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Evaluation of the Structural Homogeneity of Denim Fabric by Means of Digital Image Analysis

Abstract
A new, fast, precise and method of evaluating the homogeneity of a fabric's structure which is not destructive has been devised. In this article, the new method was tested on denim fabrics. The basis for evaluating the homogeneity of a fabric's structure is the homogeneity of the weft coat on the left side of the fabric, and the diameter homogeneity of the weft and warp yarn. Our investigation covered five fabrics with structural disturbances and one model fabric.

Key words: *denim fabric, structural homogeneity, digital image analysis.*

Introduction

Many standards for evaluating a fabric by examining its individual parameters exist, such as wave, surface mass, filling, fabric cover, thread quantity and thread spacing. On the basis of these parameters, we can draw conclusions concerning the fabric's homogeneity in the sense of its repeatability. Unfortunately, disturbances exist which are difficult to evaluate. Currently, heterogeneity in the form of stripes is evaluated by means of the subjective standard-sample method. All these methods are very time- and labour-consuming, and cause standard-sample destruction. This does not fulfil current expectations regarding the speed and precision of the non-destructive measurement of ready product quality. In this article we present a fast, precise, objective and non-destructive method for evaluating the homogeneity of denim fabric.

The homogeneity of denim fabric structure is an important indicator for evaluating the product quality. Denim fabric consists of two contrasting threads, and therefore any disturbance of its structure is very visible. Figure 1a shows the fabric with stripe structure. This phenomenon may be caused by disturbances in the weaving process or the yarn parameters. Figure 1b shows a model fabric without the stripe effect.

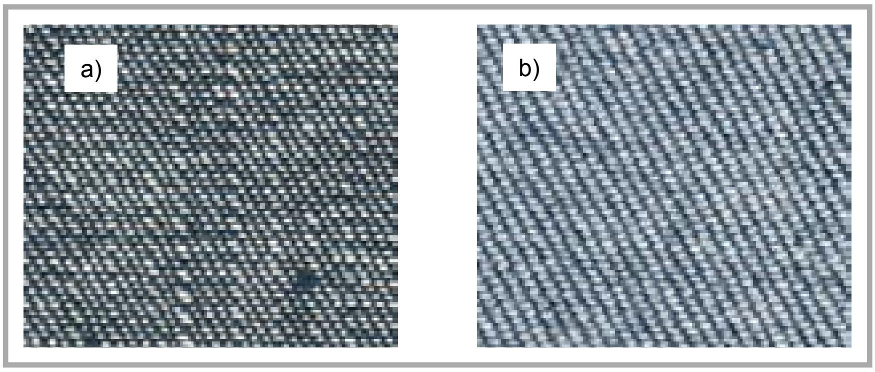

Figure 1. Image of denim fabric, left side; a) disturbed fabric structure, b) model fabric structure.

In this thesis two directions of fabric structure analysis were applied:
- a homogeneity analysis of the fabric structure, and
- a homogeneity analysis of the weft and warp yarns which establish the fabric.

For evaluation we took 5 fabrics with disturbed structures produced on 5 different weaving machines, and one model fabric without any disturbances.

Homogeneity analysis of the denim fabric structure

It has been supposed that a fabric's structural homogeneity is understood as the repeatability of a certain weave element in the fabric structure area. In the case of the homogeneity analysis of denim's fabric structure, the weft overlap in the left side of the fabric has been taken as this element. Figures 2a and 2b show images of the right and left side of the fabric with a disturbed structure. It seems that these disturbances are more clearly visible on the left side of the fabric, where the weft

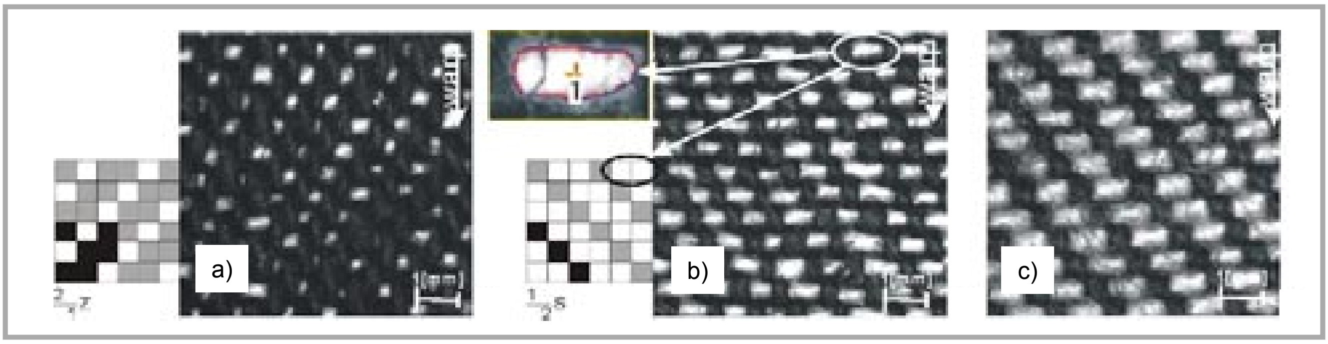

Figure 2. Denim fabric, zoom 0.62 related to (7×7) mm² of fabric tested; a) right side of the disturbed denim fabric with related weave, b) left side of the disturbed fabric with related weave and with magnificated weaving element (weft overlap), c) left side of the model fabric.

overlaps (white places) include more image information. On the basis of the variation coefficient of their surface area and shape, homogeneity is defined in the structure of the fabric evaluated.

Digital image analysis of the denim fabric

Image acquisition

The first operation, image acquisition, concerns the method of recording the digital image, in this case, the fabric. Obtaining digital information about any object is a complex process. In our case we used the following modules (with sub-assemblies):

1. optical image formation module, which contains:
   - a PZO Mst Zoom 1302 stereoscopy microscope,
   - Olympus Highlight 3100 upper annular lighting,
   - a table with a movable surface in two perpendicular directions;
2. module for transforming an optical image into an electrical signal: CCD-4012 A VideOTronic camera, PAL (625×570);
3. module for transforming an electric signal into a digital image: A/D converter LFG 1024 by Logitex;
4. module for processing and analysing information from the digital image: computer with software specially written by us;
5. module for visualising processing and analysing the results, which includes a monitor and printer.

The images are drawn from a diagonal line of the whole fabric's width to avoid weft and warp repetitions. It was also assumed that the vertical threads system is known as warp threads, and the horizontal threads system is known as weft threads. Images of the fabric after acquisition are shown in Figure 2b (left side of disturbed fabric) and Figure 2c (left side of model fabric).

The criterion for selecting an algorithm image analysis is the precision of the representation –of the weave element (i.e. the weft coat on the left side of the fabric); this is shown in Figure 2b. In contrast to the model fabric, the fabric with the disturbed structure shows very irregular weft coat spaces. The model fabric has a large harness, which disturbs the image of the weft coats' fields on the left side of the fabric. The image shows less contrast. Summing up, the weft coats' fields for both fabric groups have different accessibility characters for quantitative information. Each of the fabrics discussed required an individual adaptation of image pre-processing method.

Image pre-processing

Image pre-processing of both fabric groups includes low-pass filtration, histogram modelling and non-linear filtration. The aim of these operations is to eliminate noise which is characteristic feature of the apparatus used, and to prepare the fabric image for a threshold process or separating the object from the background. After image pre-processing white objects i.e. weft coats of the fabric's left side must be clearly identified on the dark background. This is why all pre-processing operations are very important and must show the details of the bright areas.

Images of fabric with disturbed structure, due to the presence of irregular, small, poorly visible weft coats areas, require additional brightening of the whole image to correctly identify whole objects in further processing.

In model fabric image, correct identification of the white areas is disturbed by the hairiness of the thread, which divides these areas into small fragments. Hairiness is not the subject of our research, so it must be removed from the white areas. This aim was accomplished thanks to the use of a histogram modelling operation followed by non-linear filtration.

The histogram modelling of the grey-scale image is an excellent tool, which has many options for obtaining important information from the image which previously were unavailable. Additionally it allows disturbances to be eliminated from images with a 'sandy' character, to obtain depth in the image, and to prepare the image for separation of the objects from their background.

Non-linear filtration, in contrast, completes the improvement of the image quality by stronger image contrasting, which mostly consists in muffling details which are in the dark area on the background. The final effect of the image pre-processing is shown in Figure 3a, for the image of a disturbed fabric structure, and Figure 3b for model fabric.

Segmentation

After pre-processing an operation to convert the image to grey-scale should be carried out, in order to obtain dark areas for analysis. (Figure 4a).

Segmentation (Figure 4b) is the operation of separating the objects from the image background. A binary image with two grey levels is created: 0 – black and 1 – white. After this operation, the separated objects are not perfect; that is, they display cracks, holes, insets and peninsulas on their surface (Figure 4c). To eliminate these elements morphological filters can be used, erosion and dilatation. Each filter has its own advantages and defects. Carrying out a closing operation (first dilatation, then erosion) (Figure 4d) and then an opening operation (first erosion, then dilatation) (Figure 4e) eliminates the defects of these filters, and at the same time enables to obtain very good effects when removing imperfections of image objects.

Representation and description

The very important final stage is the representation and description of the objects in the image. Our program is based on the cluster analysis method, which allows us to find all the weave elements, the weft coats of the fabric's left side, their indexation and quantitative description (Figure 5).

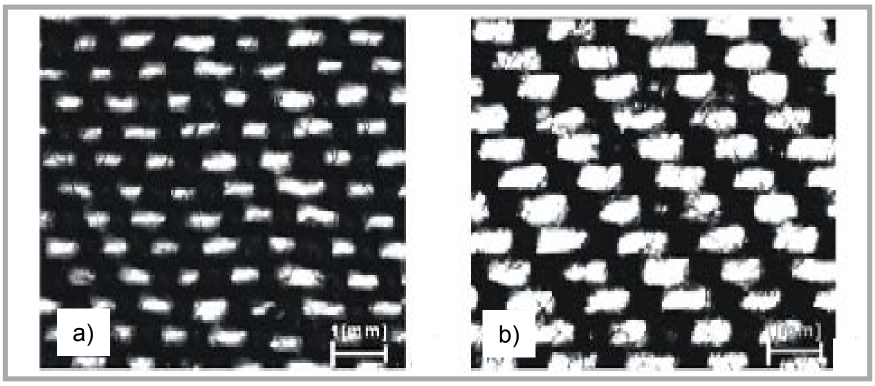

Figure 3. *The effect of the image pre-processing: a) disturbed fabric structure, b) model fabric structure.*

Parameters of denim fabric's structural homogeneity

A description was created from all image parameters of all the weave elements. Their area and shape are described using the following formulas:

Size of weft coat area of denim fabric left side

$$A = \sum_{i=1}^{n}\sum_{j=1}^{m} p(i, j), \text{ pixel} \qquad (1)$$

were:
A – area
$p(i, j)$ – the area of the (i, j) pixel
i, j – two dimensional coordinate
n, m – spantial resolution.

Shape of weft coat

K_{SH} –general shape coefficient

$$K_{SH} = 0.45\ Feret + 0.45\ AspecR + 0.1\ FormF \qquad (2)$$

where:
0.45, 0.1 – the values of *Feret*, *AspectR* and *FormF* coefficients were chosen by estimation
Feret – extension rate

(0≤*Feret*<1)→ vertical extension;
(*Feret*≈1) → square;
(1<*Feret*<∞)→ horizontal.

$$Feret = \frac{W}{H} \qquad (3)$$

W - area width, H – area hight,

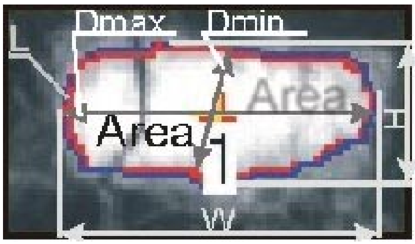

Figure 5. *Identification and description of denim weave's structural elements.*

AspectR – shape oval rate

(0≤*AspectR*<1)→ elliptically flattened;
(*AspectR*≈1) → oval

$$AspecR = \frac{D_{MIN}}{D_{Max}} \qquad (4)$$

D_{MIN} – min diameter of area,
D_{MAX} – max diameter of area.

FormF – edge development rate (1– not corrugated; 0 – very corrugated)

(0≤*FormF*<1)→ corrugated;
(*FormF*≈1) → not corrugated

$$FormF = \frac{4\Pi \cdot A}{L^2} \qquad (5)$$

L – area circumference.

As the next step for each parameter, the variation coefficients (V) were calculated using the following formula:

$$V = \frac{\delta}{\bar{x}} \cdot 100\% \qquad (6)$$

where:
δ – standard deviation,
$\bar{x}$ – average,

They describe the level of the fabric structure's homogeneity accordingly:
V_A – area homogeneity of weft coat
V_K_{SH} – shape homogeneity of weft coat
V_Feret – extension homogeneity of the weft coat
V_AspR – oval homogeneity of the weft coat
V_FormF – edge development homogeneity of weft coat

Results

In Table 1 and Figure 6, we show the averages, standard deviations and variation coefficients of the homogeneity parameters for individual fabrics with structure disturbance (f1, f2, f3, f4, f5 - fabric prepared on different weaving machines) and the model fabric (f6) Analysis of these parameters allowed us to synonymously define the difference between these fabrics.

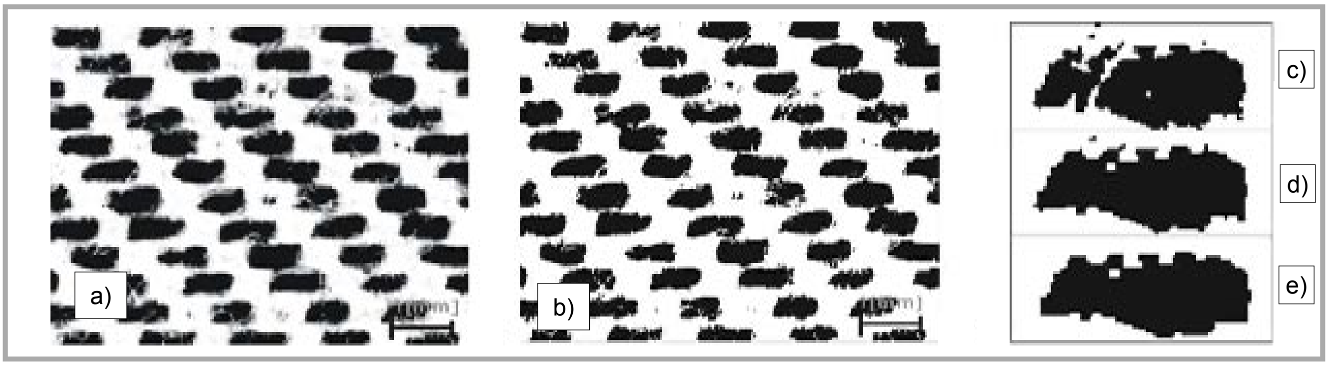

Figure 4. *Operations: a) image negative, b) image segmentation, c) weave element segmentation, d) weave element after closing operation, e) weave element after opening operation.*

Table 1. *Results of weft coat homogeneity parameters for left side of denim fabric.*

denim fabrics	Weft coat homogeneity for left side of denim fabric																			
	V_A				V_Feret				V_FormF				V_AspR				V_K_{SH}			
	$\bar{x}$, mm²	δ, mm²	V%	p%	$\bar{x}$	δ	V%	p%	$\bar{x}$	δ	V%	p%	$\bar{x}$	δ	V%	p%	$\bar{x}$	δ	V%	p%
f1 C_94388	0.121	0.04	35.52	2.85	1.89	0.37	19.78	1.59	0.51	0.05	10.01	0.80	0.40	0.08	21.17	1.70	1.12	0.15	13.58	1.09
f2 C_92577	0.128	0.05	38.09	2.89	1.91	0.42	22.22	1.69	0.51	0.05	9.54	0.72	0.39	0.09	22.24	1.69	1.13	0.17	15.48	1.17
f3 C_83989	0.126	0.05	37.09	2.71	1.85	0.38	20.37	1.49	0.51	0.05	9.61	0.70	0.40	0.08	20.64	1.51	1.10	0.16	14.18	1.04
f4 C_94050	0.123	0.05	37.15	2.71	1.92	0.39	20.29	1.48	0.51	0.05	9.77	0.71	0.39	0.09	22.04	1.61	1.13	0.16	14.07	1.03
f5 C_84664	0.135	0.05	36.02	2.34	1.82	0.39	21.36	1.39	0.52	0.05	9.52	0.62	0.41	0.09	21.54	1.40	1.10	0.16	14.46	0.94
f6 model	0.287	0.06	19.23	1.25	1.65	0.27	16.35	1.06	0.55	0.04	8.14	0.53	0.44	0.08	17.55	1.14	1.04	0.12	11.12	0.72

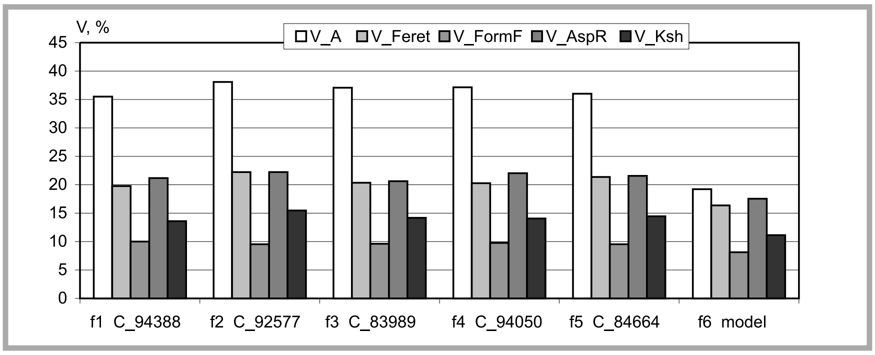

Figure 6. *Diagram of weft coat homogeneity parameters for the left side of the denim fabric – all analysed fabrics.*

The model fabric has the lowest values of the weft coat area's variation coefficient, which are lower by nearly half in comparison to the highest fabric with disturbance. (f6 model –*V_A*=19.23%, f2 C-92577 *V_A*= 38.09%). The values of the weft coat shape's variation coefficient are also lower for the model fabric.

Sample f2 C-92577 has the greatest heterogeneity of the weft coat area, *V_A* = 38.09%, and the greatest heterogeneity of the weft coat shape, V_K_{SH} = 15.48%. The greatest heterogeneity of weft coat shape is caused by the large variation of the extension rate, *V_Feret* = 22.22%, and the oval rate, *V_AspR* = 22.24.

Analysis of the shape coefficients' values leads to the conclusion that all fabrics with structure disturbance have an area with horizontal extension (*Feret*~1.9), elliptical flattening (*AspR*~0.4) and an average level of area corrugation (*FormF* =0.5). For the model fabric's coefficient of extension, the homogeneity of the weft coat is lower (*Feret* = 1.65) but the edge development's homogeneity coefficient is higher (*FormF* = 0.55).

A homogeneity analysis of the weft coat for fabrics with disturbance showed a lack of any major differences between the samples made on different weaving machines. This is also confirmed by the very high accuracy of the estimation of the homogeneity parameters (the relative accidental error p does not exceed 3% for the area and 2% for the shape).

Measuring the weft and warp yarn structure's homogeneity

The fabric consists of cotton threads of weft and warp in contrast colours. Microscope image analysis of the yarn allowed us to describe how it was manufactured. Both weft and warp yarns were manufactured in a break spinning system. This is confirmed by the sight of many fibres which were coiled in parallel and formed characteristic rings on the yarn stem (Figures 7b, c). Hairiness has a chaotic character (Figure 7a) which occurs in the shape of closed loops. In warp yarn disturbances as foreign bodies are additionally visible (Figure 8a). Thickenings and thin places of yarn are also very often visible (Figure 8b) as are entanglements (Figure 8c).

Laboratory research has been carried out to determine the approximate linear mass of warp and weft yarn. The results allowed us to calculate the linear mass on a level of 60.7 tex for warp and 76.1 tex for weft. During measurement, significant mass differences of 0.5 m warp yarn sections were observed, which suggested its great irregularity.

The precise result of warp heterogeneity was obtained by means of computer image analysis. In this case, the homogeneity of the yarn refers to the repetition of yarn diameter on short sections every

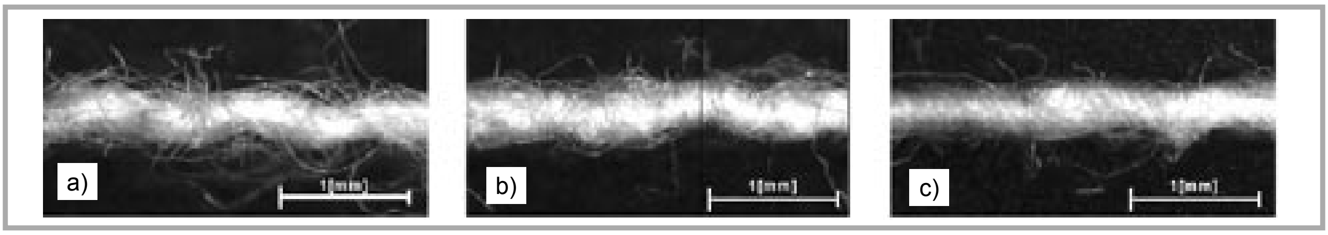

Figure 7. *Image of weft yarn (zoom 1.25=3 mm).*

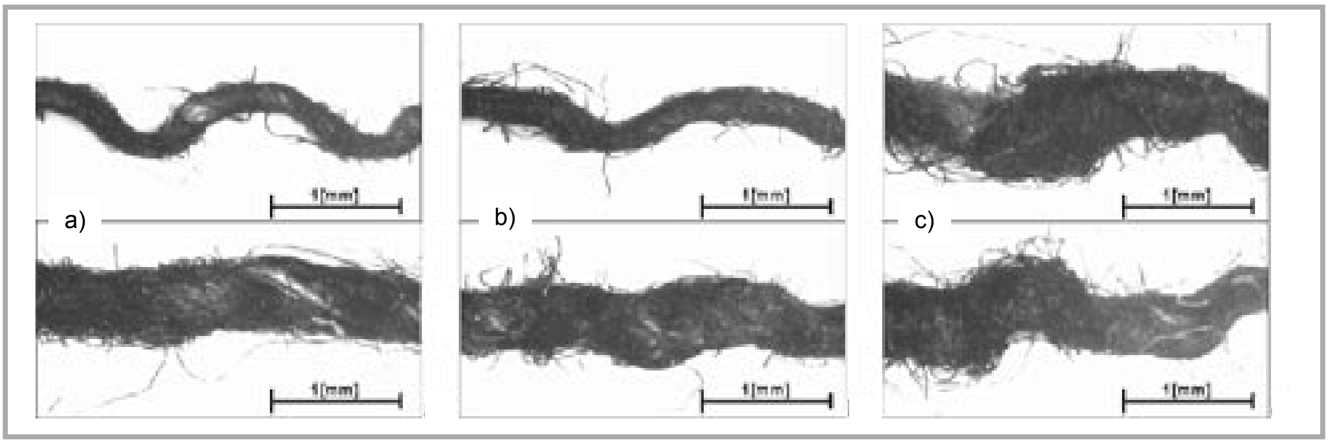

Figure 8*. Image of warp yarn (zoom 1.25=3 mm), a) foreign body inside, b) thickenings and thin places of yarn, c) entanglements.*

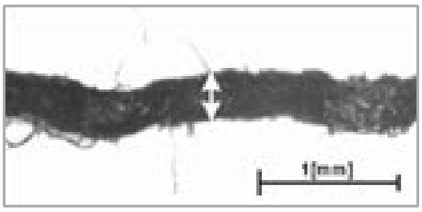

***Figure 9.** The measurement of yarn diameter on sections every 50 and 100 mm.*

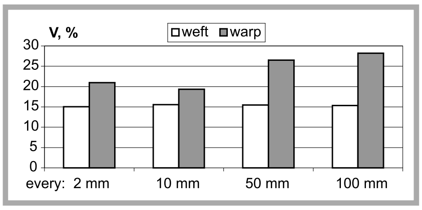

***Figure 10.** Diagram of diameter homogeneity results for evaluated yarns.*

***Table 2.** Results of homogeneity of yarn diameter.*

Homogeneity of yarn diameter				
Measurements		$\bar{x}$, mm	δ, mm	V%
weft	every 2mm	0.34	0.05	15.05
	every 10mm	0.35	0.05	15.54
	every 50mm	0.33	0.05	15.48
	every 100mm	0.33	0.05	15.34
warp	every 2mm	0.46	0.10	20.98
	every 10mm	0.45	0.09	19.34
	every 50mm	0.35	0.09	26.51
	every 100mm	0.37	0.10	28.23

2 and 10 mm, and on medium sections every 50 and 100 mm. The measurement of yarn diameter on short sections was carried out on the image created as the effect of 12 individual yarn images glueing, each with a length of 3 mm. The measurements were registered at a constant distance from each other every 2 and 10 mm on 30-mm sections of yarn.

The measurement of yarn diameter on the medium sections was carried out on individual images ofof 3 mm-long yarn sections. The measurement was always registered in the middle of an image taken from the yarn every 50 and 100 mm (Figure 9).

The homogeneity of the diameter (Table 2 and Figure 10) of weft yarn for short sections (every 2 and 10 mm) and medium sections (every 50 and 100 mm) is on average equal to a level of 15%. The weft yarn has a homogenous diameter throughout its whole length. However, the warp yarn's homogeneity is very diverse; the yarn is not homogenous throughout its whole length. Medium sections especially (every 50 and 100 mm) show great heterogeneity (up to 28%), and short sections up to 19%. The results were verified by Uster® Statistics 2001 for rotor, worsted and 100% cotton yarns (Figure 11).

The weft is within the scope of acceptable norms for this type of yarn manufacture, although for the warp, the lowest variation coefficient CV (every 10 mm) differs from Uster® Statistics.

Conclusions

A new method of analysing the homogeneity of a fabric structure was tested on denim fabric. Thanks to this innovative method of image digital analysis of fabric and yarn, the causes of structure disturbances were determined very quickly. An analysis of the structure homogeneity of fabrics with 'stripe' effect disturbances showed a lack of any major differences between the samples of fabric manufactured on different weaving machines. Testing this method on the model fabric showed that the problem of heterogeneity of a fabric with disturbances lies in its formed threads. Yarn image analysis consisted of diameter measurement of the warp and weft yarns on short sections (every 2, 10 mm) and medium sections (every 50, 100 mm). The microscope warp yarn image revealed heterogeneous fibre twisting which create thin places and thickening, and even foreign bodies, confirming the structural disturbances of these threads. An image analysis of the warp yarn showed that diameter homogeneity is variable, and that the yarn is not homogenous throughout its whole length. Medium sections especially show disturbances up to 28%. Uster® Statistics 2001 disqualify the warp yarn, although the weft is within the acceptable upper limit.

The reason for the heterogeneity of the fabrics analysed is warp yarn heterogeneity. This heterogeneity is present on short and especially long sections, what which finally creates fabric structure disturbances.

This method meets contemporary expectations of speed and precision regarding the non-destructive and objective measurement of ready product quality.

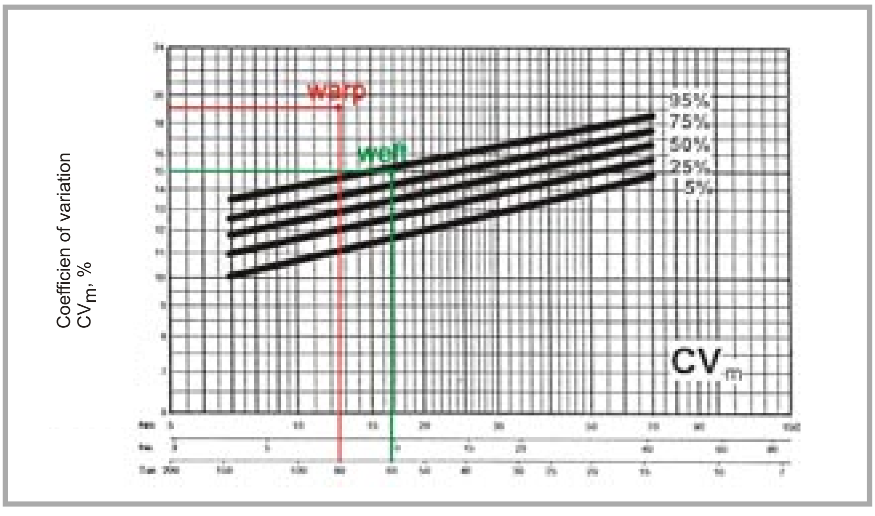

***Figure 11.** Uster® Statistics 2001 rotor, worsted, 100% cotton yarn with marked levels for weft .and short & medium sections (15%), and for warp and short sections (19%) [6].*

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