24, the increase in variation of greyness degrees was recorded from the area *c.* 1 cm^2. This can be caused by yarn irregularity or by a fault during weaving.

The total observed image area was divided into squared fields with gradually increasing areas during construction of the area-variation curve. The size of the evaluated square field has an influence on the value of greyness degrees variability, which decreases with increasing squared field area, but simultaneously the number of squared fields (number of measurements) declines. The stability of the results obtained relates to this. The results' instability shows itself as a serrated shape at the end of the curve. A certain minimum number of square fields is necessary for stability of results. Therefore the largest area of evaluated squared fields was a maximum of 1 cm^2.

Experiment No. 2

The fabric images generated by the apparatus Uster Tester on the basis of measurement of yarn irregularity and yarn faults (100% CO combed yarn) were evaluated. The appearances of woven fabrics of various weaves - plain, twill 3/1 (denim), and satin - simulated by the Uster Tester were used for evaluation by the program. The generated fabric appearances were also judged visually. The selected parameters of yarn mass irregularity (CV-value) and characteristic functions (the spectrogram and the variance-length curve) were studied together with their relation to the shape of the area-variation curve.

From the shape of the variance-length curve, it is evident that yarn No. 1 shows non-periodical irregularity in the cut length of 66 cm. This yarn has higher irregularity up to the cut length of *c.* 15 m in comparison with the other yarns. Also the spectrogram of this yarn has a worse shape, because the periodical irregularity was recorded at wavelengths of 3 m and 7 m. Yarn No. 5 has a more objectionable spectrogram too; see Figures 3-5.

No marked differences were registered in the appearance of woven fabric with the plain weave during visual judgement of the image. So, none of the appearances of the plain weave fabric can be considered markedly objectionable.

Differences in the appearances of denim weave and satin weave fabric images were visible. The simulated fabric images generated from yarns that have higher irregularity and a more objectionable spectrogram as well as variance-length curve showed worse appearances. They were more unsettled (the variation in greyness degree was higher in the image). The fabric appearances generated from yarns No. 1 and No. 5 were the worst. The appearance of simulated yarn taper boards confirmed this fact because the moiré effect was recorded there.

According to the shapes of area-variation curves (see Figures 6-8) there are minimal differences among the curves of the fabric with the plain weave. The curve of fabric No. 4 lies 0.01 cm^2 lower compared with the others. The shapes of the curves overlap, although the yarn used has a different tape board appearance and irregularity level. The

Table 1. Selected parameters of mass irregularity - combed yarn 100% CO, T = 16.5 tex.

Yarn No.	Test No.	CVm [%]	CV_m (1m) [%]	Thin – 40% [1/km]	Thin – 50% [1/km]	Thick +35% [1/km]	Thick +50% [1/km]	Neps +200% [1/km]
1	2071	14.16	5.85	179	4	526	71	203
2	2070	13.76	4.33	124	2	572	88	283
3	2069	13.19	4.37	81	0	432	61	204
4	2068	13.73	4.23	154	4	553	96	279
5	2067	13.63	4.38	149	0	468	72	236

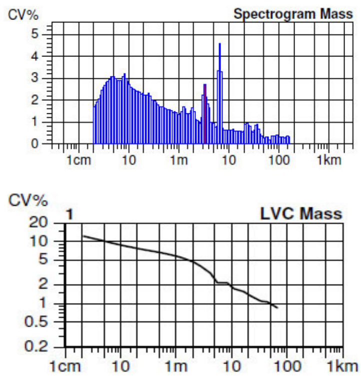

Figure 3. Spectrogram and variance length curve - yarn No. 1.

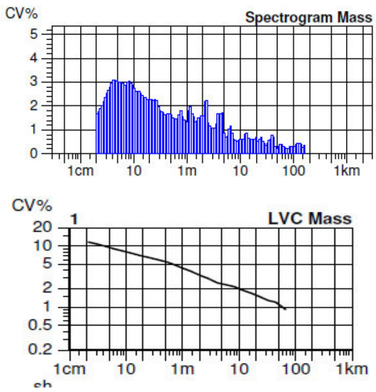

Figure 4. Spectrogram and variance length curve - yarn No. 5.

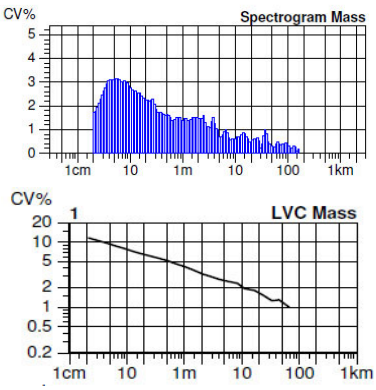

Figure 5. Spectrogram and variance length curve - yarn No. 4.

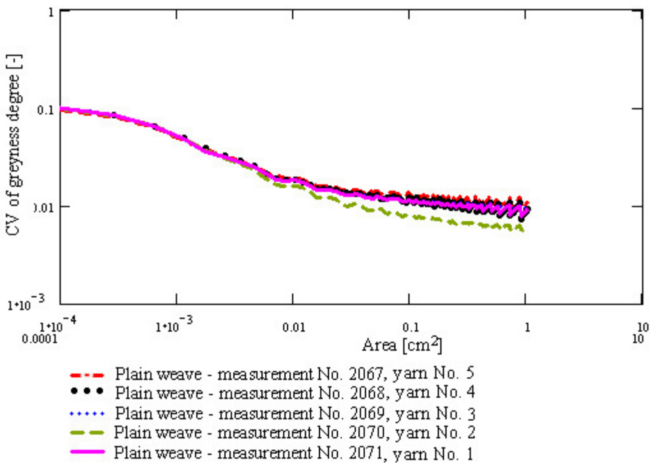

Figure 6. Area-variation curve: combed yarn 100% CO, T = 16.5 tex, plain weave.

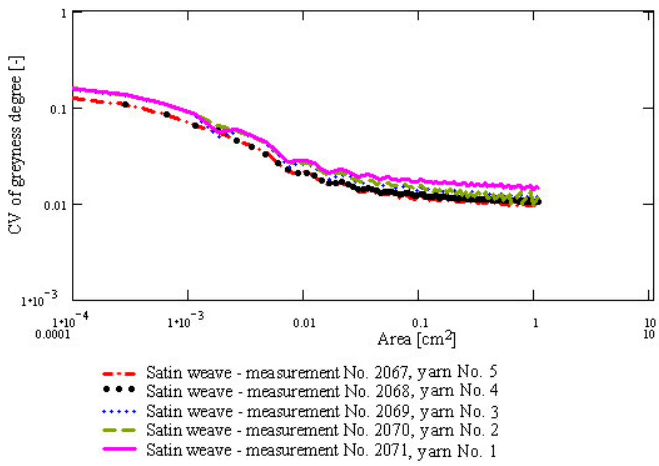

Figure 8. Area-variation curve: combed yarn 100% CO, T = 16.5 tex, satin weave.

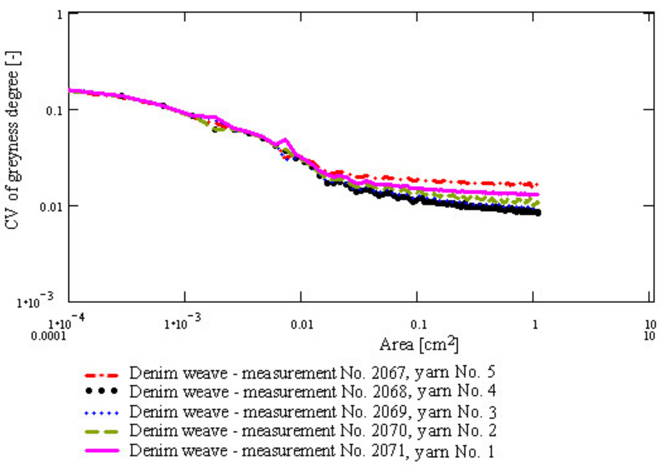

Figure 7. Area-variation curve: combed yarn 100% CO, T = 16.5 tex, denim weave.

reason for the difficulty of identification of the surface irregularity is probably the high weave density, which does not contain so-called thread floats and hides the yarn irregularity.

In the case of denim weave, the area-variation curve of fabric with yarn No.1 shows deflections in the area of 0.0018 cm^2 and 0.0071 cm^2. The curve of the fabric with yarn No. 5 has the highest values of CV-greyness degree from the area *c.* 0.01 cm^2. In the case of fabrics with satin weave, all area-variation curves have similar shapes. The curve of fabric with yarn No. 1 lies uppermost. This curve together with the curves of yarns No. 2 and No. 3 shows deflections in the same areas as in the case of the curve of the denim weave. The shapes of curves correspond to the visual assessment of simulated fabric appearance.

Differences in the simulated fabric appearances are more visible and identifiable in fabric weaves that are not so dense (the denim and satin weaves). Here, the fabric appearance corresponds more with measured values of yarn mass irregularity and yarn appearance. Yarns with higher mass irregularity (CV) and worse spectrograms as well as shape of variance-length curve had worse simulated fabric appearances too. The yarn mass irregularity is not hidden and it can be identified in the float thread in these fabric weaves.

Experiment No. 3

The unevenness of real woven fabrics of various weaves was evaluated (Table 2).

The fabrics were manufactured in both a standard way and with a fault (the stripiness in the direction of warp, meaning the periodical long-term irregularity) on the same loom. The stripes were obtained during warping. The yarn bobbins produced in different spinning lots were set on half of the creel. The parameters of these yarns were the same, but the colour shade of the cotton differed.

The area-variation curves (Figure 9) were constructed by averaging of the area-variation curves calculated from six

Table 2. Selected parameters of used woven fabric.

Fabric weave	Weft sett (threads/ 10 cm)	Weft sett (threads/ 10 cm)	Yarn fineness in the warp and weft [tex]	Raw material
Satin 1/7 (5)			14.5	
Twill ½ (Z)			14.5	
Twill 5/5 (Z)	350	388	14.5	100% CO
Plain			14.5	
Hopsack 2/2			14.5	

samples of each type of woven fabric. The shapes of the average curves were compared with each other. From the shapes of the area-variation curves it was found that:

- Fabric faults were recorded only in the case of the satin 1/7 (5) and plain weaves. The area-variation curves of faulty fabrics with these weaves showed deflections and lay under the curve of fabric without faults. The significance of the difference in position was tested by the t-test and the F-test;
- In the case of fabrics with other weaves, the area-variation curve did not record the fault: curves of normal and faulty fabric were laid side-by-side closely and differences in their positions were non-significant;
- The area-variation curve of fabric with the hopsack weave showed a markedly waved shape. But these waves were caused by the fabric weave itself - relatively larger full places (a weft and a warp thread interlacing) and relatively larger empty places take turns in such woven fabric. The area of the place was doubled compared to the plain weave. Therefore the program evaluated them as a marked regular variation of dark and light places in the fabric image. Thus, the resultant curve showed marked waves.

Conclusion

The area-variation curve is a tool suitable for the quantification of surface unevenness on the basis of evaluation of a flat textile image. The surface unevenness expresses itself in the fabric appearance as the variation of flat textile colouration. The flat textile image is divided into squared fields and the fluctuation of colour shade (greyness degrees) is evaluated among individual squared fields by means of the area-variation curve. On the basis of the experiments carried out and shapes of area-variation curves it can be claimed that:

- The shape of the area-variation curve is analogous to that of the variance-length curve. It falls with increasing squared field area. The deflection in its shape means a change of unevenness: deflection in the upwards direction indicates that the unevenness has downgraded;
- Scanning of the fabric sample with black underlay is suitable for obtaining the real fabric image. The black underlay accentuates the fluctuation of yarn diameter and distance between threads. Hence, the changes in colour shade are more visible;
- The method of evaluation of surface unevenness is suitable for the evaluation of fabric images generated by an instrument for the yarn mass irregularity measurement where the images are simulated on the basis of measured irregularity values and yarn imperfections. The generated image serves for the prediction of future flat textile appearance;
- The shape of area-variation curves is influenced by the fabric weave. Fabrics with greater covering (in the plain weave) show a lower variability of greyness degree. Thus, its unevenness is identifiable with more difficulty. In the case of woven fabric with less covering (denim and satin weaves), the unevenness is more easily identifiable.
- The area-variation curve is a more suitable tool for identification of the non-periodical irregularity. The

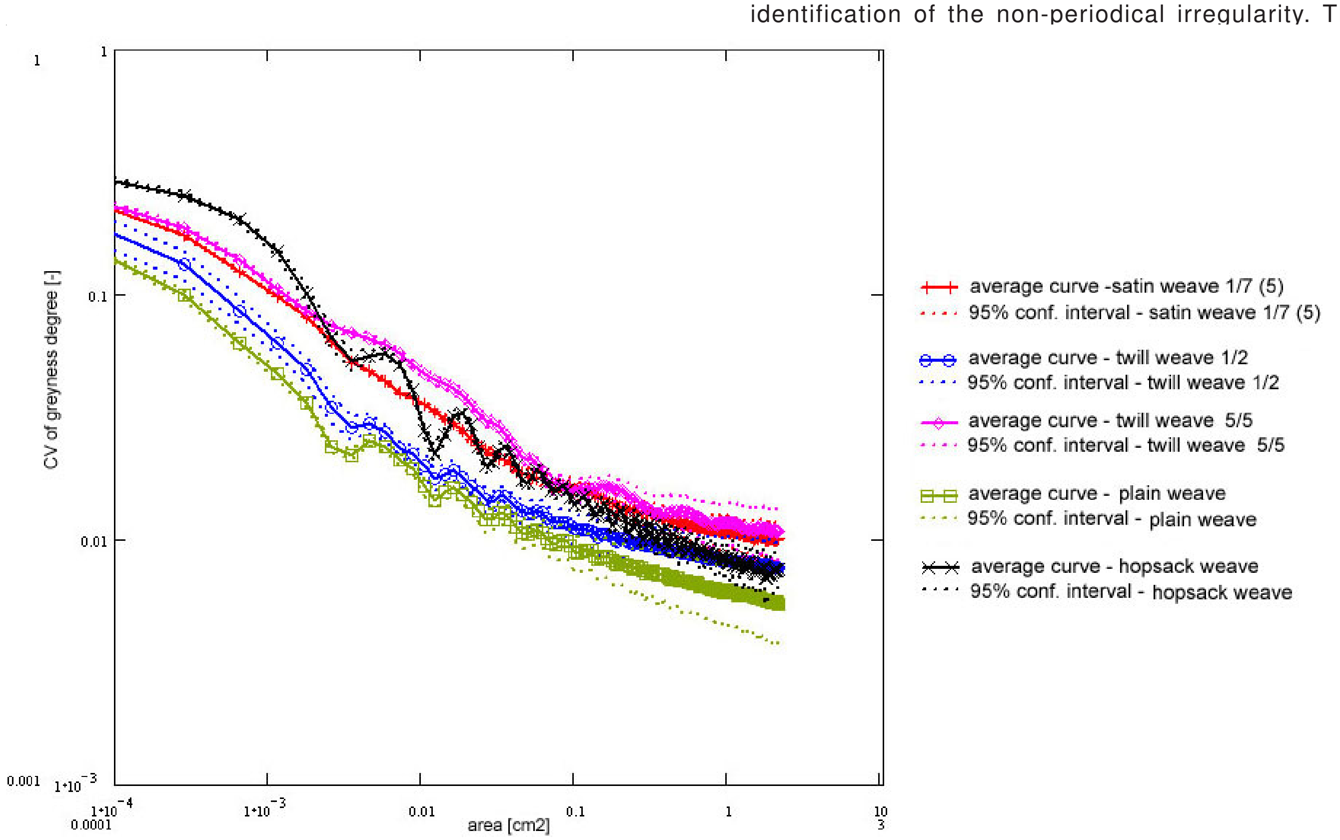

Figure 9. Area-variation curves of normal woven fabrics.

periodical unevenness is recorded in specific cases only. Semivariograms seem to be a better tool for the identification of periodical unevenness [12].

Acknowledgement

This work was supported by research project VCT II No. 1M0553.

References:

1. *Uster News Bulletin, Ed. by K. Douglas, B.Sc., C. Eng., M. I. Mech. E., C. Text., A. T.I., No. 15. Zellweger Uster, Switzerland, 1971.*
2. *Uster News Bulletin, Ed. by K. Douglas, B.Sc., C. Eng., M. I. Mech. E., C. Text., A. T.I., No. 35. Zellweger Uster, Switzerland, 1988.*
3. *Wegener, W.; Peuker, H.: Die Beziehung zwischen der Garnungleichmäßigkeit und dem Warenbild textiler Fläschengebilde, Institut für Textiltechnik der Technischen Hochschule, Aachen, 1961.*
4. *Wegener, W.; Hoth, E.G.: Die CD(F) - Flächenvariation, Textil - Praxis 1958, Vol. 13, p. 485.*
5. *Militky, J.: Probability model of nonwovens unevenness, Proceedings of 7th International Conference Structure and Structural Mechanics of Textile Fabrics, pp.193?198, Technical University of Liberec, Liberec, 2000.*
6. *Militky, J.; Klicka, V.: Characterization of textiles mass variation in plane, Proceedings of 5th World Textile Conference Autex 2005, pp. 750?755, University of Maribor, Faculty of Mechanical Engineering, Department of Textiles, Maribor, 2005.*
7. *Ursíny, P.; Jiraskova, P.: Mass irregularity of flat textile and possibilities of its determination. Proceedings of 9th International Conference Structure and Structural Mechanics of Textile Fabrics, pp. 247?254, Technical University of Liberec, Liberec, 2002.*
8. *Suh, M. W.: Electronic imaging of fabric qualities by on-line yarn data. Available from www.ntcresearch.org/pdf-rtps/AnRp01/I01-A1.pdf. Accessed: 2005-02-01.*
9. *Suh, M. W.: Electronic imaging of fabric qualities by on-line yarn data. Available from www.ntcresearch.org/pdf-rtps/AnRp01/S01-NS12-A2.pdf. Accessed: 2005-02-01.*
10. *Militky, J.; Rubnerova, J.; Klicka, V.: Spatial statistics and unevenness of surface mass of non-woven textiles, Proceeding of 7th National Conference Strutex, pp. 199?203, Technical University of Liberec, Liberec, 2000.*
11. *Jiraskova, P.; Mouckova, E.: Unevenness of flat textiles and its quantification, Proceedings of 3rd International Textile, Clothing & Design Conference - Magic World of Textiles, pp. 612?617, Faculty of Textile Technology, University of Zagreb, Zagreb, 2006.*
12. *Mouckova, E.; Jiraskova, P.: Stripiness of woven fabric versus area variation curve and semivariogram. Proceedings of 16th International Conference Structure and Structural Mechanics of Textile Fabrics, CD-ROM edition, Technical University of Liberec, Liberec, 2009.*

∇∆