KAUNAS UNIVERSITY OF TECHNOLOGY

INGA AUDZEVIČIŪTĖ-LIUTKIENĖ

INVESTIGATION AND EVALUATION OF DEFORMATIONS OF WOVEN AND KNITTED FABRICS AND THEIR FILAR SYSTEMS

Summary of Doctoral Dissertation
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INTRODUCTION

Rapidly developing and improving science, along with new technologies considerably influence many industries. Therefore the textile and apparel industry are changing continually. Textile materials with new characteristics and specific, complex apparel products with various types of combinations are being developed. In recent years, the textile industry has been directed towards special types of garments, which should be comfortable for consumers, and technical, economical and quality is also an important side of the industry. Textile materials‘ mobility depends on its structure and elements position, in addition to its fabric deformation properties, so that the textile materials can hold their dimensional shape. Textile materials are characterized as anisotropic and heterogeneous due to it being very important to predict fabric properties in the garments‘ reaction depending on various factors: different parts of orientation in the garment, different and various fabrics anisotropy, different parts of garment mobility in various directions, direction of seams and etc. According to the scientists, researchers are determined that characteristics of shear and extension characterize behaviour of textile materials during their manufacture and exploitation. At present, many new methods of evaluation of textile materials‘ deformations are created but researchers face the problem of finding inexpensive, simple and efficient methods of evaluating the mechanical characteristics of textile materials and their systems, especially location of deformations and their intensity. Often, traditional evaluation methods are use to determine deformations characteristics of textile materials. However, researchers are searching for new methods for a more comprehensive evaluation of complex deformations.

3D modelling and simulations of the deformations properties of textile materials and garments has received much attention in recent years in scientific literature. In the textile and apparel industry, 3D modelling is used not only for simulation of the virtual garments‘ view, but it is used for the evaluation of the fabrics mechanical properties without the necessity to create a real product. Finite element method (FEM) is one of the most universal and widely used in engineering. In the textile industry, FEM is used for the optimization of textile materials, garment manufacturing processes, evaluation and the investigation of stress/strain distribution in fabrics.

Relevance of the topic

Textile materials structure are anisotropic and heterogenous and acting forces have a different effect on the type and degree of their deformation. Therefore it is importance to evaluate and predict fabrics properties in manufacture processes (modelling constructions, cutting, joining different parts of the garment and etc.), to guarantee high quality in exploitation (wearing, laundering and etc.). Evaluation of the textile materials deformation and their location let users increase efficiency of the product manufacture process, to choose the optimal modelling construction of the garment and to guarantee a high quality in exploitation.

New textile materials with a complicated deformational behaviour constantly emerge in the market. According to scientific literature, it was observed that researchers face a problem of finding inexpensive, simple and efficient methods to evaluate the mechanical characteristics of textile materials and their systems. However, there is a deficit of universal methods for the evaluation of unique deformational behaviour of various textile materials and their systems. It is important to decrease the amount of tested specimens, experimental materials, investigation costs and time expenditure. The seams and specific, complicated combinations of garment parts decrease the tensile properties. However, very few studies analyse the seams mobility, influence on the fabrics stability and tensile properties. It was observed that the finite element method (FEM) has been used in engineering in the last few decades, but there is very few scientific research papers in the textile and apparel industry.

The aim of the dissertation

Develop a new, universal and simple method for the evaluation of the behaviour of textile materials and their filar systems according to the complex behaviour of textile materials during exploitation.

The objective of the research

1. To determine tensile level of textile materials during uniaxial tension till break and at low-stress;
2. To investigate the potential and suitability of the parallelepiped specimen method for evaluation of thin one layer textile materials deformations;
3. To develop a new, universal and simple method for evaluating the behaviour of textile materials and their systems according to the complex behaviour of textile materials and acting forces during exploitation. Also to find suitable characteristics for the evaluation of textile materials and their systems deformational behaviour;
4. To develop a numerical research methodology of a new shape specimen using the finite element method (FEM) and verify the numerical model based on experimental results.

Scientific novelty and practical importance

Developed new method is suitable for investigation and evaluation of textile materials and their systems deformations according to pecularities of wearing processes. In this work were defined optimal research conditions and suitable parameters of evaluation. Deformation properties are evaluated by graphical, digital and numerical methods. The new Y shape specimen method is close to real wearing conditions. The developed numerical research methodology of the Y shape specimen using the finite element method (FEM) provides and evaluates deformations of textile materials without the necessity to perform real experiments. Also, narrow limits of textile numerical research methods was extended.

Defensive propositions

1. Values of characteristics of the parallelepiped specimen method did not correlate with the values of traditional uniaxial tension method. Therefore, the parameters of the parallelepiped specimen method are not suitable for evaluation of thin one layer textile materials deformational behaviour;
2. New Y shape specimen method and determined parameters of longitudinal, transverse and angular deformations are suitable to evaluate deformations properties of textile materials and their systems at low stress;
3. Numerical research methodology of the Y shape specimen using the finite element method (FEM) is adequate for experimental methods, results are correct and suitable for both, practical and scientific use.

Structure of the doctoral dissertation

The dissertation consists of: introduction, 3 chapters, conclusions, list of references (207 entries) and list of scientific publications and 8 appendixes. The material of the dissertation is presented in 110 pages, including 62 pictures and 6 tables.

Approbation of the research results

The results of the research are present in 9 – scientific publications, 2 of them in journals from the list of the Institute for Scientific Information (ISI). The results of the research were presented in 5 – international and 2 – national conferences.

CONTENT OF THE DISSERTATION

Introduction presents the relevance of the investigations, defines the aim and objectives of research, and discusses scientific novelty and practical significance of the dissertation.

Chapter One reviews the literature related to the topic of the dissertation.

Chapter Two. Materials. The key characteristics of the investigated textile materials are shown in **Table 1**. The fabrics were chosen intending to global demand of textile materials and to evaluate new method universality for various textile fabrics and to use experiments results in various fields of application. For the experiments were used two groups of textile materials: woven (1st group) and knitted (2nd group) fabrics. First group is consists of 5 woven fabrics containing elastane fibres and 4 woven fabrics without elastane. The second group of textile materials consists of 3 knitted fabrics containing elastane fibres and 4 knitted fabrics without elastane.

Table 1. The specification of tested fabrics

Fabric code		Composition of yarns, %	Weave structure	Mass per unit area *w*, g/m²	Density, cm⁻¹	
					Warp (Lengthwise) direction	Weft (Crosswise) direction
1st group. Woven fabrics	A1	100 WO	½ twill	200	23	19
1st group. Woven fabrics	A2	65 CO, 35 PES	plain	227	26	19
1st group. Woven fabrics	A3	50CO, 50 CV	½ twill	217	42	18
1st group. Woven fabrics	A4-EL-a	98 CO, 2 EL	½ twill	292	56	24
1st group. Woven fabrics	A5	57 LI, 43 CO	Plain	228	20	13
1st group. Woven fabrics	A6-EL-ma	96 PES, 4 EL	plain	294	25	21
1st group. Woven fabrics	A7-EL-a	70 CO, 27 PES, 3 EL	1/3 twill	279	40	30
1st group. Woven fabrics	A8-EL-a	50 CV, 48 PES, 2 EL	½ twill	251	37	18
1st group. Woven fabrics	A9-EL-m(a)	97 PES, 3 EL	½ broken twill	281	31	27
2nd group. Knitted fabrics	M1	70 CMD, 30 milk protein	Double weft-knitted	166	15	15
2nd group. Knitted fabrics	M2-EL-e	66 CMD, 30 milk protein, 4 EL	weft-knitted	162	21	31
2nd group. Knitted fabrics	M3	100 bamboo	weft-knitted	168	17	22
2nd group. Knitted fabrics	M4-EL-e	95 bamboo, 5 EL	weft-knitted	176	19	27
2nd group. Knitted fabrics	M5-EL-(e)	97 bamboo 3 EL	weft-knitted	172	18	23
2nd group. Knitted fabrics	M6	100 CO	weft-knitted	120	17	23
2nd group. Knitted fabrics	M7	100 PP	weft-knitted	180	13	18

Methodology I. Investigation of the tensile of the textile materials and their systems during uniaxial tension until breaking according to standard LST ISO 13934 – 1: 2013 and at low-stress (490 N/m for woven and 50 N/m for knitted fabrics). The measurements of rectangular shaped specimens were l_{V1} = 100 mm and b_{V1} = 50 mm (**Fig. 1 a**). The specimens with vertical and horizontal seams were also used in this investigation for knitted fabrics (**Fig. 1 b, c**). The distances for the seam locations were choose as follows l_{V2} = 50 mm, b_{V2} = 25 mm. Flat seams of 7 mm width were made by a four-thread overedge stitch machine *JANOME 204D* (stitch type 514, stitch rate – 3 stitches/cm, differential feed ratio - 1.0). The threads of 100 % PES were used for seams. Every specimen data were evaluated in lengthwise and crosswise directions using average results of six specimens. The specimen's extension was carried out using a *Tinius Olsen HT10* tension machine. The cross-head speed was kept at v_V = 100±5 mm/min. The coefficients of variation of the received results did not exceed 5.5 %.

The characteristics of the fabrics break force F_{Vtr} and break elongation ε_{Vtr} were determined from the load-extension curves. Break elongation anisotropy coefficient an_V was calculated as follows:

$$an_V = \frac{\varepsilon_{max}}{\varepsilon_{min}} \quad (1.1)$$

where ε_{max} – maximal brak extension, (mm); ε_{min} – minimal brak extension, (mm).

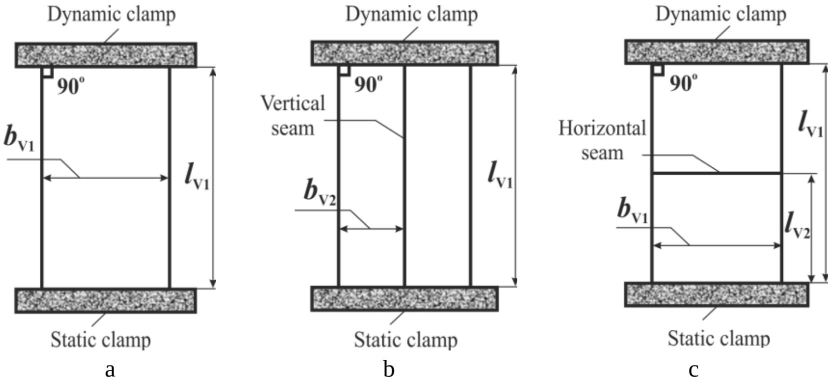


Figure 1. Rectangular specimen without seam (a), with horizontal (b) and vertical (c) seams

In ***Methodology II,*** the investigation and evaluation of the tested textile materials deformations using parallelepiped shape specimens are presented. The measurements of the parallelepiped shape specimen's were as follows: width b_G = 50 mm and distance between the clamps l_G = 100 mm, additional selvages l_{Gp} length is 14 mm (**Fig. 2**).

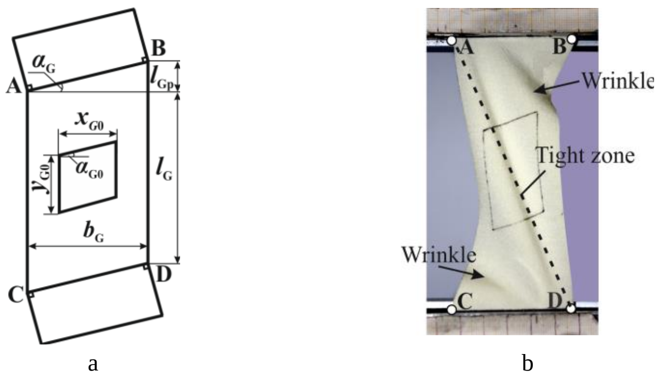


Figure 2. Initial shape of the parallelepiped shape specimen and its basic measurements (a) and the specimen after fixation in the clamps (b)

The specimen's upper (AB) and bottom (CD) selvages were cut at $\alpha_G = 16°$ angle. The extension distance, which is necessary to transform the parallelepiped specimen shape into the rectangular shape, was $\varepsilon_{G14} = 14$ % (for woven and knitted fabrics), $\varepsilon_{G45} = 45$ % (for knitted fabrics) and woven fabrics' specimens were transformed untill ε_G, when jogs disappeared. In the middle of specimen, a parallelepiped was drawn (30 x 30) mm^2, which sides are parallel to the specimen selvages A-B-C-D (**Fig. 2 a**). After the specimen selvages AB and CD were fixed in the clamps, it forms jogs in the bias direction (selvages AC and BD) (**Fig. 2 b**).

The characteristics of the fabrics tensile force F_{G14}, F_{G45} and F_G were determined from the load-extension curves. Characteristics x'_G, y'_G, x'_{G45}, y'_{G45}, α'_{G45}, α'_G were calculated as follows:

$$x'_{G;G45} = \frac{x_{G1} - x_{G0}}{x_{G0}} 100\%; \qquad (1.2)$$

where x_{G0} – the drawn parallelepiped sides width before stress (30 mm); x_{G1} – the drawn parallelepiped sides width after extension $\varepsilon_{G45} = 45$ % and ε_G.

$$y'_{G;G45} = \frac{y_{G1} - y_{G0}}{y_{G0}} 100\%; \qquad (1.3)$$

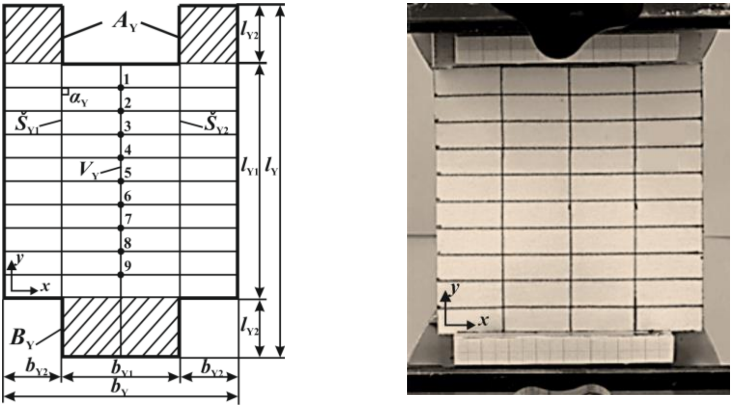
where y_{G0} – the drawn parallelepiped sides length before stress (30 mm); y_{G1} – the drawn parallelepiped sides length after extension $\varepsilon_{G45} = 45$ % and ε_G.

$$\alpha'_{G;G45} = \frac{\alpha_{G1} - \alpha_{G0}}{\alpha_{G0}} 100\% \qquad (1.4)$$

where α_{G0} – the drawn parallelepiped angle before extension (16º); α_{G1} – the drawn parallelepiped angle after extension $\varepsilon_{G45} = 45$ %.

Each specimens' data were evaluated in lengthwise and crosswise directions using average results of six specimens. The specimen's extension was carried out using a *Tinius Olsen HT10* tension machine. The cross-head speed was kept at $v_G = 100 \pm 5$ mm/min. The coefficients of variation of the received results did not exceed 9.8 %.

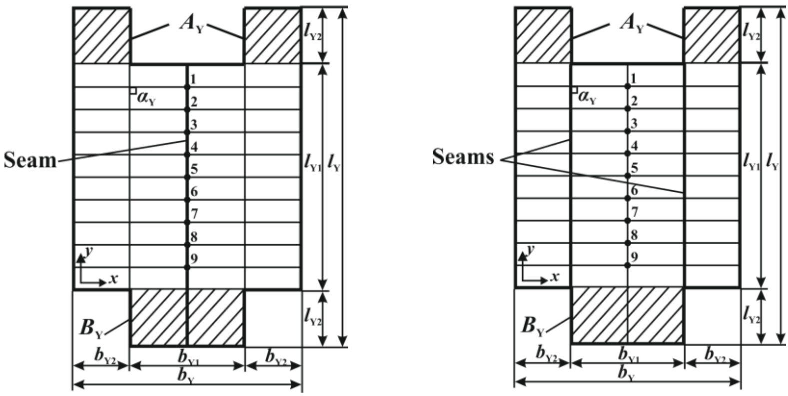
In ***Methodology III***, investigation and evaluation of the tested textile materials and their systems deformations using Y shape specimens are presented. The measurements of the Y shape specimen: $b_Y = 100$ mm, $b_{Y1} = 50$ mm, $b_{Y2} = 25$ mm, l2= 25 mm, $l_Y = 200$ mm, $l_{Y1} = 100$ mm, $l_{Y2} = 25$ mm (**Fig. 3 a**). At the beginning of the experiment, the angle between lengthwise and crosswise threads was $\alpha_Y = 90°$. In the specimen, horizontal lines (10 mm± 1 mm interval) which are parallel to the specimen horizontal selvages were drawn and are marked from 1 to 9. Also, on the specimen sides two vertical lines $Š_{Y1}$, $Š_{Y2}$ and one vertical line V_Y in the middle of specimen were drawn (**Fig. 3 b**). The specimen upper selvages A_Y and bottom selvage B_Y were fixed in the clamps.



a b

Figure 3. Initial shape of the Y shape specimen and its basic measurements (a) and the specimen after fixation in the clamps (b)

Evaluation of seams to deformations of the textile materials were used in two types of Y shapes specimens with a vertical seam in the middle of the specimen (**Fig. 4,a**) and two vertical seams in the sides of the specimen (**Fig. 4 b**).



a b

Figure 4. Initial shape of the Y shape specimen with vertical seam in the symmetry axis of specimen (a) and vertical seams in the cut selvages of specimen (b)

The seam, with stitch density 3 stitches per cm, was produced by the sewing machine *JANOME Memory Craft 6600P* for woven fabrics (stitch type

301, seam width 10 mm, differential feed ratio - 1.0). Flat seams of 7 mm width were made by four-thread overedge stitch machine *JANOME 204D* for knitted fabrics (stitch type 514, stitch rate – 3 stitches/cm). The threads of 100 % PES were used for seams. The extension distance was ε_{Y10} = 10 % (for woven fabrics) and ε_{Y40} = 40 % (for knitted fabrics).

During the experiment three more characteristic points of specimen – 1, 5 and 9 were chosen in order to determine the longitudinal, transversal and angular deformations of the fabrics characteristics $h_i{}'_{Y10;Y40}$, $vs_i{}'_{Y10;Y40}$, $\alpha_i{}'_{Y10;Y40}$ (**Fig. 5**).

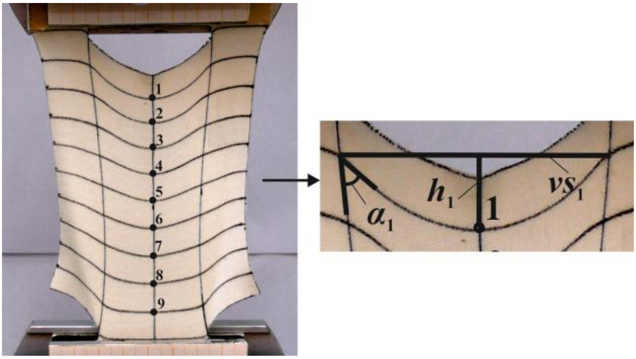


Figure 5. Metrical scheme of geometrical parameters during tension process

The characteristics as fabrics tensile force F_{Y10} and F_{Y40} were determined from load-extension curves. Characteristics $h_i{}'_{Y10;Y40}$, $vs_i{}'_{Y10;Y40}$, $\alpha_i{}'_{Y10;Y40}$ were calculated as follows:

$$h'_{iY10;40} = \frac{h_1}{l_{Y1}} 100\%; \tag{1.5}$$

where h_1 – distance from horizontal line to the new position of the point after extension, mm, i = 1, 5 and 9 points; l_{Y1} – specimen length before tension, (100 mm).

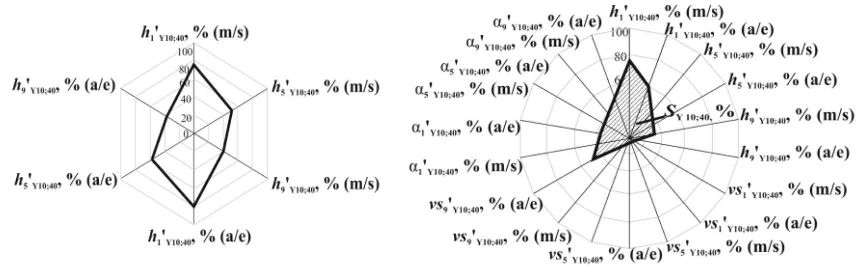
$$vs'_{iY10;40} = \frac{|vs_1 - vs_0|}{vs_0} 100\%; \tag{1.6}$$

where vs_0 – initial distance between $\check{S}_{Y1}$ and $\check{S}_{Y2}$ before tension, (50 mm); vs_1 – distance between $\check{S}_{Y1}$ and $\check{S}_{Y2}$ after extension, mm, i = 1, 5 and 9 points.

$$\propto'_{iY10;40} = \frac{|\propto_1 - \propto_0|}{\propto_0} 100\%; \tag{1.7}$$

where α_0 – initial angle between horizontal and vertical lines before tension (90°); α_1 – angle between horizontal and vertical lines after extension, °, i = 1, 5 and 9 points.

An evaluation of the tested textile materials and their systems deformations circular chart was used. The circular charts were used in two stages. In the first stage characteristics $h_i'_{Y10;Y40}$, $vs_i'_{Y10;Y40}$, $\alpha_i'_{Y10;Y40}$ were plotted individually (**Fig. 6 a**). In second stage all characteristics were plotted on the same chart (**Fig. 6 b**). According to the hysteresis values area $S_{Y10;40}$ was drawn. *AutoDesk AutoCAD 2014* software package was used to calculate area $S_{Y10;40}$.



a b

Figure 6. Circular chart of the first stage (a) and second stage (b)

Each specimens' data were evaluated in a lengthwise and crosswise direction using the average results of six specimens. The specimen's extension was carried out using a *Tinius Olsen HT10* tension machine. The cross-head speed was kept at v_Y = 10±5 mm/min. The coefficients of variation of received results didn't exceed 5.9 %.

All fabrics (in methodology I, II and III) are conditioned in standard atmosphere conditions of 65 % RH and 20°C.

In ***Methodology IV***, investigation and evaluation of the tested textile materials deformations using numerical model (*ANSYS* sofware package). The algorithm of numerical solution was as follows:

- ***Pre-processing Phase***. In this part the geometrical model of Y shape specimen was formed, in a way that would be easy to change the geometry, materials. Segmentation of the geometrical model was performed by finite elements;
- In the part of ***Solution Phase***, calculations were performed;
- ***Post-processing Phase***. In this part, analysis of the obtained results was performed.

The investigated structure is axis symmetrical, thus to reduce the calculation duration (**Fig. 7 a**). In order to ensure adequacy of the model to the real stress-strain state, typical in the case of the whole Y shape specimen, the structure is fixed by indicating symmetry conditions to corresponding surfaces. Displacements of the structure are restricted by fixing part B_Y rigidly, allowing for parts A_Y to move only vertically. Knitted fabric M7 (100 % PP) in lengthwise was selected for the modelling. Fabric mechanical characteristics are: E_x = 0,9 MPa and E_y = 2,0 MPa (Young's modulus), $G_{x,y}$ = 0,018 MPa (Shear modulus), μ= 0,018 and μ= 0,018 (The Poisson ratio). Since all the components of the real investigated object were basically of flat type, its geometrical modeli s made from surfaces, while in numerical model these surfaces are split using *Plane 42* type finite elements (**Fig. 7 b**).

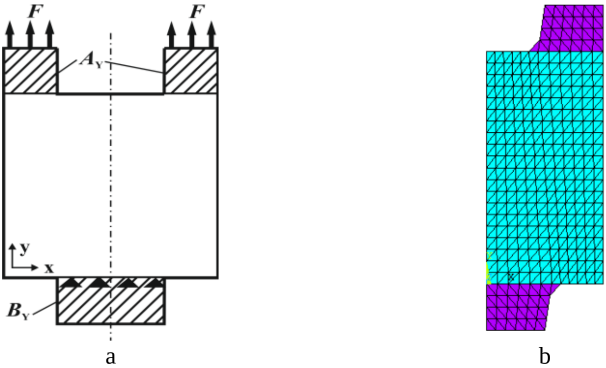


Figure 7. Principal scheme of Y shape specimen (a) and specimen divided into finite elements (b)

The grid was regular, which elements had two degrees of freedom in every nodal point and allow calculating all the parameters, necessary to evaluate the state of elastically deformable flat thin-walls structures. Designing the numerical model, it is considered that knitted fabric is deformed up to 40 mm by 5 mm steps.

Fixing conditions of Image analysis technique

During the experiments, the image of the analyzed objects were obtained using a mirror digital photo camera *Pentax K7* (18 – 55 mm F/3.5 – 5.6 AL lens). Distance from specimen to the lens was 500 mm. For the calibration of the obtained images, a ruler (accuracy 0.5 mm) was fixed on the tension machine clamps. During the tension experiment of the parallelepiped specimen, the images of the analyzed objects were obtained using two side lighting, when the lighting angle was 60 degrees (**Fig. 8 a**). During the tension experiment of the Y shape specimen, one side lighting was used (**Fig. 8 b**).

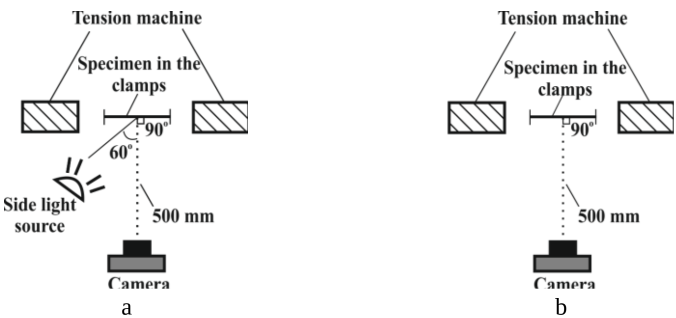


Figure 8. Register scheme of a deformed parallelepiped (a) and Y shape specimen (b)

LED type one or two side lighting used *Epistar* 9W lamps with colour temperature of 3000 – 6000 K. *Adobe Photoshop CS4* software package was used for the correction of images. Also *AutoDesk AutoCAD 2014* software package was used to make the measurements of the specimens‘ geometrical parameters.

Chapter 3. Results. Evaluation of tensile of textile materials and their systems during uniaxial tension untill break and at low-stress. Woven fabrics.

Values of characteristics as tensile force F_{Vtr}, break elongation ε_{Vtr} and break elongation anisotropy coefficient an_V are presented in **Table 1**. Values of break force F_{Vtr} ranged from 57.8 N/cm to 225.6 N/cm, break elongation ε_{Vtr} ranging from 11.5 % to 119.0 % and break elongation anisotropy coefficient an_V ranged from 0.2 to 0.9. The results indicate that the lowest values of F_{Vtr} were received for fabric A1 in both directions (F_{Vtr} = 57.8 and 71.7 N/cm), whereas the highest break force F_{Vtr} was received for fabric A3 in the warp direction (F_{Vtr} = 204.8 N/cm) and fabric A5 in the weft direction (F_{Vtr} = 225.6 N/cm). According to the results obtained, fabric A1 showed higher structural stability in both directions. It shows low values of break elongation ε_{Vtr} (29.9 % (warp direction), 27.1 % (weft direction)) and break elongation anisotropy coefficient $an_{V,}$ which is about one ((an_V = 0.9).

Table 1. Values of woven fabrics characteristics

Code	F_{Vtr}, N/cm		ε_{Vtr}, %		an_V
	warp	weft	warp	weft	
A1	**57.8±1.14 ***	**71.7±1.20 ***	29.9	27.1	**0.9 ****
A2	176.5±1.02	207.1±1.11	20.9	26.6	0.8
A3	**204.8±1.14 ****	108.2±1.19	24.3	**11.5 ***	0.5
A4-EL-a	190.4±1.44	89.5±2.90	**19.3 ***	56.1	0.3
A5	112.5±1.25	**225.6±2.20 ****	21.4	16.0	0.8
A6-EL-ma	185.2±1.14	136.5±1.32	104.0	69.2	0.7
A7-EL-a	95.2±2.00	84.7±1.02	44.8	92.0	0.5
A8-EL-a	130.7±1.11	151.4±0.69	24.6	**105.2 ****	**0.2 ***
A9-EL-m(a)	180.8±0.66	124.5±1.27	**119.0 ****	62.7	0.5

***** – minimal value; ****** – maximal value

During the investigation, it was found that fabrics A6-EL-ma, A7-EL-a (weft direction), A8-EL-a (weft direction), A9-EL-m(a) (warp direction) are the most formability and flexible, and values of elongation reached to about 100 %. It can be seen that fabrics A2, A3 and A5 can be characterized as the most stable. This effect may be related to the fabrics composition of cotton and non-elastane yarns, due to a more significant friction between their yarns.

During uniaxial tension at low-stress (490 N/m) of woven fabrics, a close connection between break elongation ε_{Vtr} and elongation ε_{V490} was found (**Fig. 9**). Strong linear dependency (R^2 = 0.8520÷0.9413) shows that the deformations properties of woven fabrics could be observed at low-stress, when the fabric structure elements are still undamaged.

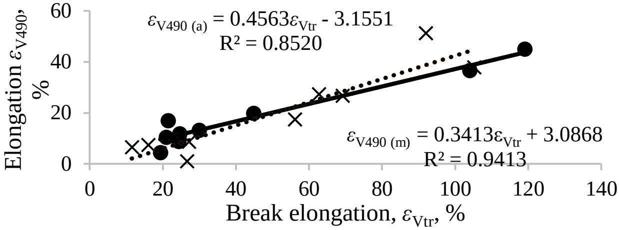


Figure 9. The relationship between break elongation ε_{Vtr} and elongation ε_{V490}: ● – warp; × – weft

Evaluation of tensile of textile materials and their systems during uniaxial tension till break and at low-stress. Knitted fabrics.

Values of characteristics as break force F_{Vtr}, break elongation ε_{Vtr} and break elongation anisotropy coefficient an_V are presented in **Table 2**.

Table 2. Values of knitted fabrics characteristics

Code	F_{Vtr}, N/cm		ε_{Vtr}, %		an_V
	lengthwise	crosswise	lengthwise	crosswise	
M1	**68.9±1.18 ****	28.3±1.01	**70.1 ***	207.0	0.3
M2-EL-e	41.0±2.20	**36.5±0.88 ****	**300.0 ****	300.0	**1.0 ****
M3	40.2±1.13	27.1±2.25	89.8	184.5	0.5
M4-EL-e	36.3±1.74	35.2±1.15	285.4	275.4	**1.0 ****
M5-EL-(e)	53.3±0.90	35.0±1.19	174.8	234.4	0.7
M6	**31.7±1.12 ***	**25.9±1.21 ***	91.0	**166.5 ***	0.6
M7	40.8±1.12	30.0±0.91	82.0	**432.0 ****	**0.2 ***

***** – minimal value; ****** – maximal value

Values of break force F_{Vtr} ranged from 25.9 N/cm to 68.9 N/cm, break elongation ε_{Vtr} ranged from 70.1 % to 432.0 % and break elongation anisotropy coefficient an_V ranged from 0.2 to 1.0. The results indicate that fabric M1 is the most elastic in the lengthwise direction and value of break elongation ε_{Vtr} is the lowest (ε_{Vtr} = 70.1 %). The maximum values of break longation were observed with fabric M7 in the crosswise direction (ε_{Vtr} = 432.0 %), although values of break elongation was one of the lowest in the lengthwise direction (ε_{Vtr} = 82.0 %). It was found that fabrics M2-EL-e and M4-EL-e have a structure with a high level of yarn mobility and formability in both direction due to the elastane fibre in the crosswise threads. Also these fabrics contain the highest percentage of elastane fibre (4 %–5 %). According to the received results the highest break elongation anisotropy coefficient an_V was calculated for fabrics M1, M3, M6 and M7 without elastane fibre.

During uniaxial tension at low-stress (50 N/m) of knitted fabrics, a close connection between break elongation ε_{Vtr} and elongation ε_{V50} was found (**Fig. 10**).

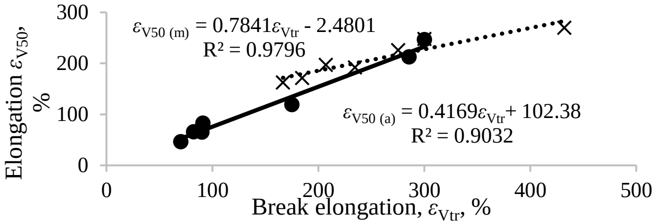


Figure 10. The relationship between break elongations ε_{Vtr} and elongation ε_{V50}: ● – lengthwise; × – crosswise

Strong linear dependency (R^2 = 0.9032÷0.9796) shows that the deformations properties of knitted fabrics could be observed at low-stress, such as woven fabrics. According to the received results of break elongation (**Table 1** and **Table 2**) knitted fabrics have 3–4 times higher values of elongation than woven fabrics were determined. Therefore, the influence of vertical and horizontal seams on the extensibility of the knitted fabrics' specimen was determined.

Values of characteristics as break force $F_{Vtr\text{-}S}$, break elongation $\varepsilon_{Vtr\text{-}S}$ and break elongation anisotropy coefficient $an_{V\text{-}S}$ are presented in **Table 3**.

Table 3. Values of knitted fabrics characteristics joined with seams

Code	$F_{Vtr\text{-}S}$, N/cm		$\varepsilon_{Vtr\text{-}S}$, %		$an_{V\text{-}S}$
	lengthwise	crosswise	lengthwise	crosswise	
With vertical seam					
M1	**86.7±2.22 ****	37.1±1.08	**70.4 ***	222.0	0.3
M2-EL-e	**39.1±2.00 ***	**44.6±0.94 ****	**268.4 ****	293.6	**0.9 ****
M3	48.6±1.91	36.1±2.21	95.4	200.0	0.5
M4-EL-e	48.1±1.70	43.5±1.01	249.2	276.1	0.9 **
M5-EL-(e)	63.8±1.14	41.2±1.17	175.2	222.5	0.8
M6	39.8±1.12	32.6±0.99	91.2	**161.5 ***	0.6
M7	41.6±1.15	**30.9±0.97 ***	80.0	**427.0 ****	**0.2 ***
With horizontal seam					
M1	**37.2±1.01 ****	26.3±0.66	**62.2 ***	212.0	0.3
M2-EL-e	25.0±0.69	**32.0±0.92 ****	**261.0 ****	294.0	**0.9 ****
M3	27.5±0.91	23.8±1.20	78.5	180.5	0.4
M4-EL-e	29.5±1.12	**21.8±1.03 ***	217.6	281.4	0.8
M5-EL-(e)	30.2±1.18	**32.1±1.12 ****	137.5	225.3	0.6
M6	**22.9±1.20 ***	**21.7±1.11 ***	92.5	**167.5 ***	0.6
M7	37.7±1.31	**32.3±1.00 ****	80.4	**445.0 ****	**0.2 ***

***** – minimal value; ****** – maximal value

It can be seen that after tension of the fabrics with a vertical seam the values of break force $F_{Vtr\text{-}S}$ inscreased from 2.0 % to 20.9 % (in a lengthwise direction) and from 2.1 % to 28.1 % (in a crosswise direction). However the values of break force F_{Vtr-S} of fabrics with horizontal seams decrease from 7.5 % to 45.9 % (in a lengthwise direction) and 7.1 % to 38.1 % (in a crosswise direction).

Values of break elongation ε_{Vtr-S} of knitted fabrics ranged from 70.1 % to 432.0 % without a seam, 70.4 % – 427.0 % with vertical seam and 62.2 % – 445.0 % with horizontal seam. It should be noted that alterations of break force F_{Vtr-S} is significant, but the alterations of break elongation ε_{Vtr-S} did not change considerably. Changes of break elongation of the specimen with vertical a seam reached from 0.2 % to 12.7 % (in a lengthwise direction), from 0.3 % to 7.8 % in a crosswise direction. Changes of break elongation of the specimen with horizontal a seam reached from 1.6 % to 23.8 % (in a lengthwise direction), from 0.6 % to 3.9 % in a crosswise direction. Alterations of break elongation anisotropy coefficient an_{V-S} is about 0.2 %. It should be noted that knitted fabrics with elastane yarns were mostly influenced by the seams.

Results. Evaluation of tested textile materials deformations using parallelepiped shape specimens. Woven fabrics.

It should be noted that none of the fabrics tested showed pure shearing when ε_{G14} = 14 %. More or less sharp jogs remained on the plane of the deformed specimen, therefore all the specimens were extended till ε_G (when the waves disappear). Values of elongation ε_G range from 18 % to 58 % (**Fig. 12**).

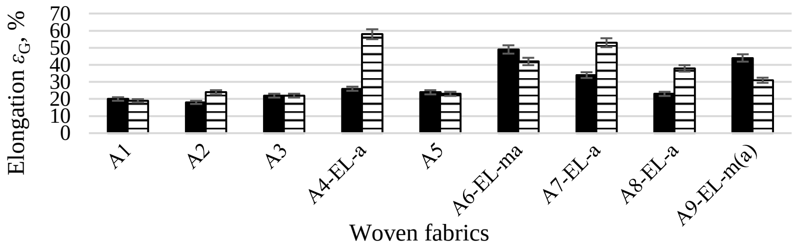


Figure 12. The elongation ε_G of tested woven fabrics : ■ – warp direction; ▤ – weft direction

It is known that during the woven fabric's extension, yarns in the direction of loading are straightened and denser; meanwhile transverse yarns are waving and crimpled. These deformations were determined using characteristics x'_G (**Fig. 13**) and y'_G (**Fig. 14**).

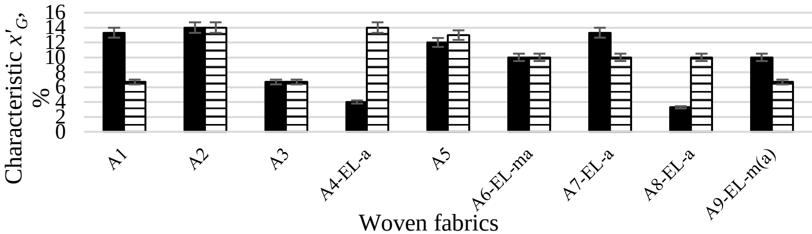


Figure 13. Values of the characteristic x'_G: ■ – warp direction; ▤ – weft direction

It was found that alterations of characteristic x'_G varied in limits of 15 %, meanwhile alteration of characteristic y'_G had reached 60 %.

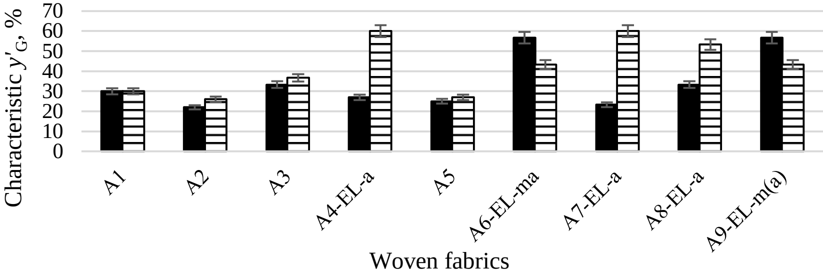


Figure 14. Values of the characteristic y'_G: ■ – warp direction; ▤ – weft direction

During specimens' deformation, part of the longitudinal yarns are straightened, depending on the thread tensile properties. It has been determined that there is a strong relation between characteristic y'_G of longitudinal yarns tension and elongation ε_G (R^2 = 0,6949÷0,8402) (**Figure 15**).

The alteration of parallelepiped allowed research to define what part of the specimen's deformation depends on the yarns stretch and what part on the shear between warp and weft yarns occurs. In the case of free shear, which can appear if the yarns of fabric are less extensible the characteristic, α'_G is close to 90º. If α'_G is less than 90º, it shows that part of the deformation occurs due to the threads extension. During the investigation, it was found that characteristic α'_G varied from 3º for fabrics with elastane fibre and α'_G varied in limits of 1º.

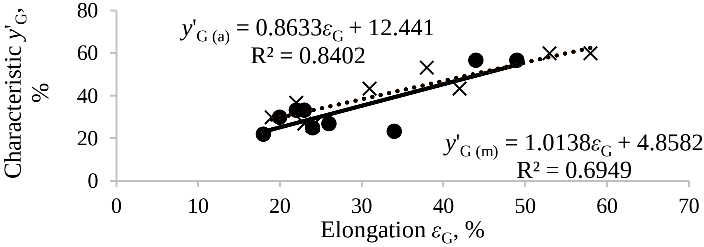


Figure 15. Values of the characteristic y'_G after specimens' deformation till ε_G (a) and y'_G dependence of the elongation ε_G: ■ , ● – warp direction; ▤, ✕ – weft direction

Results. Evaluation of tested textile materials deformations using parallelepiped shape specimens. Knitted fabrics.

The tensile force F_{G45}, which represents the resistance of tested fabrics to the deformation ε_{G45} = 45 %, is presented in **Fig. 16**. It can be seen that tensile force F_{G45} values have ranged from 0.1 N/cm to 3.0 N/cm. According to results, the highest values of tensile force F_{G45} are fabrics M2-EL-e and M4-EL-e, which are the most flexible due to the largest percentage of elastane yarns (4 % – 5 %). Composition of yarns of fabrics M1, M3 and M6 is composed of non-elastane fibres as the friction between their yarns is more significant than elastane yarns.

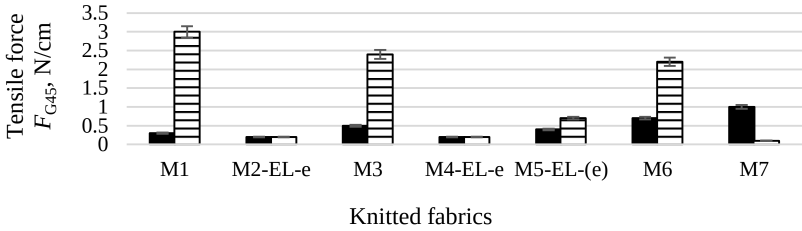
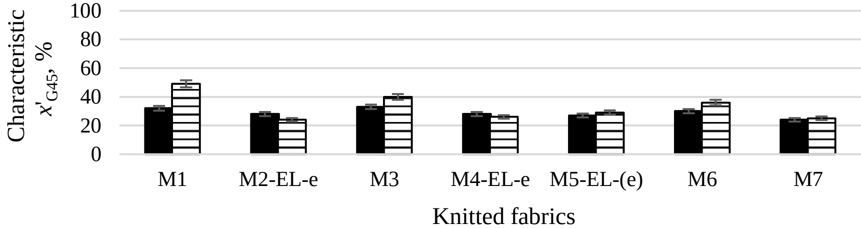
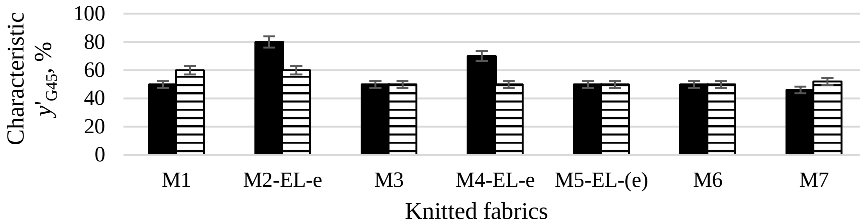


Figure 16. The tensile force F_{G45} of tested knitted fabrics after their deformation ε_{G45} = 45 %: ■ – lenghtwise direction; ▤ – crosswise direction

Alterations of transverse dimensions were characterized by characteristic x'_{G45} (**Fig. 17 a**) and longitudinal by y'_{G45} (**Fig. 17 b**). It can be seen that x'_{G45} values ranged from 24 % to 49 % and y'_{G45} ranged from 50 % to 80 %. It was found, that side x_{G0} of many knitted fabrics has narrowed to 30 %, meanwhile the side y_{G0} has lengthened by about 50 %. During the investigation, research of the dependency between tensile force and characteristics x'_{G45} **(Fig. 17 a)** and y'_{G45} (**Fig. 17 b**) has been conducted. As it is evident from **Fig. 18** the dependency between tensile force and characteristics x'_{G45}, y'_{G45} is low. A strong linear relation (R^2 = 0.9439) between characteristic x'_{G45} and tensile force F_{G45} was determined in the crosswise direction only.



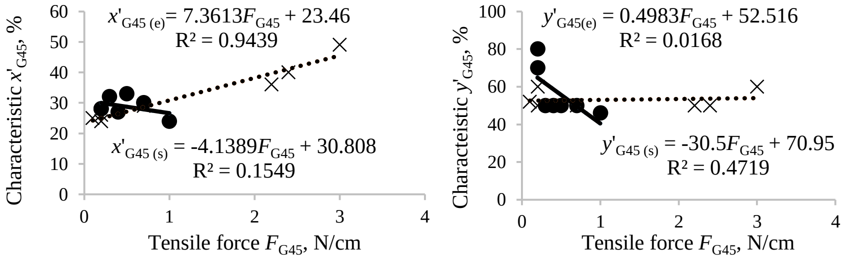
a



b

Figure 17. Values of the characteristic x'_{G45} (a) and y'_{G45} (b) after specimens' deformation till ε_{G45} = 45 %: ■ – lenghtwise direction; ▤ – crosswise direction

Loop of the fabrics were only extended but not stretching at all because the distance (45 mm) was too small for shear occurrence and wrinkles did not disappear. During deformation of more than 45 mm the structure of knitted fabrics was broken. So, the results have shown, that parallelepiped specmen's method is complicated for mobile woven and especially knitted fabrics. Therefore this method was not used in futher investigations.



a b

Figure 18. Dependency between tensile force F_{G45} and characteristics x'_{G45} (a) and y'_{G45} (b): ● – lenghtwise direction; × – crosswise direction

Results. Evaluation of tested textile materials deformations using Y shape specimens. Woven fabrics.

The tensile force F_{Y10}, which represents the resistance of woven fabrics to the deformation ε_{Y10} = 10 %, is presented in **Fig. 19**. It can be seen that tensile force F_{Y10} values have ranged from 0.3 N/cm to 9.6 N/cm. It was found that the values of tensile force F_{Y10} of the tested woven fabrics underwent small loads and large strains by method of Y shape specimen. Therefore fabrics are deformed in limits of elasticity and elements of the fabrics structure undamaged.

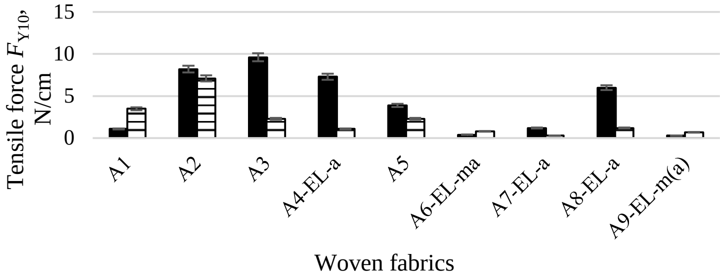
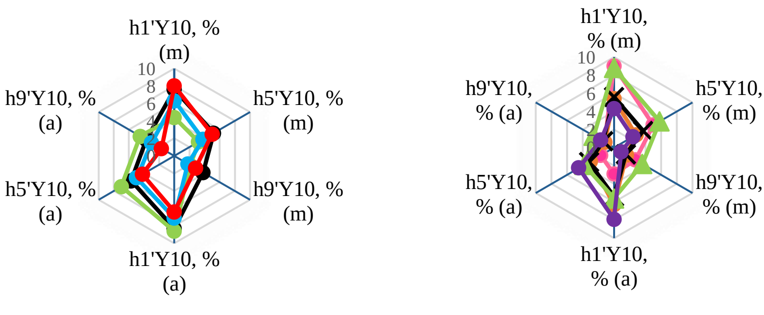


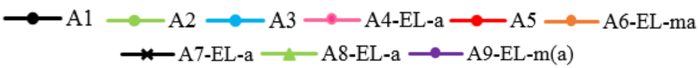
Figure 19. The tensile force F_{Y10} of tested woven fabrics after their deformation ε_{Y10} = 10 %: ■ – warp direction; ▤ – weft direction

The characteristics $h_i'_{Y10}$, $vs_i'_{Y10}$ and $\alpha_i'_{Y10}$, which represents the deformation properties of the tested fabrics, is presented in **Fig. 20, Fig. 21** and **Fig. 22**. Characteristics $h_1'_{Y10}$, $h_5'_{Y10}$ and $h_9'_{Y10}$ define longitudinal deformations and alterations of longitudinal dimensions. It was found that alterations of $h_i'_{Y10}$ are the most significant in the first point and had reached 10 % in both directions (**Fig. 20**). Meanwhile, alterations of $h_i'_{Y10}$ reached 7 % in 5th point and the least in 9th point (to 5 %).



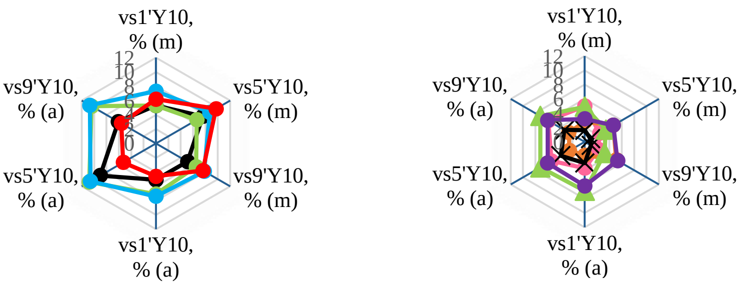
a b

Figure 20. Characteristic $h_i'_{Y10}$ in three points of the specimen without elastane fibres (a) and with elastane fibres (b): m – warp direction, a – weft direction



It has been determined that the curves of the circular chart of non-elastane fabrics are similar to regular shapes. Meanwhile, the curves of the circular chart of fabrics with elastane are similar to irregular shapes. This means that fabrics with a regular shape of circular chart are characterized as more stable and less mobile. It can be seen that the characteristic $h_i'_{Y10}$ values of fabrics A1 and A3 in the warp direction are similar to the weft direction. Also, the curves of the circular chart are similar to regular shapes. Fiber content of fabric A1 is composed of 100 % wool and the density in both directions is also alike. Therefore, fabric A1 is more stable in both directions. Fiber content of fabric A3 is composed of cellulose yarns but the warp density differs from the weft density, due to the values of characteristic $h_9‘_{Y10}$ are slighty decreased in the warp direction. One of the reason for the significant differences between $h_i‘_{Y10}$ values in warp and weft directions is the different composition of yarns. For example, fabric A2 warp is composed of natural cotton yarns and the weft is synthetic polyester. The second reason for significant differences between $h_i‘_{Y10}$ values in the warp and weft directions is the different density. Density of fabric A4-EL-a is twice as denser in the warp direction as in the weft direction.

Characteristics $vs_1‘_{Y10}$, $vs_5‘_{Y10}$ and $vs_9‘_{Y10}$ define transverse deformations and alterations of transverse dimensions (**Fig. 21**). It was found that alterations of characteristic $vs_i‘_{Y10}$ of fabrics A4-EL-a, A6-EL-ma, A7-EL-a, A8-EL-a, A9-EL-m(a) is less significant than other non-elastane woven fabrics. These fabrics have good extensibility due to the spacing between yarns decreses after their extension. Values of characteristic $vs_i‘_{Y10}$ is the highest for fabrics A2, A3 and A5. These fabrics composition of yarns are composed of cotton without elastane fibres. Therefore the friction between yarns is more significant and the spacing between structure elements is rapidly closed.



a b

Figure 21. Characteristic $vs_i‘_{Y10}$ in three points of specimen without elastane fibres (a) and with elastane fibres (b): m – warp direction, a – weft direction

A1 A2 A3 A4-EL-a A5 A6-EL-ma
A7-EL-a A8-EL-a A9-EL-m(a)

The minimum changes in transverse dimensions were determined for woven fabric A7-EL-a in both directions. This effect may be related to the fabric‘s A7-EL-a 1/3 twill waves. The threads system of 1/2 twill and plain wave structure is shorter than 1/3 twill wave and has more influence to the spacing decrease between structure elements. Characteristics $\alpha_1‘_{Y10}$, $\alpha_5‘_{Y10}$ and $\alpha_9‘_{Y10}$ define angular deformations (**Fig. 22**).

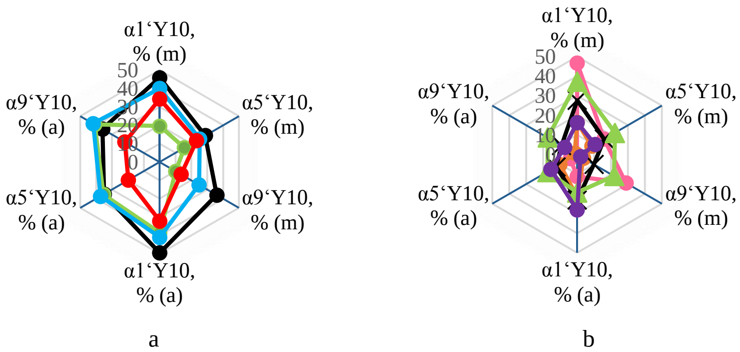
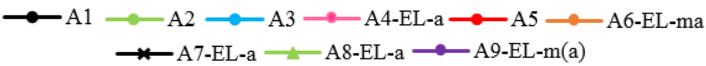


Figure 22. Characteristic α_i‘$_{Y10}$ in three points of specimen without elastane fibres (a) and with elastane fibres (b): m – warp direction, a – weft direction



It has been determined that angular deformations are more significant for fabrics A1, A2, A3 and A5. Therefore, it can be seen that alterations of characteristic α_i‘$_{Y10}$ is significant in every point. The results indicate that the lowest values of characteristic α_i‘$_{Y10}$ were received for the cotton/flax blend fabric A5. The structure of this woven fabric is affected with large friction forces, threads react against shear and characteristic α_i‘$_{Y10}$ changes not significant

Results. Evaluation of tested textile materials deformations using Y shape specimens. Knitted fabrics.

The tensile force F_{Y40}, which represents the resistance of knitted fabrics to the deformation ε_{Y40} = 40 %, is presented in **Fig. 23**. It can be seen that tensile force F_{Y40} values have ranged from 0.1 N/cm to 4.8 N/cm. It was found that values of tensile force F_{Y40} of the tested knitted fabrics underwent small loads and large strains in the woven fabric case. Therefore fabrics are deformed in limits of elasticity and elements of the fabrics structure undamaged. Tensile force F_{Y40} for knitted fabrics M1, M3, M6 and M7 are more significant in the lengthwise direction and has amounted to 5.5 N/cm.

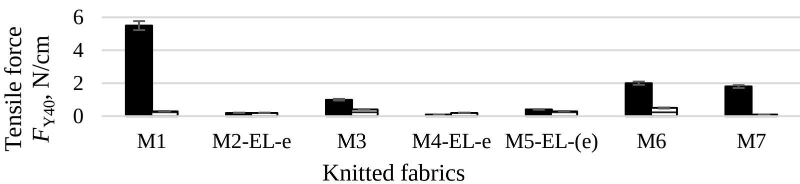
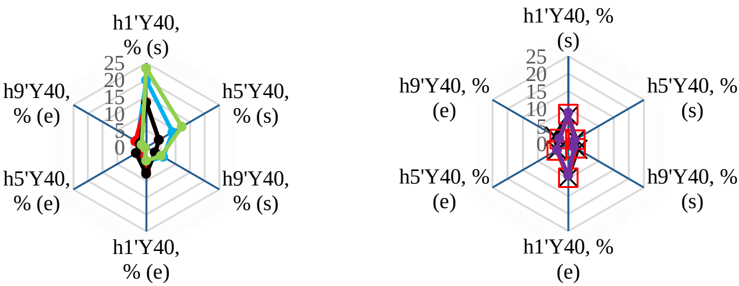


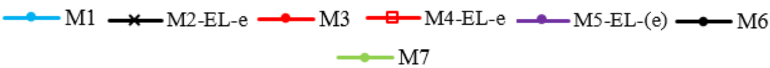
Figure 23. The tensile force F_{Y40} of tested knitted fabrics after their deformation ε_{Y40} = 40 %: ■ – lengthwise direction; ▤ – crosswise direction

The characteristics $h_i'_{Y40}$, $vs_i'_{Y40}$ and $\alpha_i'_{Y40,}$ which represents the deformation properties of the tested fabrics, is presented in **Fig. 24, Fig. 25** and **Fig. 26**. Characteristics $h_1'_{Y40}$, $h_5'_{Y40}$ and $h_9'_{Y40}$ define longitudinal deformations and alterations of longitudinal dimensions. It is found that alterations of $h_i'_{Y40}$ are the most significant in the first point and reaches 25 %. Meanwhile the least values of $h_i'_{Y40}$ up to 4–5 times in the 9th point were determined. As it is evident from Fig.24, differences between values of $h_i'_{Y40}$ in crosswise direction are not significant as against in the lengthwise direction. Knitted fabrics M1 and M7 values of $h_i'_{Y40}$ in the lengthwise are 5 times higher than the crosswise direction. The least values of characteristic $h_i'_{Y40}$ of fabrics M2-EL-e, M4-EL-e and M5-EL-(e) in 1st point were determined (reached 10 %). In the lengthwise direction, knitted fabrics were classified as follows: M1 and M7, M3 and M6, and M2-EL-e, M4-EL-e, M5-EL-(e). In **Fig.24** it can be seen that characteristic $h_i'_{Y40}$ values of knitted fabrics with elastane fibers in the lengthwise direction is similar to the crosswise direction. Also, the curves of the circular chart are alike too. Deformations of these knitted fabrics divide up more gradually in all the specimen' area.

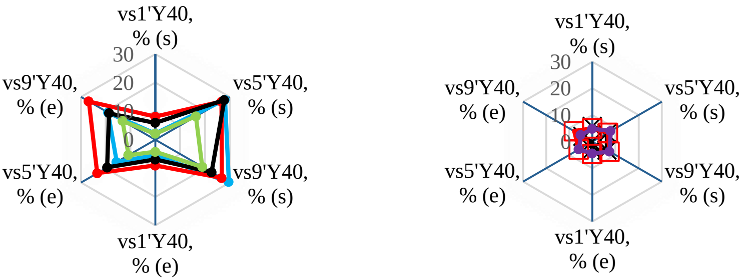


a b

Figure 24. Characteristic $h_i'_{Y40}$ in three points of specimen without elastane fibres (a) and with elastane fibres (b): s – lengthwise direction, e – crosswise direction



According to the results of characteristic $vs_i'_{Y40}$ many more values were determined in the 5th and 9th points as against in 1st point **(Fig. 25**). In 1st point values of characteristic $h_i'_{Y40}$ did not exceed 9 %. As it is evident from **Fig.25,** the values of characteristic $vs_i'_{Y40}$ is most significant for fabrics M1, M3 and M6 at the 5th and 9th points. These fabrics are less mobile and tensile due to the yarns being more affected by friction, along with the compression forces and transverse dimensions of specimens narrowing more rapidlly.

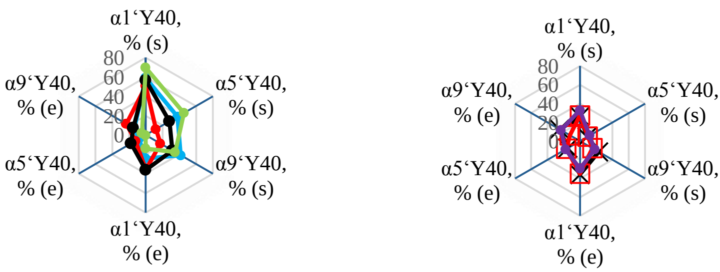


a b

Figure 25. Characteristic *vs*$_i$‘$_{Y40}$ in three points of specimen without elastane fibres (a) and with elastane fibres (b): s – lengthwise direction, e – crosswise direction

M1 M2-EL-e M3 M4-EL-e M5-EL-(e) M6 M7

The characteristic α_i‘$_{Y40}$ is represents is presented in **Fig. 26.** The same trend is observed in the analysis of the values of characteristic h_i‘$_{Y40}$ and characteristic α_i‘$_{Y40}$. This means that the values are the highest in the lengthwise direction as against in the crosswise direction (**Fig. 26**). It was found that alterations of characteristic α_i‘$_{Y40}$ are less (about 2 times) significant for fabrics M4-EL-e, M5-EL-(e). It can be seen that curves of cilcular chart of tensile knitted fabrics are located near the centre.



a b

Figure 26. Characteristic *vs*$_i$‘$_{Y40}$ in three points of specimen without elastane fibres (a) and with elastane fibres (b): s – lengthwise direction, e – crosswise direction

M1 M2-EL-e M3 M4-EL-e M5-EL-(e) M6 M7

Results. Evaluation of deformations of the tested textile materials‘ systems using Y shape specimens. Woven fabrics.

The influence of two types of vertical seams on the extensibility of woven fabrics’ specimens were determined. Values of tensile force F_{Y10} without seam, with vertical seam in the middle of the specimen and two vertical seams on the sides of the specimen are presented in **Fig. 28**. It can be seen that after tension of fabrics with seams, the values of tensile force F_{Y10} increased by 20 %. More significant alterations of tensile force were determined for fabrics A1 and A3. It was found that the values of tensile force of fabric A1 with seams increased about 18 % in the warp direction and 20 % in the weft direction. Tensile force F_{Y10} of fabric A3 with seams increased about 17 % in the warp direction.

The influence of seams on the characteristics $h_i`_{Y10}$, $vs_i`_{Y10}$, $\alpha_i`_{Y10}$ of woven fabrics was determined. It was found that after tension of the fabrics with seams the values of $h_i`_{Y10}$ has changed to 4.0 %. Values of $h_9`_{Y10}$ have decreased to 2.0 % for fabric A1 in the warp direction (with seam in the middle of specimen). The same trend was observed for fabric A2. Although, values of $h_1`_{Y10}$ was increased by about 1.5 %–2.0 % in the warp direction, and the same decrease in the weft direction (with seam in the middle of specimen). It was found that values of $h_i`_{Y10}$ were increased from 1.5 % to 2.5 % for fabric A3 in both directions and in the 1$^{st}$, 5$^{th}$ and 9$^{th}$ points (with seam in the middle of specimen). Much more significant alterations of characteristic $h_1`_{Y10}$ and $h_5`_{Y10}$ were observed for fabric A5 with two types seams (about 1.5 %). According to the results influence of middle seam was determed for fabrics A6-EL-ma and A7-EL-a. The values of $h_1`_{Y10}$ and $h_5`_{Y10}$ increased to 2.0 % for fabric A6-EL-ma and increased.

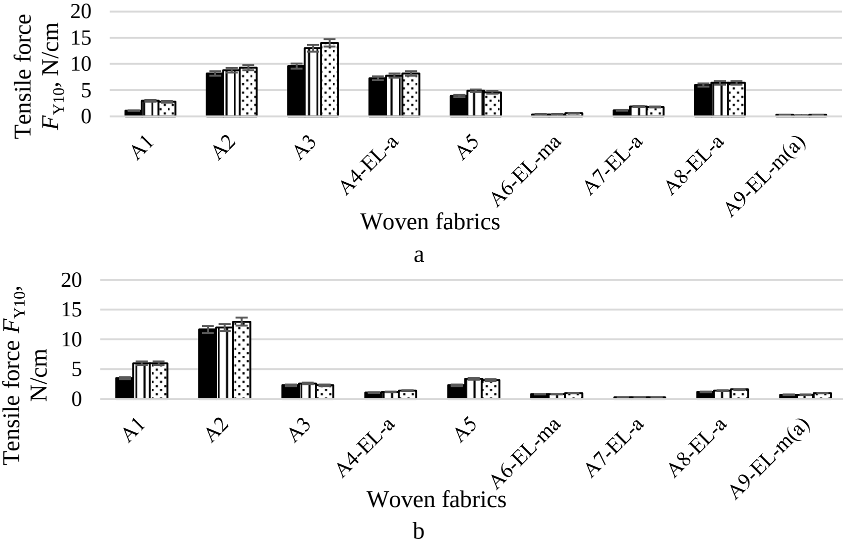
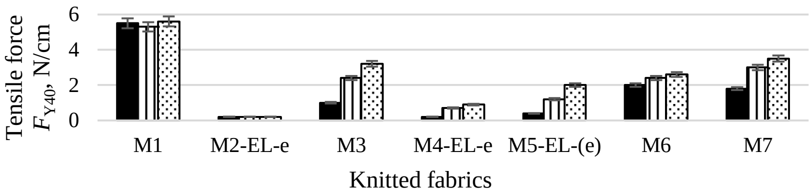


Figure 28. The tensile force F_{Y10} of tested woven fabrics after their deformation ε_{Y10} = 10 % in warp (a) and weft (b) directions:
■ - specimen without seam, ▯ - with seam in the middle of specimen , ▒ - with two vertical seams in the sides of specimen

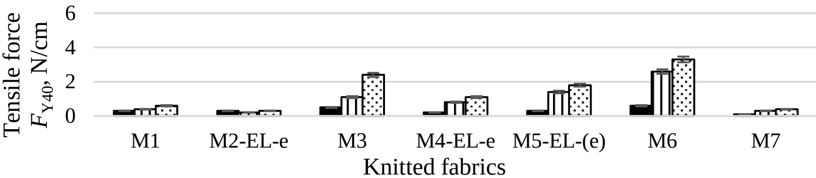
Values of $h_1‘_{Y10}$ increased by 3.0 %–4.0 % in warp direction. It was found that values of $h_i‘_{Y10}$ were increased to 2.5 % for fabric A9-EL-m(a) in both directions and in the 1st, 5th and 9th points (with both type seams). The minimum changes of characteristic $h_i‘_{Y10}$ were determined for fabric A8-EL-a (up to 1.0 %). According to the results, it was observed that $vs_i‘_{Y10}$ alterations of transverse dimensions were much more significant and reached up to 55 %. This means that seams limit mobility of cross elements of fabric structure. More significant value changes of characteristic $\alpha_i‘_{Y10}$ was determined for fabrics with two vertical seams on the sides of the specimen. Obviously, the seams on the sides of the specimen affect the decrease of the central zone mobility especially for tensile fabrics A7-EL-a and A9-EL-ma.

Results. Evaluation of deformations of tested textile materials' systems using Y shape specimens. Knitted fabrics.

The influence of two types of vertical seams on the extensibility of knitted fabrics' specimens were determined. Values of tensile force F_{Y40} without seam, with a vertical seam in the middle of the specimen and two vertical seams on the sides of the specimen are presented in **Fig. 29**. It can be seen that after tension of fabrics with seams the values of tensile force F_{Y10} inscrease till 50 %. More significant alterations of tensile force were determined for fabrics M3, M4-EL-e, M5-EL-(e), M6 and M7.



a



b

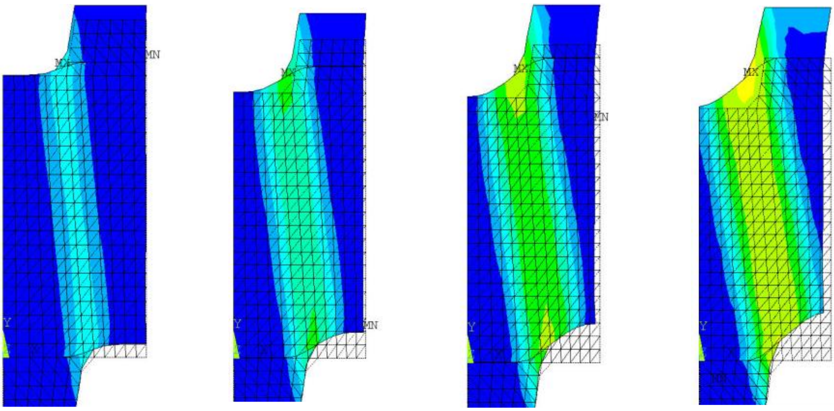
Figure 29. The tensile force F_{Y40} of tested knitted fabrics after their deformation ε_{Y40} = 40 % in lengthwise (a) and crosswise (b) directions:
■ - specimen without seam, ▯ - with seam in the middle of specimen , ▩ - with two vertical seams in the sides of specimen

It was found that the values of tensile force of fabric M3, M4-EL-e, M5-EL-(e) and M7 with seams increase about 30-40 % in a lengthwise direction and 15-50 % in a crosswise direction (fabrics M3, M4-EL-e, M5-EL-(e), M6 and M7).

The influence of seams on the characteristics $h_i{}'_{Y40}$, $vs_i{}'_{Y40}$, $\alpha_i{}'_{Y40}$ of knitted fabrics was determined. It was found that after tension of the fabrics with seams the values of $h_i{}'_{Y40}$ has changed to 5.0 %. Values of $h_9{}'_{Y10}$ has increased from 1.0 % to 1.5 % for fabric M2-EL-e, M4-EL-e and M5-EL-(e) in both directions. Alterations of characteristic $h_i{}'_{Y10}$ was determined for knitted fabrics M3 and M6 in both lengthwise (in all three points) and crosswise (in 9th point) directions. According to the results, it was observed that $vs_i{}'_{Y40}$ alterations of transverse dimensions were much more significant and reached 45 %. This means that seams limit mobility of cross elements of the fabric structure like woven fabrics. It was found that changes of $vs_i{}'_{Y40}$ for fabrics M1, M3, M6 and M7 are less significant. Meanwhile alterations of $vs_i{}'_{Y40}$ for fabrics M2-EL-e and M4-EL-e reach 45 %. It was found that value changes of characteristic $\alpha_i{}'_{Y40}$ were significant and reached 50 %. More significant are alterations of $\alpha_i{}'_{Y40}$ was determined for fabric M2-EL-e, M3, M4-EL-e, M5-EL-(e) and M6 in 9th point.

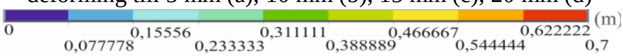
Evaluation of tested textile materials deformations using numerical model. Vertification of experimental and numerical method results

Y shape specimen was deformed till 40 mm by 5 mm steps. The views of deformations zones are shown in **Figure 30** and **Figure 31**.



a b c d

Figure 30. The views of deformations zones in knitted fabric M7 when specimen is deforming till 5 mm (a), 10 mm (b), 15 mm (c), 20 mm (d)



It can be seen that the deformations zones are not significant and located from upper to bottom selvages diagonally deforming by 5 mm – 10 mm (**Fig. 30 a, b**). Deformations zones reach 40 mm extension, when the displacement is 15 mm – 20 mm (yellow field) (**Fig. 30 c, d**).

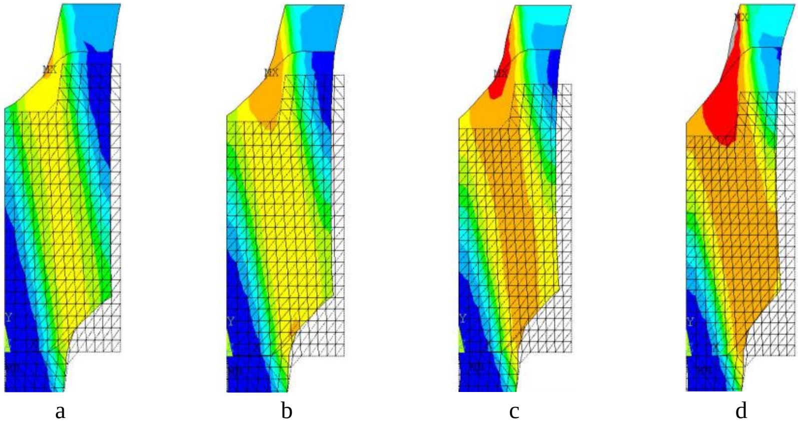
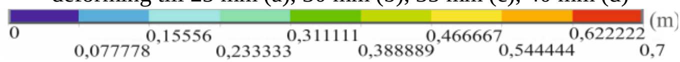


Figure 31. The views of deformations zones in knitted fabric M7 when specimen is deforming till 25 mm (a), 30 mm (b), 35 mm (c), 40 mm (d)



Deformations zones extend and reach the middle of the specimen deforming by 30mm (**Fig. 31 a)**. In the specimen selvages, especially upper, deformations reach a critical limit and deformations zones extend almost in the whole specimen deforming till 30 mm (**Fig. 31 b**). In the upper and bottom selvages of the specimen, extension reaches about 60 mm, deforming is from 35 mm to 40 mm (**Fig. 31 c, d**). Also, the most significant deformations zones are located in the upper selvages, top of the middle part of specimen and the sides of specimen.

In case to verify acceptability of results of made numerical research methodology ($h_{sk}i'_{Y40}$), there was compared with experimental results ($h_i'_{Y40}$) in the 1st, 5th and 9th points (**Fig. 32**).

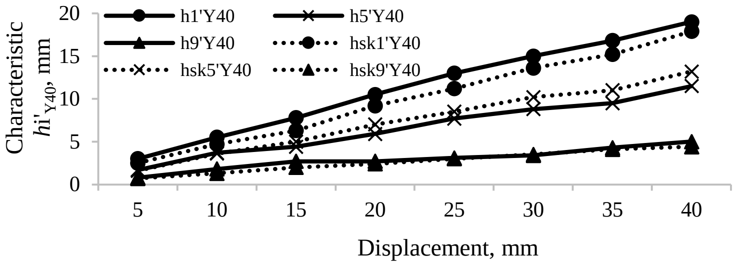


Figure 32. Comparison of results of experimental (hi'_{Y40}) and numerical ($h_{sk}i'_{Y40}$) methods

As it is evident from **Fig. 33**, the difference between characteristics hi'_{Y40} and $h_{sk}i'_{Y40}$ does not exceed 9.8 %. Also, the linear dependency between experimental and numerical methods has been determined (**Fig. 32**).

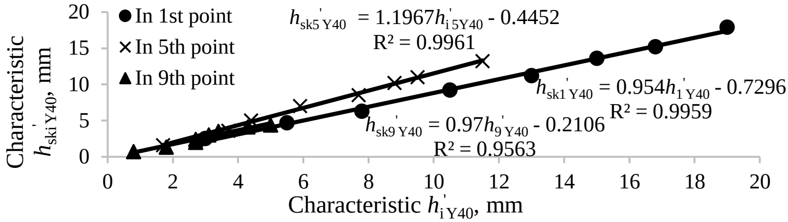


Figure 33. Dependency between experimental hi'_{Y40} and numerical $h_{sk}i'_{Y40}$ methods

As it is evident from **Fig. 33,** the strong dependency between characteristics hi'_{Y40} and $h_{sk}i'_{Y40}$ is $R^2 = 0.9563 \div 0.9961$ was determined. This identifies the strong linear dependency between the experimental and numerical methods. Therefore it can be stated, that the results are suitable for both, practical and scientific use.

CONCLUSIONS

1. The strong linear dependency ($R^2 = 0.8520 \div 0.9413$ for woven fabrics, $R^2 = 0{,}9032 \div 0{,}9796$ for knitted fabrics) was determined. It shows that the deformations properties of woven fabrics could be observed at low-stress, with the fabric structure elements still undamaged.
2. It was found that break elongation ε_{Vtr} ranged from 11.5 % to 119.0 % using the uniaxial method to breaking and elongation ε_{V490} ranged from 1.1 % to 51.2 % at low-stress for woven fabrics. Break elongation ε_{Vtr} ranged from 70.1 % to 432.0 % using the uniaxial method to breaking and elongation ε_{V50} ranged from 46.8 % to 246.6 % at low-stress for knitted fabrics.
3. Alterations of knitted fabrics break elongation $\varepsilon_{Vtr\text{-}S}$ ranged from 0.2 % to 12.7 % (with vertical seam) and from 0.6 to 23.8 (with horizontal seam) using the uniaxial method to breaking. Also, less significant alterations of break elongation anisotropy coefficient ($an_{V\text{-}S}$ ~ 0.2 %) was determined.
4. The results have shown, that the parallelepiped specimen‘s method is complicated for mobile woven and especially knitted fabrics. During the investigation, it was found that characteristic α'_{G45} did not exceed 1% for knitted fabrics. The loop of the fabrics were just extended but not stretching at all because distance (45 mm) was too small for shear occurrence and wrinkles did not disappear. During deformation of more than 45 mm the structure of knitted fabrics was broken.
5. It was determined that tensile force F_{Y10} of the tested woven and knitted fabrics underwent small loads (9.6 N/cm for woven fabrics, 4.8 N/cm for knitted

fabrics) using the method of the Y shape specimen. Therefore, fabrics are deformed in limits of elasticity and elements of the fabrics structure undamaged.

6. Characteristics h_1‘$_{Y10;40}$, h_5‘$_{Y10;40}$ and h_9‘$_{Y10;40}$ define longitudinal deformations and alterations of longitudinal dimensions of the Y the shape specimen. It was found that alterations of h_1‘$_{Y10}$, h_5‘$_{Y10}$ and h_9‘$_{Y10}$ are the most significant at the first point and had reached 10 % and the least alterations were determined at the 9 th point (up to 5 %) for woven fabrics. It was found that alterations of h_i‘$_{Y40}$ are the most significant at the first point (to 25 %) and the least alterations were determined at the in 9 th point (by 4–5 times) for knitted fabrics.

7. Characteristics vs_1‘$_{Y10;40}$, vs_5‘$_{Y10;40}$ and vs_9‘$_{Y10;40}$ define transverse deformations and alterations of transverse dimensions of Y shape specimens. It was found that alterations of characteristic vs_i‘$_{Y10}$ is similar to h_i‘$_{Y10}$ and did not exceed 12 % for woven fabrics. Also it was determined that values of characteristic vs_i‘$_{Y40}$ much more values were determined in 5th and 9th points as against in 1st point for knitted fabrics.

8. Characteristics α_1‘$_{Y10;40}$, α_5‘$_{Y10;40}$ and α_9‘$_{Y10;40}$ define angular deformations of Y shape specimen. It was found that α_i‘$_{Y10}$ has changed 50% for non-elastane woven fabrics. It is these fabrics angular deformations that more significant for fabrics and alterations of characteristic α_i‘$_{Y10}$, which is significant at every point, especially at the 1st and 9th points. Values of characteristic of S_{Y10} reach 5 % for more stable woven fabrics and did not exceed 1.5 % for more tensile woven fabrics. It was found that alterations of α_i‘$_{Y40}$ reached 70% for knitted fabrics. The results indicate that the lowest values of characteristic α_i‘$_{Y10;40}$ were identified for more tensile and mobile fabrics.

9. The influence of seams on the alterations of tensile characteristics reach 20 % for woven fabrics (Y shape specimen). It was found that after tension of woven fabrics with seams the values of h_i‘$_{Y10}$ changed by 4.0 %. Meanwhile vs_i‘$_{Y10}$ alterations of transverse dimensions were much more significant and reached 55 %. More significant values changes of characteristic α_i‘$_{Y10}$ were determined for woven fabrics with two vertical seams on the sides of the specimen.

10. The influence of seams on the alterations of tensile characteristics reach 55 % for knitted fabrics (Y shape specimen). It was found that after tension of knitted fabrics with seams the values of h_i‘$_{Y40}$ has changed by 5.0 %. According to the results, it was observed that vs_i‘$_{Y40}$ alterations of transverse dimensions were much more significant and reached 45 %. It was found that value changes of characteristic α_i‘$_{Y40}$ were significant and reached 50 %.

11. Research determined the significant correspondence between numerical and experimental methods. Difference between characteristics hi’$_{Y40}$ and $h_{sk}i$’$_{Y40}$ does not exceed 9.8 %. The strong dependency between characteristics hi’$_{Y40}$ and $h_{sk}i$’$_{Y40}$ was R^2 = 0.9563 9961 was determined. This means there is strong linear

dependency between experimental and numerical methods. Therefore it can be stated, that the results are suitable for both, practical and scientific use.

LIST of PUBLICATIONS ON THE THEME OF DISSERTATION

Articles in the Journals from the list Web of Science – Thomson Reuters:

1. Sacevičienė, Virginija; Masteikaitė, Vitalija; Klevaitytė, Ramunė; Audzevičiūtė, Inga. Influence of the Elastane Fibre on the Woven Fabric Structural Mobility // Materials science = Medžiagotyra / Kaunas University of Technology, Academy of Sciences of Lithuania. Kaunas : Technologija. ISSN 1392-1320. 2011, vol. 17, no. 4, p. 413-416. [Science Citation Index Expanded (Web of Science)].
2. Masteikaitė, Vitalija; Sacevičienė, Virginija; Audzevičiūtė-Liutkienė, Inga. Influence of Structural Changes in Cotton Blend Fabrics on Their Mobility // Fibres and Textiles in Eastern Europe. Lodz : Institute of Chemical Fibres. ISSN 1230-3666. 2013, vol. 21, no. 1(97), p. 55-60. [Science Citation Index Expanded (Web of Science)].

Articles Referred in the Other Databases of Institute for Scientific Information (ISI) [ISI Proceedings]

1. Sacevičienė, Virginija; Klevaitytė, Ramunė; Masteikaitė, Vitalija; Audzevičiūtė, Inga. Influence of Textile Structure on Their Tensile deformation // ITC&DC : 5th International Textile Clothing & Design Conference – Magic World of Textiles, October 3-6, 2010, Dubrovnik, Croatia : book of proceedings. Zagreb : University of Zagreb. ISSN 1847-7275. 2010, p. 700-704. [ISI Proceedings].
2. Audzevičiūtė-Liutkienė, Inga, Masteikaitė, Vitalija, Sacevičienė, Virginija, Analysis of knitted fabrics deformation using uniaxial tension methods. // Magic world of textiles : 6th international textile clothing & design conference, October 7-10, 2012, Dubrovnik, Croatia : book of proceedings / University of Zagreb. Faculty of Textile technology. Zagreb : University of Zagreb. ISSN 1847-7275. 2012, p. 30-35. [ISI Proceedings].

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1. Sacevičienė, Virginija; Masteikaitė, Vitalija; Audzevičiūtė, Inga; Klevaitytė, Ramunė. Influence of the Polyurethane Fibre on the Woven Fabric Structure Mobility // Baltic Polymer Symposium 2010 : Palanga, September 8-11, 2010 : programme and abstracts / Kaunas University of Technology, Vilnius University. Kaunas : Technologija, 2010. ISBN 9789955258384. p. 57.
2. Audzevičiūtė, Inga; Masteikaitė, Vitalija; Sacevičienė, Virginija; Klevaitytė, Ramunė. Elastano pluošto įtaka audinių paslankumui // Gaminių technologijos

ir dizainas 2010 : konferencijos pranešimų medžiaga / Kauno technologijos universitetas. Kaunas : Technologija. ISSN 1822-492X. 2010, p. 36-40.
3. Masteikaitė, Vitalija; Sacevičienė, Virginija; Audzevičiūtė-Liutkienė, Inga; Adomaitienė, Loreta. Mechanical Behaviour of Knitted Fabrics under Different Tension Conditions // Baltic Polymer Symposium 2011 : Pärnu, Estonia, September 21-24, 2011 : program and abstracts / Tallinn University of Technology. Tallinn : Tallinn University of Technology, 2011. p. 66.
4. Audzevičiūtė, Inga; Masteikaitė, Vitalija. Bandinio formos įtaka mezginių deformacijai jų tempimo metu // Gaminių technologijos ir dizainas 2013 : konferencijos pranešimų medžiaga / Kauno technologijos universitetas. Kaunas : Technologija. ISSN 1822-492X. 2013, p. 3-7.
5. Audzevičiūtė-Liutkienė, Inga; Masteikaitė, Vitalija. The Influence of Specimen‘s Type on Deformation of Knitted Fabrics during Their Extension // 15th International Conference-School 2013 : Palanga, Lithuania, August 27-31, 2013 : book of abstracts / Kaunas University of Technology. Kaunas : Technologija, 2013. ISSN 1822-7759. p. 159.

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REZIUMĖ

Sparčiai vystantis ir tobulėjant mokslui, šiuolaikinių technologijų vystymasis daro didelę įtaką visoms pramonės šakoms, todėl tekstilės ir aprangos sektorius visame pasaulyje taip pat sparčiai kinta. Tekstilės medžiagos yra nuolat tobulinamos, sukuriamos ne tik inovatyvios ir sudėtingos struktūros medžiagos, bet ir sudėtingos aprangos gaminių konstrukcijos, sujungtos įvairaus tipo siūlėmis. Pastaraisiais metais aprangos pramonė vis labiau orientuota į specialiosios paskirties aprangos gamybą, kuriai keliami aukšti kokybės reikalavimai, tenkinantys ne tik vartotojų poreikius, bet atitinkantys techninius, ekonominius rodiklius bei kokybės standartus. Tekstilės medžiagos, priklausomai nuo savo sandaros, struktūros elementų išsidėstymo bei deformacinių savybių, gali ne tik

lengvai deformuotis, bet ir išlaikyti erdvinę formą. Tekstilės medžiagos yra anizotropinės ir nehomogeniškos, todėl svarbu prognozuoti gaminio medžiagos savybes, atsižvelgti į veikiančius įvairius veiksnius: nevienodą detalių orientaciją gaminyje, skirtingų medžiagos sluoksnių anizotropiškumą, skirtingai orientuotų gaminio detalių paslankumą, siūlių orientaciją bei jų paslankumą ir pan. Moksliniais tyrimais nustatyta, kad tekstilės medžiagų elgseną gamybos bei eksploatacijos metu geriausiai įvertina jos deformacinė geba, apibūdinama ištįsos ir šlyties charakteristikomis. Nors šiuo metu sukurta daug naujų tekstilės medžiagų deformacinių savybių vertinimo metodų, tačiau vis dar trūksta metodų, leidžiančių nebrangiai, nesudėtingai ir našiai įvertinti medžiagos ir siūlių mechanines charakteristikas, ypač deformacijų pasiskirstymą, jų netolygumus. Tekstilės medžiagų deformacines savybes galima įvertinti įprastais standartiniais tyrimo metodais, bet išsamesniems ir tikslesniems tyrimams tenka ieškoti naujų tyrimo metodų arba tobulinti jau sukurtus.

Pastaraisiais metais, kai tekstilės medžiagų ir aprangos deformacinės savybės tiriamos ir vertinamos 3D kompiuterinio modeliavimo metodais, sparčiai išaugo mokslinių tyrimų skaičius. Virtualus trimatis gaminio vaizdas aprangos pramonėje naudojamas ne tik realiam vaizdui sukūrti, bet ir dėl galimybės imituoti tekstilės medžiagų mechaninių savybių elgseną be būtinybės pagaminti realų gaminį. Baigtinių elementų metodas (BEM) yra vienas universaliausių ir plačiausiai taikomų metodų inžinerijoje, kuriuo galima optimizuoti ir aprangos medžiagų bei gaminių gamybos procesus, numatyti procesų eigą, prognozuoti deformacijų, įtempių pasiskirstymą medžiagose.

Temos aktualumas ir tiriamoji problema

Dėl savo anizotropiškumo bei nehomogeninės sandaros, tekstilės medžiagos pasižymi įvairiomis ir dažnai sunkiai prognozuojamomis savybėmis. Dėl šių priežasčių yra labai svarbu įvertinti bei numatyti medžiagų savybes gaminio projektavimo ir gamybos metu (sudarant konstrukciją, kerpant, jungiant skirtingas detales ir kt.), garantuoti kokybę eksploatuojant gatavą gaminį (dėvint, skalbiant ir kt.). Nustačius ir įvertinus medžiagos deformacijų pasiskirstymą, jų netolygumo priežastis, galima padidinti gaminio gamybos našumą, parinkti optimalią gaminio konstrukciją, užtikrinti jo kokybę eksploatacijos metu.

Pastaruoju metu didelis dėmesys skiriamas naujų medžiagų kūrimui, didėja pasiūla bei medžiagų asortimentas, tačiau, remiantis mokslinių darbų apžvalga, pastebėta, kad trūksta nesudėtingų, universalių metodų, leidžiančių įvertinti įvairių medžiagų, taip pat jų junginių deformacijas, atsirandančias gaminio eksploatacijos metu. Pasigendama metodų, leidžiančių viena eksperimentine metodika įvertinti įvairias tekstilės medžiagų deformacinių savybių charakteristikas, ir taip sumažinti bandinių skaičių, eksperimentinių medžiagų kiekius ir kaštus bei laiko sąnaudas. Gaminio detalių skaidymas ir siūliniai junginiai mažina gaminio dalių paslankumą. Nors siūlių kokybės nustatymo metodų ir mokslinių tyrimų yra daug, tačiau siūlės įtakos medžiagų stabilumui, tąsumui ir paslankumui išties nedaug.

Baigtinių elementų metodas (BEM) inžinerijoje taikomas jau kelis dešimtmečius, tačiau tekstilės ir aprangos mokslo sektoriuje pasigendama mokslinių darbų, kuriuose būtų siekiama praplėsti tekstilės medžiagų deformacinės elgsenos modeliavimo skaitiniais metodais ribas.

Darbo tikslas

Sukurti naują universalų, nesudėtingą tekstilės medžiagų ir jų junginių deformacijų vertinimo metodą, atsižvelgiant į eksploatuojamų gaminių tekstilės medžiagų elgsenos dėsningumus.

Darbo uždaviniai:

1. Nustatyti tekstilės medžiagų bei jų junginių tąsumo ribas tradicinio vienaašio tempimo metu suardant bandinius ir neviršijant mažų apkrovų ribos;
2. Ištirti gretasienio formos metodo taikymo galimybes ir tinkamumą vienasluoksnių liaunų tekstilės medžiagų deformacinėms savybėms vertinti;
3. Sukurti naują universalų tekstilės medžiagų ir jų junginių deformacinių savybių tyrimo metodą, atsižvelgiant į aprangos deformacinius ypatumus bei nustatyti tekstilės medžiagų ir jų junginių deformacinę elgseną apibūdinančius rodiklius;
4. Baigtinių elementų metodu (BEM) sudaryti naujo metodo bandinio modelį, atitinkantį realų eksperimentą bei įvertinti medžiagų deformacinę elgseną, palyginti skaitinio ir eksperimentinio metodų rezultatus.

Darbo mokslinis naujumas ir praktinis pritaikymas

Naujai sukurtu metodu galima nustatyti ir įvertinti tekstilės medžiagų ir jų junginių deformacines savybes bei eksploatuojamų gaminių deformavimosi ypatumus. Darbe naujam metodui parinktos optimalios bandymų sąlygos, nustatyti tekstilės medžiagų ir jų junginių deformacinę elgseną apibūdinantys rodikliai. Naujuoju metodu deformacinės savybės vertinamos kompleksiškai, t. y. grafiniu, vizualiniu bei modeliavimo baigtiniais elementais būdais. Pagal naują metodą bandinys deformuojamas iki deformacijų, artimų dėvėjimo metu atsirandančioms deformacijoms. Baigtinių elementų metodu (BEM) sudarytas medžiagos Y formos bandinio deformavimo modelis suteikia galimybę analizuoti tekstilės medžiagų deformacines savybes neatliekant realių eksperimentų, taupant eksperimento kaštus bei laiką. Taip pat naujuoju metodu praplėstos tekstilės medžiagų deformacinės elgsenos modeliavimo skaitiniais metodais ribos.

Ginamieji teiginiai:

1. Gretasienio formos bandinio metodu gautos charakteristikos nekoreliuoja su vienaašio metodo gautomis charakteristikomis, ir gretasienio metodo

kriterijai nėra tinkami vienasluoksnių liaunų tekstilės medžiagų deformacinėms savybėms vertinti;
2. Naujai sukurtu Y formos bandinio metodu ir parinktais išilgines, skersines bei kampines deformacijas apibūdinančiais rodikliais galima įvertinti tekstilės medžiagų ir jų junginių deformacines savybes esant dėvėjimo lygio apkrovoms;
3. Baigtiniais elementais sudarytas modelis yra adekvatus eksperimentiniam modeliui, tad gali būti naudojamas kaip alternatyvus būdas laiką ir kaštus eikvojantiems eksperimentams bei pateikti rezultatai yra patikimi ir tinkami tiek praktiniu, tiek moksliniu požiūriu.

IŠVADOS

1. Nustatytas glaudus ryšys (R^2 = 0,8520÷0,9413 audiniams, R^2 = 0,9032÷0,9796 mezginiams) tarp santykinių pailgėjimų, deformuojant audinių ir mezginių bandinius iki bandinių suardymo ir neviršijant mažų apkrovų ribos. Tai rodo, jog tekstilės medžiagų deformacinės savybės išryškėja jau pradinėmis deformavimo stadijomis, kai pasiekiamos nedidelės apkrovos. Todėl tekstilės medžiagų deformaciėmsms savybių vertinti galima naudoti ne tik standartinius metodus, kurie skirti bendrajai deformacinei elgsenai nustatyti, bet ir netradicinius metodus, kai bandiniai deformuojami neviršijant tamprumo ribos ir nesuardant jų struktūros elementų.
2. Vienaašiu metodu tempiant tiriamas tekstilės medžiagas iki bandiniams suyrant, nustatyta, kad audinių santykinės trūkimo ištįsos $\varepsilon_{\mathrm{Vtr}}$ vertės svyruoja 11,5 %–119,0 % tąsumo ribose. Deformuojant audinius, kai neviršijama mažų apkrovų riba, santykinio pailgėjimo $\varepsilon_{\mathrm{V490}}$ vertės kinta 1,1 %–51,2 % tąsumo ribose. Tempiant mezginių bandinius vienaašiu metodu iki bandiniams suyrant, nustatyta, kad santykinės trūkimo ištįsos $\varepsilon_{\mathrm{Vtr}}$ vertės svyruoja 70,1 %–432,0 % tąsumo ribose ir yra kelis kartus didesnės nei audinių. Deformuojant mezginius, kai neviršijama mažų apkrovų riba, santykinio pailgėjimo $\varepsilon_{\mathrm{V50}}$ vertės kinta 46,8 %–246,6 % tąsumo ribose. Nustatyta, kad mezginiai, priešingai nei audiniai, jau mažų dėvėjimo lygio apkrovų metu pasiekia aukštas tąsumo ribas.
3. Vienaašiu metodu deformuojant siūlėmis sujungtus mezginių bandinius, jų santykinės trūkimo ištįsos $\varepsilon_{\mathrm{Vtr\text{-}S}}$ verčių pokyčiai svyruoja nuo 0,2 % iki 12,7 % (bandiniai sujungti vertikalia siūle) bei nuo 0,6 % iki 23,8 % (bandiniai sujungti horizontalia siūle). Taip pat nustatyti ir nežymūs santykinės trūkimo ištįsos anizotropiškumo koeficiento $an_{\mathrm{V\text{-}S}}$ verčių pokyčiai, po bandinių sujungimo siūlėmis, kurie siekia ~ 0,2 %.
4. Eksperimentų metu gauti rezultatai patvirtino, kad gretasienio formos bandinio deformavimo metodas netinkamas paslankių audinių, o ypač mezginių deformacinėms savybėms vertinti. Tyrimų metu nustatyta, kad mezginių bandiniuose lygiagretainio kampo tarp kraštinės x_{G0} ir y_{G0} pokyčio rodiklis α'_{G45}, deformuotiems bandiniams santykinio pailgėjimo dydžiu $\varepsilon_{\mathrm{G45}}$ = 45 %, nesiekė 1 %,

t. y. nubraižytas lygiagretainis beveik nepakito. Gauta, kad tirtų mezginių deformaciją sudarė medžiagų struktūros elementų tįsimas, o ne šlytis. Ištempus bandinius ištįsa didesne nei 45 mm, bandiniuose nubraižytas lygiagretainis netapo stačiakampiu, o medžiagų struktūros elementai pradėjo irti.

5. Nustatyta, kad tempiant tekstilės medžiagas nauju Y formos bandinio metodu, medžiagos yra deformuojamos neviršijant mažų apkrovų tamprumo ribos, t. y. tempimo jėga audiniams neviršija 9,6 N/cm, o mezginiams 4,8 N/cm. Taigi medžiagas sudarantys struktūros elementai nepažeidžiami.

6. Y formos bandinio metodu deformuotų audinių išilgines deformacijas ir bandinių ilginių matmenų pokyčius nusakančių rodiklių h_1‘$_{Y10}$, h_5‘$_{Y10}$ ir h_9‘$_{Y10}$ vertės yra didžiausios 1-ame taške (neviršija 10 %), o mažiausios – 9-ame taške ir kinta iki 5 %. Mezginių išilginių deformacijų pokyčius nusakančio rodiklio h_i‘$_{Y40}$ vertės, kaip ir audiniuose, yra didžiausios 1-ame bandinio taške ir kai kurių medžiagų siekia 25 % ribą, o mažiausi – 9-ame taške ir yra iki 4–5 kartų mažesni nei 1-ame taške dėl mezginių savybės tįsti.

7. Y formos bandinio viduryje nubraižytų vertikalių linijų $Š_{Y1}$ ir $Š_{Y2}$ susiaurėjimo rodiklio vs_i‘$_{Y10}$ pokyčiai yra artimi h_i‘$_{Y10}$ vertėms ir neviršija 12 %. Taip pat nustatyta, kad mažesniu struktūros elementų paslankumu pasižyminčiuose audiniuose (A2, A3, A5) išilginių ir skersinių deformacijų pasiskirstymas visuose trijuose taškuose yra pakankamai tolygus ir audiniai išlieka gana stabilūs visame bandinio plote. Priešingai nei rodiklio h_i‘Y40, mezginių vidurio susiaurėjimo vs_i‘$_{Y40}$, tarp bandinyje nubraižytų vertikalių linijų, vertės 1-ame bandinio taške išsidėsto kur kas mažesnėse verčių ribose, nei 5-ame ir 9-ame taškuose. Nustatyta, kad mažesniu struktūros elementų paslankumu pasižyminčių mezginių vidurio susiaurėjimo vs_i‘$_{Y40}$ vertės yra vienos didžiausių, ypač 5-ame ir 9-ame bandinio taškuose.

8. Y formos bandinio kampines deformacijas apibūdinančio rodiklio α_i‘$_{Y10}$ vertės audiniuose kinta iki 50 %, ypač audiniuose be elastano. Nustatyta, kad tokiuose audiniuose sudėtingos kampinės deformacijos veikia visame bandinio plote, tai rodo ir kampo pokyčio α_i‘$_{Y10}$ vertės, kurios yra žymios visuose trijuose bandinio taškuose, o ypač 1-ame ir 9-ame bandinio taškuose. Tokių audinių gerą struktūros stabilumą patvirtina ir rodiklio S_{Y10} vertės, kurios siekia 5 %, kai tuo tarpu kitų medžiagų rodiklis neviršija 1,5 %. Mezginių kampo pokyčio α_i‘$_{Y40}$ vertės siekia net 70 %. Nustatyta, kad paslankesnių mezginių kampo pokytis α_i‘$_{Y40}$ yra perpus mažesnis nei mažiau paslankių medžiagų. Todėl rodiklio α_i‘$_{Y40}$ vertės rodo, jog paslankios ir elastingos medžiagos patiria mažesnes kampines deformacijas.

9. Nustatyta, kad siūlės įtaka Y formos audinių bandinių tempimo jėgos pokyčiams siekia iki 20 %. Siūlių įtaka audinių išilginių matmenų kitimui yra nežymi ir rodiklio h_i‘$_{Y10}$ pokyčiai siekia iki 4,0 %. Tuo tarpu daugelio audinių bandinyje nubraižytų vertikalių linijų $Š_{Y1}$ ir $Š_{Y2}$ susiaurėjimo rodiklio vs_i‘$_{Y10}$ pokyčiai siekia net iki 55 %. Taigi, gauta, kad siūlių įtaka bandinio skersinių matmenų pokyčiams yra žymi. Žymesni audinių bandiniuose nubraižytų

horizontalių ir vertikalių linijų kampo pokyčiai α_i‘$_{Y10}$ nustatyti bandiniams su siūlėmis bandinio kirptiniuose kraštuose. Tokios siūlės sumažina bandinio centrinės dalies paslankumą ir dėl kampinių deformacijų poveikio labiau pasireiškia šlytis.

10. Nustatyta, kad siūlės įtaka tempimo jėgai buvo didesnė Y formos mezginių bandiniams nei audiniams ir siekė 55 %. Siūlės įtaka mezginių išilginiams matmenų kitimo rodiklio h_i‘$_{Y40}$ verčių pokyčiams siekia iki 5 %. Mezginiuose skersinių matmenų rodiklio vs$_i$‘$_{Y40}$ verčių pokyčiai, po sujungimų siūlėmis, ypač dideliu struktūros elementų paslankumu pasižymintiems mezginiams svyruoja iki 45 %. Rodiklio α_i‘$_{Y40}$ verčių pokyčiai mezginiuose, kai bandiniai sujungiami siūlėmis, taip pat yra akivaizdūs ir siekia 50 %.

11. Nustatytas žymus skaitinio ir eksperimentinio tyrimų rezultatų sutapimas. Didžiausias skirtumas tarp eksperimentinio ir skaitinio metodo rodiklio hi'_{Y40} verčių yra apie 9,8 %. Nustatytas stiprus ryšys (R^2 = 0,9563 ÷ 0,9961) tarp eksperimentinių ir skaitinių tyrimų rezultatų. Taigi, pateikti rezultatai yra teisingi ir tinkami tiek praktiniam, tiek moksliniam panaudojimui.

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