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Peculiarities of Specimen Preparation for the Investigation of Woven Structure Deformations using Image Analysis

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The paper presents a method based on non – contact image analysis, which allows to simplify experimental process and increase measurement accuracy, identifying local deformations of woven material. Striving to gain accuracy of image analysis results, specimen preparation and deformation process fixation stages are of great importance. For the studies differently marked specimen groups were prepared. Their behaviour in process of tension was analysed using a special calibrated image acquisition system. Using digital images of deformed specimen the displacement of the marked surface elements - points and their shape changes were measured and material deformations in separate specimen parts (A and B) were described. According the obtained results zones of uniform deformations were established and it confirmed that stretched specimen was deformed unevenly. Mild deformations obtained in part A and the highest values of deformation recorded in the centre of part B: local deformations in the transverse to tension direction were set up to −42.9 % and 27.6 % of local elongation along tension direction. Results of local deformation variation explain buckling phenomenon of bias stretched fabric. Particular local deformation values allow us to describe behaviour of deformed material, bring opportunities to perform experimental and modelling comparison of the results. The suggested methodology could be applied for the investigation of differently deformed material behaviour.

Keywords: woven structure, specimen preparation, printed grid, image analysis, local deformations, buckling.

1. INTRODUCTION

Digital image analysis is widely applied in the fields of research and industrial areas, including medicine, microscopy, earth observation, astronomy, defence, material analysis, manufacture, safety, robot techniques, data processing, etc.

Image analysis methods are generally applied for textile materials (thread, woven, knitted, non-woven) properties evaluation, textile quality control or material deformation peculiarities investigations [1]. Current research mainly focuses on the non-contact optical deformation measuring methods, such as methods for determining plane (2D) and out of plane (3D) strains [2 – 3]. Different techniques: holography, speckle and Moiré interferometry, the grid methods and digital image correlation (DIC), have been developed and applied for this purpose [4 – 12].

Mathematical analysis is used to analyze interferometric object images in order to measure the deformation by recording difference of the scattered light wave from the test object surface before and after deformation. Interferometric techniques can measure surface deformations in real time but they require additional surface preparation and it is difficult to apply for cellular materials (foams, polymeric and textile materials) investigations [10].

Using non interferometric techniques (grid and DIC methods) the surface displacement is evaluated by grey scale intensity changes of the object surface before and after deformation [3, 10, 14 – 15].

The digital image correlation method uses optical instruments and optimised correlation algorithms to provide displacement and strain data for mechanical testing. To calculate the displacement of any surface point the proper preparation of the object is very important in order to identify separated elements of the deformed object by special program [12].

The speckle pattern is necessary for the object deformation investigations by image analysis. In order to obtain random grey intensity distribution of a specimen surface, the objects with natural texture are used or surface is treated by spraying black and/or white paints [7, 10, 13]. It is important to achieve sufficient contrast and good speckle pattern in an acquired image.

More then 90 % of image analysis problems are associated with object and image acquisition system arrangement [16]. In order to obtain sufficient accuracy and contrast regular gridlines on specimen surface can be constructed using paint markers [17]. Other scientists propose to use grid of 6 mm circles printed in dark colour on a light colour fabric [18].

The properties of woven fabric are very different from conventional materials (polymers, metals) [19, 20]. Current methods to investigate strain deformations are usually established traditional one dimensional strain-stress curve, however they are incapable of determining local strains [1]. Textile behaviour during stretching has anisotropic peculiarities, as a result, there are not even deformations in separate specimen areas. Methodic, which allows to determine local deformations of woven material, will increase the accuracy of obtained result and will give additional information about woven structure behaviour during deformation.

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The present paper focuses on problems of specimen preparation for the image analysis that could easy and quickly establish local deformations of the deformed textile materials by objective parameters.

2. EXPERIMENTAL

2.1. Analysis method

For the analysis plain woven fabric was selected (Table 1).

To demonstrate capabilities and reliability of the proposed image analysis method the simplest and most commonly used uniaxial tensile test was chosen. Universal testing machine "Thinus Olsen" was used at upper clamp speed 10 mm/min.

Table 1. Characteristics of tested fabric

Surface density, g/m^2	Thickness, mm	Number of threads per unit length, cm^{-1}		Linear density, tex		Composition	
		warp	weft	warp	weft	warp	weft
155	0.43	28	20	39.9	18.1	70 % Cotton 30 % PES	100 % PES

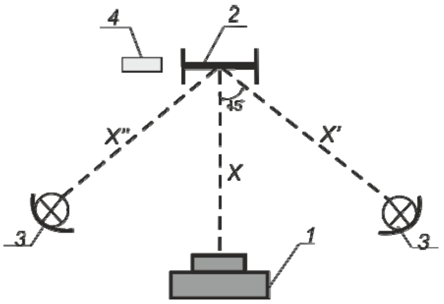


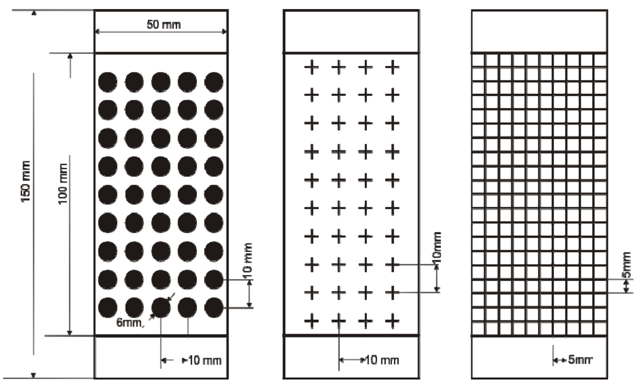
Fig. 1. The scheme of experiment: 1 – digital camera, 2 – specimen, 3 – light source, 4 – ruler

For the investigation specimen 2 was captured by digital camera "Olympus E620 1" (lens 14-42 with resolution 4032 × 3024 pixel), that was located stationary in front of the specimen 2 at a distance $X = 350$ mm (Fig. 1). The centre of camera lens was set in front of tensioned specimen plane. Two light sources 3 in the angle of 45° (300 W Phillips halogen lemp, 3000 K) were placed at distance $X' = X'' = 350$ mm. The images of deformed specimen were acquired at every step of 5 % of specimen elongation until the bias fabric starts to buckle and buckling wave appear. For the digital image calibration the rule 4 was placed at the same plane as deformed specimen.

2.2. Sample preparation

Rectangular specimens with subsidiary line grid – I type with filled circles, II type with crosses, III type with gridlines, were prepared of operating area 50 mm × 100 mm (Fig. 2). Samples were printed in black colour on a light colour fabric.

To evaluate the influence of print on the sample properties tension curves of printed specimen were analysed (Fig. 3). It was found that curves of non printed fabric and fabric printed with type I and type II grid cover each other, and parameters change in standard error limit.



a b c

Fig. 2. The schemes of specimen preparation: a – type I (fill circles grid); b – type II (crosses grid); c – type III (gridlines)

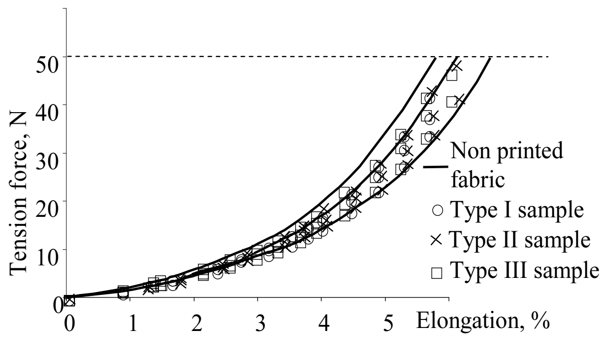


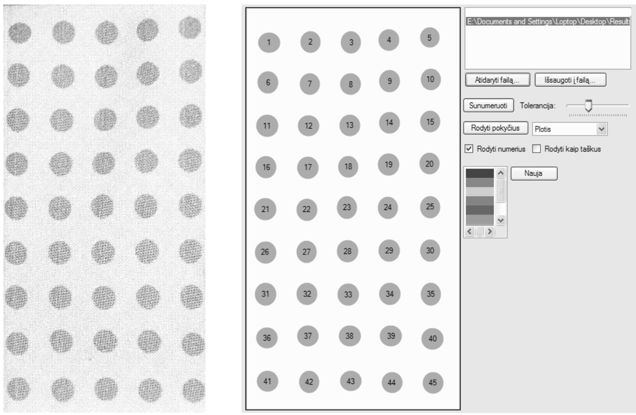
Fig. 3. Tension curves of non-printed samples and samples with different type grid

A calibration experiment was performed to quantify the chosen equipments and system of image acquisition. The image of sample with printed 5 mm × 5 mm gridlines was recoded by proposed system. In the calibration experiment, correction of distortion was carried out using acquired image and virtual gridlines produced by "Corel DRAW 13" program. The obtained error was less then 0.02 mm.

2.3. Image analysis

The input images were converted to grey scale of 8-bit image. To reduce the effect of noise Gaussian blur filter with radius $\sigma = 3$ was applied. Image processing by threshold procedure was used to restore the grid of an acquired image of deformed sample. The threshold value was determined as mean value of approximated histogram of a specimen image.

Specialised program "ImageJ" was supplemented by developed subprogram "KTU_Image JD" (Fig. 4) and measurements of height h and width b of each grid point were made (Fig. 5). Measurements of the captured image during the calibration process were transferred to the desired metric units.



a b

Fig. 4. Image processing: a – acquired image of printed specimen; b – simulated image by program “KTU_Image JD”

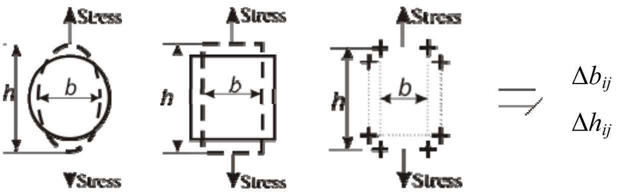


Fig. 5. The scheme of grid point height *h* and width *b* measurements

Investigations of the printed mesh showed that calculated variation of grid point height *h* and width *b* displays the actual place of specimen local displacements in longitudinal (tension) direction Δh_{ij} and perpendicular to tension direction Δb_{ij}:

$$\Delta b_{ij} = \frac{b_0 - b_{ij}}{b_0}, \quad (1)$$

$$\Delta h_{ij} = \frac{h_0 - h_{ij}}{h_0}, \quad (2)$$

where b_0 – initial width of grid point, h_0 – initial height of grid point, b_{ij}, h_{ij} – value of *i* grid point deformation at moment *j*.

3. RESULTS AND DISCUSSION

The choice of sample preparation method and printed grid type takes into account such criteria as simplicity, reproducibility and reliability of obtained measurements. After investigation of the samples with I, II and III type grid (Fig. 2) close maximum values of parameters Δb and Δh were observed in all three types of prepared specimens. The obtained difference was 0.14 % (Table 2).

For the samples with gridlines (III type) whole specimen area was examined, but during acquired digital image processing much noise appeared, which may distort the results of calculated local deformations. It was found that gridlines disturb processing of deformed sample image as fine lines of the grid can not be acquired with high quality and problems associated with missed edge points occur.

Table 2. Maximum values of parameters Δb_{ij} and Δh_{ij} at 20 % elongation

Specimen direction	Printed grid type	$\Delta b_{20\,max}$, %	$\Delta h_{20\,max}$, %
Bias	I type	–42.93	27.57
	II type	–42.91	27.54
	III type	–42.81	27.43

For the samples with cross type auxiliary lines (II type) the coordinates of cross centre were estimated and obtained values of local deformations were close to I type sample.

Images of the I type samples were processed by program “KTU_Image JD” when filled circus grid restored as mathematical description of the ellipse. Samples of the I type were chosen for later investigations because of grid points correlation algorithm accuracy and possibility to obtain more then two parameters of measurements.

Due to the rigid edges fixation in clamps of tension machine specimen experiences uneven deformations. A and B parts were separated for the investigated specimens (Fig. 6). As it is stated in earlier scientific researches [18] slight changes in the woven structure are estimated in part A: proposed method showed up to 4 % elongation in the longitudinal direction and up to 10 % contraction in transverse direction. The highest values of deformation are recorded in the centre of part B of stretched bias specimen. Uneven deformations are estimated at initial stages of specimen elongation and clear zones of local longitudinal and transverse (Fig. 6) deformations are composed. At elongation $\varepsilon_i = 5$ % two zones are separated and obtained amount and shape of these zones convenient with one presented in literature [15, 18]. 3 new local deformation zones release (part B) when woven specimen reaches elongation $\varepsilon_i = 10$ %: specimen elongates up to 5.3 % and contracts up to 20.7 % in a centre zone. Later stretching of the specimen causes not only woven structures changeover, but changes of weft and warp threads crimp as well. Due to the changes of the interspaces between fabric threads new zones of local deformations are recorded and 5 different zones are separated when specimen elongation increases up to 15 %. Spatial deformations start when specimen reaches the limit of critical elongations and buckling phenomenon reveals. It was found that investigated fabric buckles when bias specimen elongation overcomes 20 %.

The highest values of local contraction deformations ($\Delta b_{i20} = 42.6$ %) are estimated in the centre of specimen middle line when local longitudinal elongation $\Delta h_{i20} = 27.4$ % and total specimen elongation $\varepsilon_i = 20$ % (Fig. 8). In the specimen centre the values of longitudinal deformations varies more slowly than the transverse contraction deformations and conditions for specimen buckling are composed ($\Delta b < 0$, $\Delta h > 0$).

Poisson's ratio of surface points that evaluates the ratio between transverse and longitudinal strains was calculated at every stage of specimen elongation (Figs. 9, 10). The estimated graphs prove that the Poisson’s ratio is not distributed uniformly, it values depend on point position and specimen elongation.

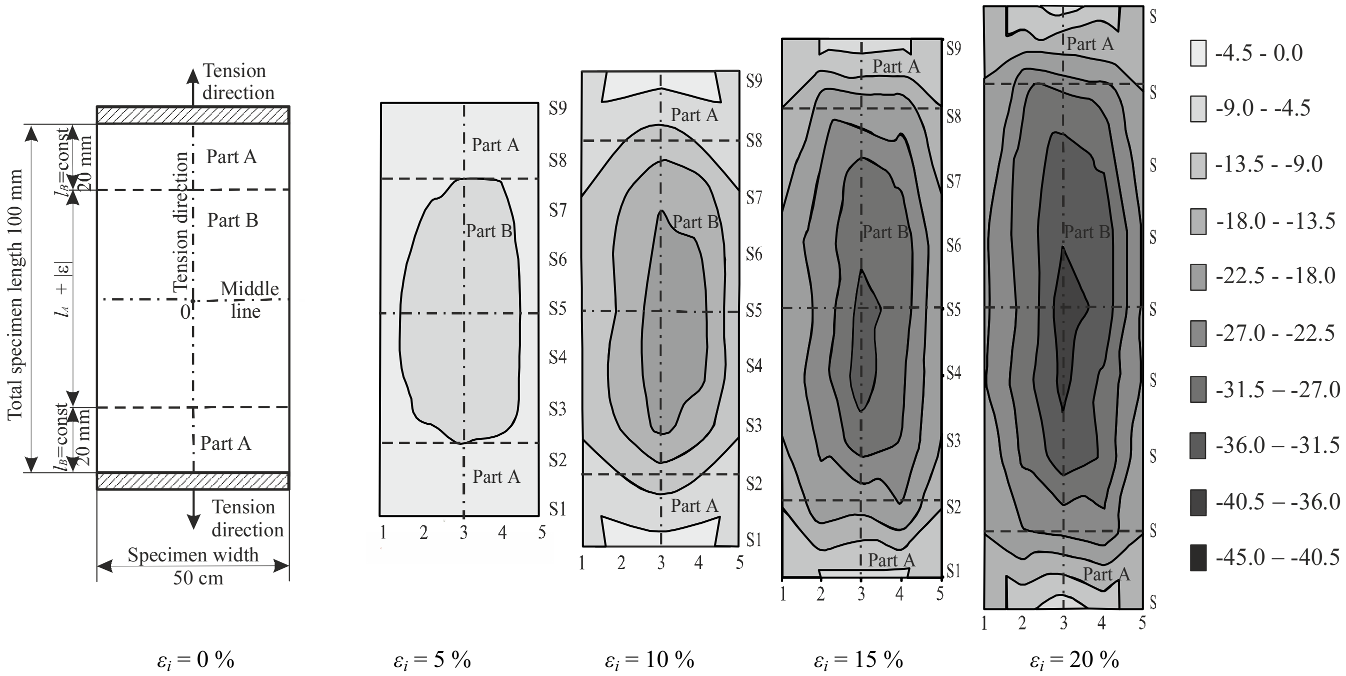


Fig. 6. The view of bias specimen local deformation zones estimated on the basis of parameter Δb_{ij} variation

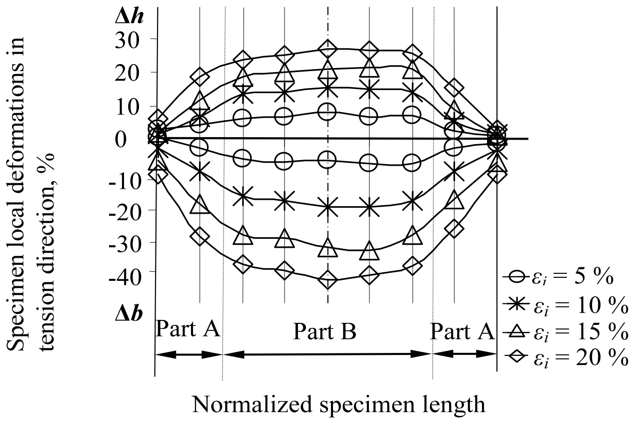


Fig. 7. Maximum deformations in the bias specimen vertical centre line

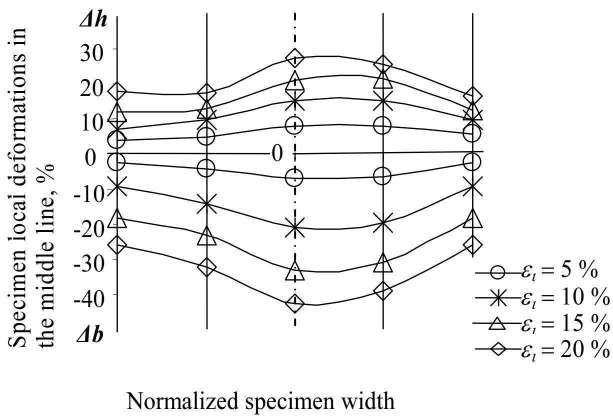


Fig. 8. Maximum deformations in the bias specimen middle line

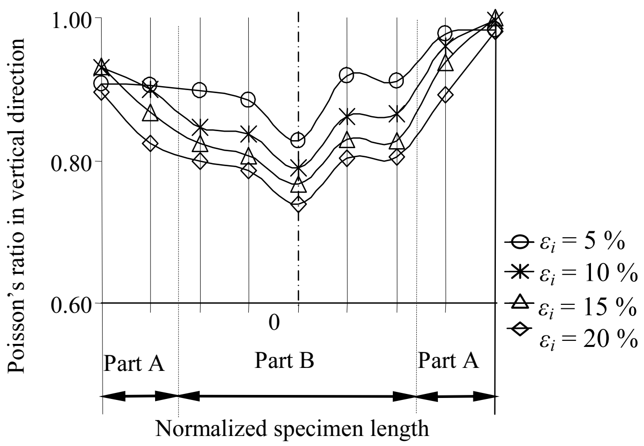


Fig. 9. Variation of Poisson's ratio in the specimen vertical centre line

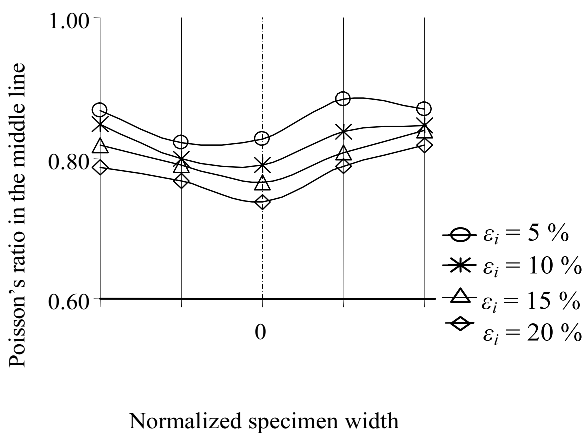


Fig. 10. Variation of Poisson's ratio in the specimen middle line

4. CONCLUSIONS

Non-contact image analysis method for plane strain measurement allows to display the local deformations of the specimen when changes of printed grid geometry evaluate the real time displacements of deformed woven sample. The increase of woven specimen elongation ε_i raises changes of grid point width *b* and height *h*. Clear zones of uniform specimen deformation appear and number of these zones increases when specimen elongates. The highest values of local deformations are obtained in the stretched bias specimen part B centre. The buckling phenomenon of bias fabric can be explained more detailed analysing local deformations of deformed specimen.

The proposed digital image based methodology can be applied to study behaviour of various materials. Both the local longitudinal and transverse deformations can be estimated simultaneously and it contributes results obtained by traditional uniaxial strain testing method.

According to the observations it can be stated that proposed method and parameters well reflect the behaviour of the investigated textile material and also could validate traditional mechanical models of textile materials more conveniently.

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