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Anisotropy of Woven Fabric Deformation after Stretching

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Abstract

A garment should receive elongations and deformations of proper magnitude in various directions during its exploitation. It should also return to its previous shape. Elastane yarn extends the deformation possibilities of woven fabrics. The aim of this research was to establish a method for correct evaluation of garment behaviour during its manufacture and wear. An original method was created to evaluate the deformation anisotropy of fabrics under tension. The main idea of the experimental part was to evaluate the deformation of specimens after loading. At each experimental stage after delayed recovery, we measured the decrease in the specimen's width, the shear angles, the difference in length of the specimen's edges, the elongation at a fixed load, and the width of the specimen. The weave structure of textile fabrics, the existence of elastane fibre and the direction of the tensile force have an influence on the non-uniformity of the deformation. The anisotropy of tested woven fabrics also depends on the type of yarns and their structure, as well as on the warp and weft yarn orientation with respect to the tensile force. The results of this experiment also showed that the structure of elastane influences the anisotropy of deformation of fabrics. This method can be used not only for stretched but also for other fabrics which have larger anisotropy of tensile properties.

Key words: *woven fabric, elastane, uni-axial tension, anisotropy of deformation.*

Introduction

For comfortable clothes which allow free movement, the deformation characteristics are very important for the wearer. During garment wear, the fabrics need to be stretched or bent to a certain degree and in various directions. Woven fabrics have a bigger or smaller level of structural anisotropy, therefore their properties are non-uniform in different directions. Many works have been devoted to the study of the anisotropic deformation of woven fabrics [1 - 5]. Fabric behaviour during stretching depends, to a large extent, on its structure. The main fabric structure parameters are warp and weft yarn types, their linear density, the warp and weft setting, and the fabric weave [6]. The higher the linear density, the more difficulty it is for the yarn to move, and therefore it is less likely that the fabric will deform. Fabric firmness depends on the weave type. Plain weave has the maximum number of interlacing or binding points. Fabrics with very long floats may be more unstable [6]. The degree of deformation also depends on the chemical composition, mass and thickness of the fabric. Milašius [7] suggested a new integrated fabric structure factor φ which has an influence on the mechanical and end uses of woven fabrics. This factor can be calculated as follows:

$$\varphi = \sqrt{\frac{12}{\pi}\frac{1}{P_1}}\sqrt{\frac{T_{av}}{\rho}}S_2^{\frac{1}{1+2/3\sqrt{T_1/T_2}}}\,S_1^{\frac{2/3\sqrt{T_1/T_2}}{1+2/3\sqrt{T_1/T_2}}} \qquad (1)$$

where P_1 is the theoretical weave factor, T_{av} is the average linear density of the fabric, ρ is the fibre density, $S_{1(2)}$, are warp and weft settings, respectively, $T_{1(2)}$ are the linear densities of the warp and weft.

In work [8] it was determined that the integrated fabric structure factor φ has an influence on the elongation at break results of fabrics. In cases where the structure of woven fabric becomes more rigid, i.e. factor φ increases, the elongation at break also increases.

Tensile deformation is more likely to occur in composites with elastane yarns, which may either be incorporated into the fabric in a pure state or wrapped with relatively inextensible fibres. Fabrics containing elastane yarns have ten times more deformation than conventional fabrics [9 - 11]. Although the elastane filament improves yarn elasticity, it was determined [12] that only optimal elastane percentages lead to the best mechanical properties of fabric, such as tenacity and elongation.

The aim of this work was to analyse the dependence of the structural and mechanical characteristics of woven fabric and the degree of anisotropy in their change of shape during stretching.

Experimental

Ten commercially produced woven fabrics with different structure characteristics were chosen for this experiment. Basic characteristics of the fabrics tested are shown in ***Table 1***. In order to investigate the behaviour of the woven fabrics during stretching, we used three types of fabric with different tensile properties:

1 group – fabrics with elastane yarn only in the weft direction (samples M1, M4, M7 and M8);

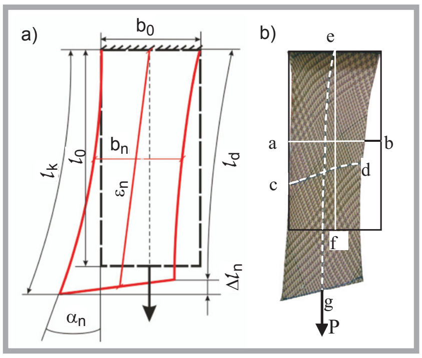

Figure 1. *Scheme of the specimen shape before and after stretching, the measured parameters (a), and view of the unequal deformation of woven fabric after stretching (b).*

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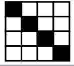
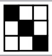
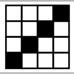
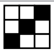
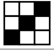
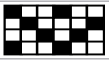
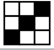
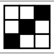
Table 1. *Characteristics of fabrics investigated.*

Fabric	Fabric composed of:	Setting, dm^{-1}		Surface density, g/m^2	Yarn elongation at break, %		Fabric elongation at break, %		Weave structure
		Warp	Weft		Warp	Weft	Warp	Weft	
M1	Rayon/Cotton+elastane twist with every second weft yarn	300	200	309	7.0	6.0 8.2	18.4	48.5	
M4	Rayon+elastane twist with weft yarn	480	280	184	5.9	26.9	16.1	77.1	
M7	Wool+elastane twist with weft yarn	400	300	279	12.1	14.6	37.5	72.1	
M8	Rayon+elastane assembled with weft yarn	370	180	251	6.6	33.0	20.6	84.5	
M6	Rayon+elastane twist with warp and weft yarns	340	240	359	15.3	8.5	73.9	58.1	
M9	PES+elastane twist with warp and weft yarns	310	270	281	30.8	20.1	77.5	48.9	
M10	PES+ elastane twist with warp and weft yarns	240	240	294	31.9	29.0	77.1	59.6	
M11	Wool+PES	280	240	203	21.8	25.0	44.0	39.0	
M12	Cotton+Flax	200	120	228	5.2	9.73	5.6	12.2	
M13	Cotton+Rayon	420	180	217	9.4	4.4	14.9	5.7	

2 group – fabrics with elastane yarn in both directions (samples M6, M9 and M10);
3 group – fabrics made from non-stretch yarns (samples M11, M12 and M13).

The elongation at break of the fabrics was tested with a Zwick tensile testing machine according to Standard ISO 13934-1 [13]. A cross-head speed of 100 mm /min was chosen. The elongation at break of yarns pulled-out from the fabrics was determined according to the standard [14].

For the analysis of the type of fabric deformation after stretching, we used a new method [15]. The specimens were stretched using a relaxometer device [16]. Taking into account real conditions of garment manufacturing and the wear process, a maximal load of 5 N/cm was used, which corresponds to 17% of the breaking strength for the weakest fabric chosen for this test. The initial load was 0.5 N/cm. After the load of 5 N/cm was reached, we waited 15 min., after which such characteristics as the specimen's elongation ε (in %) and decrease in width b (in %) were determined (***Figure 1.a***). The specimen's shape after deformation was determined by the difference Δl_n (in mm) between the length of its vertical selvages and shear angle α_n (in deg). Taking into account that after stretching, most of the specimens' bottom selvage was not horizontal, the length ε_n of the middle line *e-g* was measured and compared with the initial length l_0.

The fabric's elongation ε was calculated:

$$\varepsilon = (\varepsilon_n - l_0)/l_0 \times 100\% \qquad (2)$$

It is known that the deformation of fabric during uniaxial stretching is not uniform. Lateral contraction of the specimen does not become constant at a certain distance away from the jaws but increases gradually towards the centre of the specimen, forming a "neck". As is evident from ***Figure 1.b***, there is a change in both the width and direction of the initial centre line *a-b* of the specimen after deformation (line c-d). Therefore the specimen's width b_n after stretching was measured at the narrowest part of the specimen. The decrease in width b was calculated in comparison with the initial width b_0 of the specimen:

$$b = (b_0 - b_n)/b_0 \times 100\% \qquad (3)$$

The difference in the selvage lengths Δl_n of the specimen was determined by measuring the length of the left selvage l_k and the right selvage l_d and calculating the difference. The shear angle α_n was measured between the vertical line which indicates the initial selvage and the selvage of the stretched specimen.

Rectangular specimens with a working zone of 150 × 50 mm were used in these tests. The specimens were cut at angles of 15°, 30°, 45°, 60° and 75° with respect to the warp direction. Three repeats per specimen were carried out and the averages calculated. The coefficients of variation of the test results ranged from 0.2% to 15.5%. All the fabrics were conditioned in standard atmospheric conditions of 65% RH and 20 °C.

Results and discussion

When a tensile force acts in warp or weft direction, the specimen's length increases due to fibre tension and compaction. During the uniaxial stretching in woven fabric in a direction other than warp or weft at the initial stage, the threads reveal shearing. As a rule most woven fabrics achieve the largest elongation during stretching in the direction of 45° from the warp. From the results presented in ***Figure 2***, we can

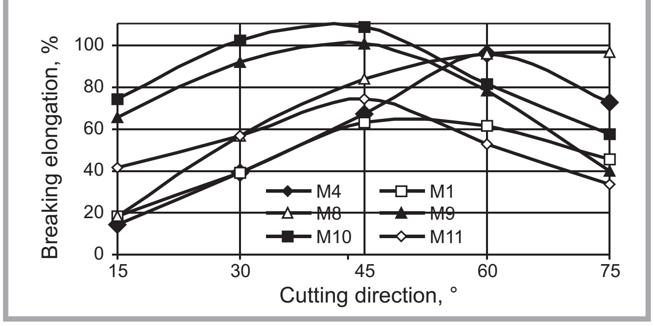


Figure 2. *Anisotropy of the elongation at break of the fabrics in various cutting directions (tested with a Zwick device).*

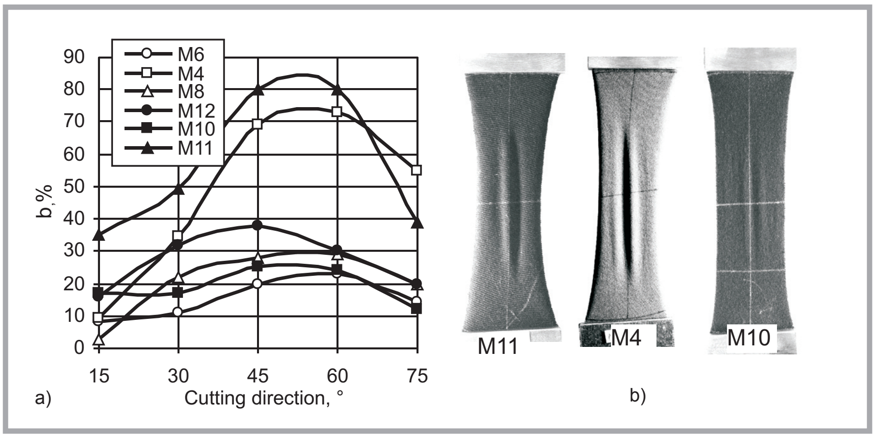


Figure 4. *Dependence of the cutting direction on the decrease in specimen width b; the buckling phenomenon in fabrics, stretched in the direction of 45° (b).*

see that some of the tested fabrics with a more uniform structure: elastane yarns in both directions (M9, M10) and without elastane (M11) confirmed the above-mentioned rule. It can be seen that, for these fabrics the shape of their curves is more similar and symmetrical on the right and left side of the diagrams . Except for fabrics containing elastane fibre only in the weft direction, the elongation at break maximum is shifted to the weft direction: about 60^0 for fabric M4 or even 75° for fabric M8. These results indicated that elastane fibres, being only in one of the woven fabric directions, increase the anisotropy of elongation at break.

In order to analyse more deeply the influence of woven fabric structure on deformation anisotropy during stretching, the integrated fabric structure factor φ was calculated (formula 1) with an original DESINT program [17]. It is known that most of the fabrics used for clothes are, on average, firm and strong, and their φ factor ranges from 0.7 to 0.8. Thin and at the same time less stabile fabrics have lower values (φ = 0.5 – 0.6). For very firm fabrics factor φ is near 1. The results indicated (***Figure 3***) that the fabrics chosen for our experiment have different degrees of firmness or stability, but most of them we can characterise as fabrics of average stability. As is evident from the results obtained, the plain weave fabric M10, with elastane fibre in both directions, is of high stability. Fabrics M8 and M12 had a value of low structure factor φ, showing low stability.

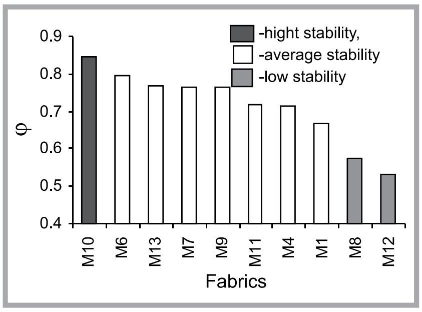


Figure 3. *Integrated fabric structure factor φ of the fabrics tested.*

During woven fabric stretching with a force lower than the breaking force and in a direction which does not coincide with the warp and weft, specimen elongation occurs due to the shearing and tightening of the fabric structure, and partly to warp and weft thread extension. Fabric shearing and tightening leads to a decrease in the width of the specimen on which the buckling phenomenon also has an influence. The test with the relaxmeter device showed that in most cases the parameter *b* of the tested fabrics did not exceed 40% (***Figure 4.a***). Only for fabrics M11 and M4 was the decrease in the width of the specimen more considerable. The especially small value of parameter *b* of fabric M11 can be explained by the high elongation of its warp and weft threads (see ***Table 1***). In most of the specimens, the buckling phenomenon was clearly observed in directions of 30°, 45°, 60° (***Figure 4.b***). Only for fabrics M1 and M6 was there no buckling obtained in any of directions tested. Therefore it can be stated that all the above-mentioned factors, such as shearing, weft and warp thread extension and specimen buckling have an influence on the considerable decrease in specimen width. The investigation revealed that fabric M10, with a low integrated structure factor φ, buckled only slightly during stretching (***Figure 4.b***) and has the smallest decrease in width: its *b* characteristic ranged from 12 to 25% in various stretching directions (***Figure 4.a***).

The dependence of woven fabric elongation (formula 2) on the decrease in specimen width *b* (formula 3) as well as the difference between the selvage lengths Δl_n and shear angle α_n were described using the second degree polynomial equation. The values of determination coefficient were 0.69 - 0.98.

It was determined that the specimen's elongation ε has an influence, more or less, on its decrease in width *b*. It should be noted that the parameter *b* depends

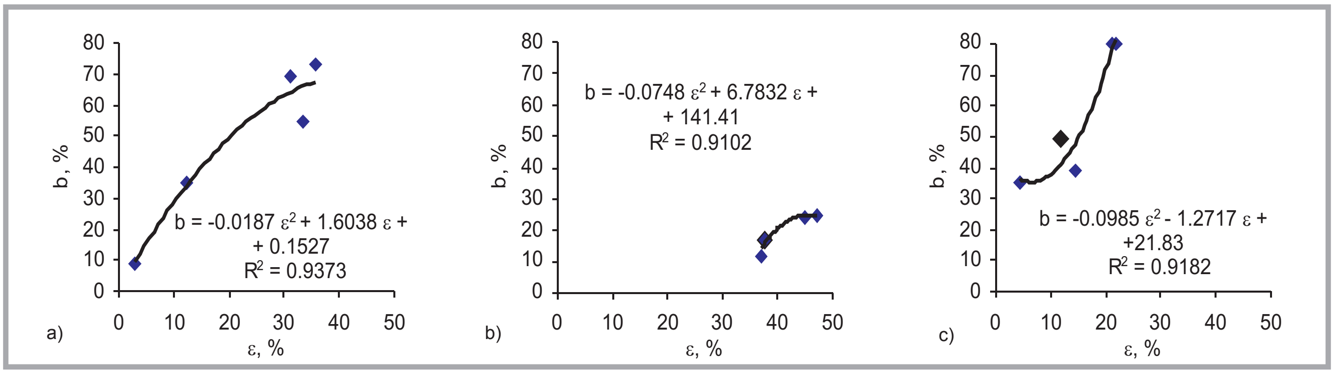


Figure 5*. Dependence of the elongation degree of the specimens on the decrease in their width b: a – fabric M4 (elastane in weft), b – fabric M10 (elastane in warp and weft), c – fabric M11 (without elastane).*

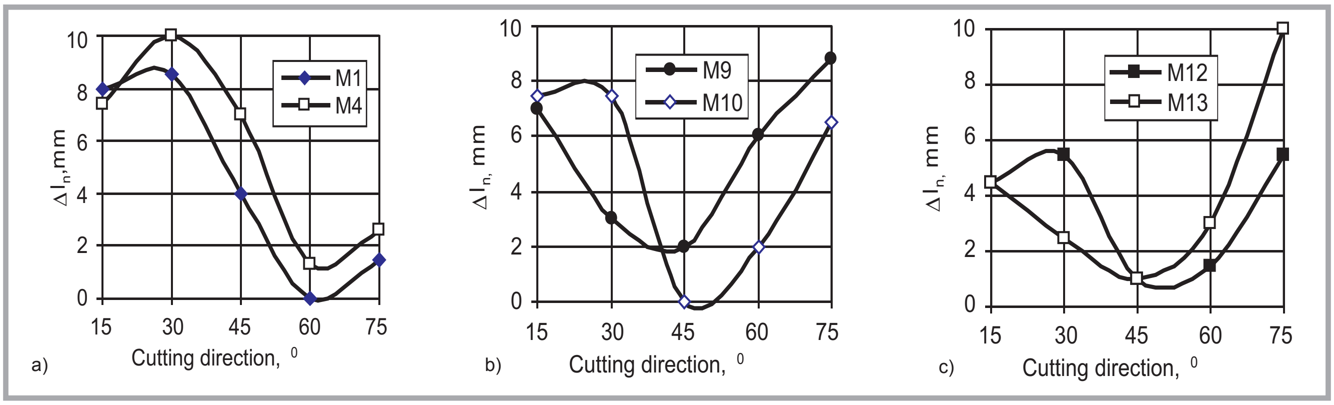


Figure 6. *Dependence of the cutting direction on the increment Δl_n: a – fabrics with elastane in weft, b – fabrics with elastane in warp and weft, c – fabrics without elastane.*

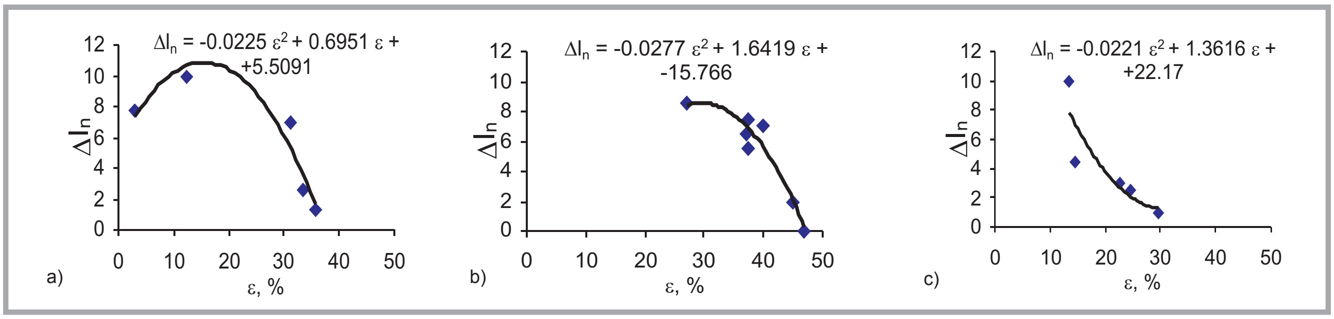


Figure 7. *Dependence of the elongation degree of the specimens on their increment Δl_n: a – fabric M4 (elastane in weft), b – fabric M10 (elastane in warp and weft), c – fabric M13 (without elastane).*

on specimen elongation more markedly for those fabrics (M4 and M11) which showed larger elongation characteristics in various cutting directions (see ***Figure 4.a***). Of course, in conjunction with larger specimen elongation, the buckling phenomenon also has an influence on the decrease in specimen width (see ***Figure 4.b***). In ***Figure 5***, as an example, the results of some tested fabrics are presented: one fabric from every group of different elongation degrees. The curves were traced using the same scale for each fabric.

As was mentioned earlier the non-uniform shape of the fabric after stretching or, in other words, the anisotropic deformation we can characterise according to the difference between the selvage lengths and shear angle of the specimens.

The differences between the selvages lengths Δl_n (see ***Figure 1,*** page 52) of the test fabric specimens in various stretch directions are presented in ***Figure 6***. From the shapes of the diagrams, it can be seen that the minimum value of increment Δl_n was determined in the direction of 45° for fabrics with elastane in both directions and for fabrics without elastane. The highest Δl_n of these fabrics was found in directions near the warp and weft (15° and 75°). The type of deformation of fabrics with elastane only in weft was different: the highest value of increment Δl_n was determined in a direction close to that of warp, especially in the direction of 30°. The lowest values of Δl_n of the specimens were in a direction close to that of weft (60°, 75°).

The relationship between specimen elongation and differences in salvage lengths Δl_n are given in ***Figure 7***. According to the results, the samples with less elongation had a larger value of increment Δl_n. Such a tendency was obtained for all three groups of fabrics tested.

The second characteristic of anisotropy of woven fabric deformation was the shear angle α_n of the specimen. As is evident from ***Figure 8***, the diagrams obtained show the same tendency with respect to differences in the selvages lengths Δl_n of the specimens. The biggest values of characteristic α_n were determined near the warp and weft direction for fabrics with elastane in the warp and weft, without elastane and only near the warp direction – with elastane in the weft.

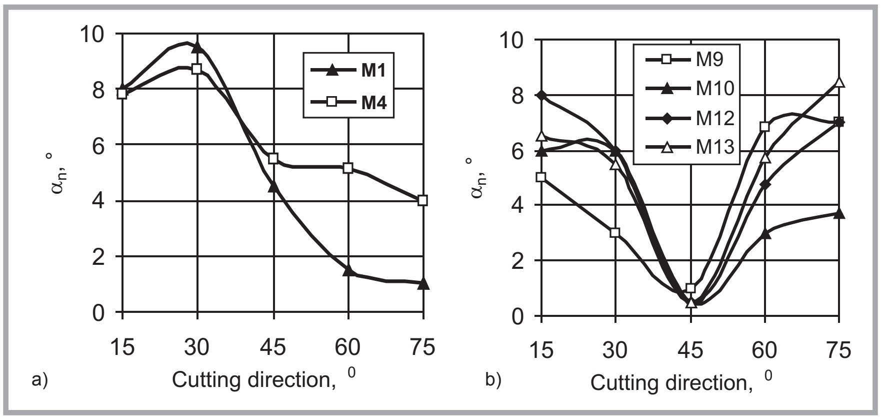


Figure 8*. Dependence of the cutting direction on the shear angle α_n: a – fabrics with elastane in weft, b – fabrics with elastane in warp and weft and without elastane.*

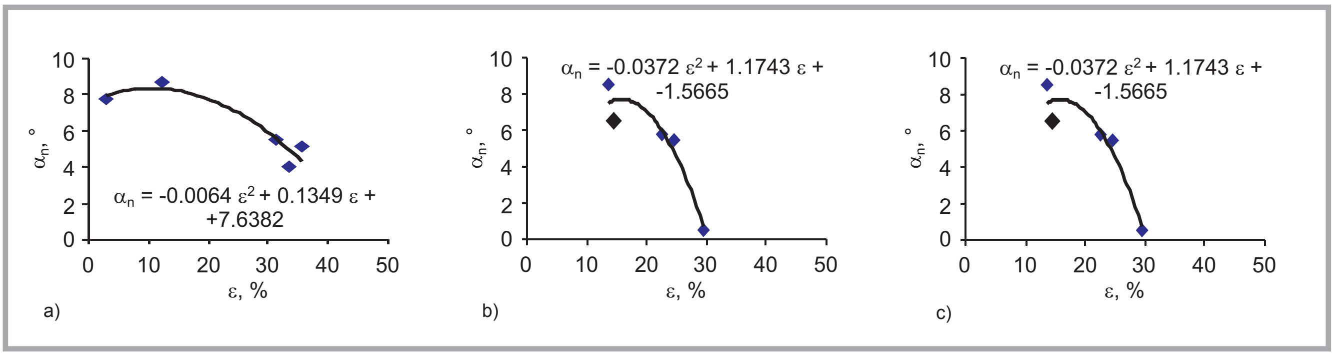


***Figure 9**. Dependence of the elongation degree of the specimens on their shear angle α_n:: a – fabric M4 (elastane in weft), b – fabric M10 (elastane in warp and weft), c – fabric M13 (without elastane).*

The dependence of woven fabric elongation on the shear angle can be also described using the second degree polynomial equation. Values of the determination coefficient were from 0.87 to 0.92. It was determined that, while increasing the elongation of the fabric without elastane (***Figure 9.c***) and the elongation of the fabric with elastane in the weft (***Figure 9.a***), the shear angle had a tendency to decrease (***Figure 9.b***). The shear angle of the fabric with elastane in the warp and weft increased until the elongation of the specimens reached 40%. Further increases in elongation reduced the shear angle.

The results also showed that for most the fabrics tested, high correlation between the difference in selvage lengths Δl_n and shear angle α_n were obtained after stretching This dependence was described using the second degree polynomial equation. Values of the determination coefficient were 0.74 - 0.97. No satisfactory correlation ($R^2 = 0.66$) between the above-mentioned characteristics was obtained for fabric M8, which was characterised as a fabric of low stability. The integrated structure factor φ for this fabric was only 0.576 (see ***Figure 3***). It was found that for fabric M11 no correlation existed between two anisotropic deformation characteristics: At various values of selvage length differences Δl_n (3.3 - 7.0), the shear angle α_n is always high: (4.9 - 7.9). Although fabric M11 is without elastane fibre, its considerable elongation characteristic was evident (see ***Figure 2***). It is possibly the main reason that no correlation between the two characteristics was obtained for this fabric.

Summary and conclusions

A study of the anisotropy of stretch and non-stretch woven fabric deformation was made using a new method which allows to determine the type of fabric deformation using such parameters as the decrease in specimen width, and the difference in the selvage lengths and shear angle of the specimen. Fabrics stretched in a direction with the lower extensibility showed the highest anisotropic deformation. In other words if the structure of the fabric in the deformation direction is more rigid, the fabric deforms in the directions in which the fibre is weaker. Fabrics with elastane fibre in both directions deform with a similar anisotropy as fabrics without elastane fibre. The different deformation anisotropy was determined for fabrics containing elastane fibre only in weft direction. The results of this experiment showed that after stretching the fabrics, the decrease in specimen width not only depends on the cutting direction but also on the elastane fibre direction in the fabric. It was determined that for fabrics with elastane fibre only in the weft direction, the decrease in specimen width is higher not only in the typical direction of 45° from the warp, but also in a direction close to that of the weft (60°). The biggest shear angle and differences in the selvage lengths of the specimens were obtained in directions with the lowest results for elongation. Contrary to expectations no relation was found between the integrated fabric structure factor of the fabrics tested and their anisotropic deformation characteristics.

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