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Investigation of Fabrics Tensile Deformations

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Tensile deformations of textile fabrics were analysed in this work. Five different woven fabrics were chosen for the experiment. Fabrics were different in fibre content, thickness, density and finishing. The specimens were cut in certain directions and tested using relaxometer device. Testing were performed at four experimental stages. Each of them had a fixed load. During experiment it was noticed that the direction of specimen's deformation often disagrees with the direction of the force vector. It was defined that types of specimen's deformation were under the influence of shear effect. Four main characteristics were measured to make the practical analysis: elongation at fixed load ε_n, specimen's width decrease Δb_n, shear angle α_n and difference of specimen's vertical edges length Δl_n. It was found that wave structure of the textile fabrics, existence of elastane fibre, fabric's coating and direction of the tensile force have influence on elongation of specimen and on the contraction rate of specimens width. As a result of this research the characteristics mentioned above were systematized and three specific cases of deformation non-uniformity were established.

Keywords: textile fabrics, cut direction, loading, deformation, elongation, shear.

INTRODUCTION

Woven fabrics are well known due to anisotropy of their properties. W. F. Kilby [1] is probably one of the first researchers who dialled with the anisotropy of the mechanical properties of woven fabrics. Anisotropy of breaking strain and tensile modulus were reported in [2]. Many authors have reported works carried out to relate objectively measured fabrics properties such as tensile extensibility, shear stiffness, shear hysteresis, bending rigidity and bending hysteresis, to subjective properties such as fabric tailorability, garment appearance, fabric handle and fabric drape [3, 4].

Shear behaviour is one of the most important characteristics that contributes to the performance and appearance of woven garments.

During garment wear process certain parts of some of fabric are stretched in various directions by forces of different intensity [5, 6]. Therefore one can expect asymmetric folds, pleats or seam pucker, which usually are not desirable during wear process of the garment, as it is illustrated in Fig. 1. To evaluate shearing behaviour of woven fabrics during garment wear new methods are presented by several researches [7 – 9]. They are aimed to investigate the influence of structural parameters on the fabrics shearing rigidity [4, 10, 11] and to define parameters of the specimen buckling during shearing [12, 13]. However in the garment we can meet the system where two peaces of textile fabrics are cut in different directions and joined with a seam. Our preliminary investigations [14] have shown that components of system deform differently. There is a lack of works where an influence of tensile force on the anisotropy of shear deformation and shape of deformed specimen are investigated. In most cases the fabric specimen were tested only in three cutting directions: warp, weft and 45°.

The aim of this paper was to investigate woven fabrics dimensions and shape changes under different loading conditions and to analyse shear anisotropy after their tension in different directions. Fabrics of different tensile rigidity were used for the experiment.

EXPERIMENTAL

Five commercially produced woven fabrics with different tensile properties were chosen for the experiment (Table 1). Two of them M5 and M9 were laminates with low degree of extensibility, one M11 – laminate with the average degree of extensibility (half-wool fabric) and two stretch fabrics containing elastane fibre (M4 and M6) – with the high degree of extensibility. Four of them were of twill weave. Such type of wave was chosen as nonsymetrical and more anisotropical. Tested materials were also different in fibre content, thickness, density and finishing.

Rectangular specimens of 150 mm × 50 mm work zone were used in these tests. The specimens were cut at angles of 15°, 30°, 45°, 60° and 75° in respect to warp direction.

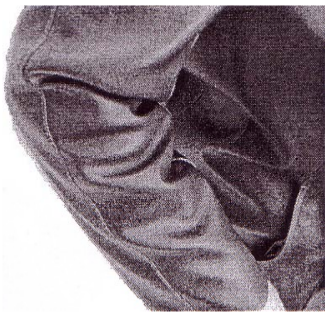

Fig. 1. Deformation of garment in wear process (photo of authors)

All fabrics were conditioned in standard atmosphere conditions of 65 % RH and 20 °C.

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Table 1. The characteristics of investigated fabrics

Fabric	Fibre content	Setting, dm^{-1}		Surface density, g/m^2	Thickness*, mm	Elongation at break, %		Weave structure
		Warp	Weft			Warp	Weft	
M4**	Rayon + elastane	480	280	184	0.5	16.1	77.0	½ Twill
M5	Cotton + PU	610	270	191	0.43	9.5	17.0	½ Twill
M6***	Rayon + elastane	340	240	359	0.9	73.8	58.0	½ Twill
M9	Cotton + PU + PVC	220	220	310	0.68	6.0	19.9	Plain
M11	Wool + PES	280	240	203	0.46	44.0	39.1	½ Twill

*Thickness at pressure of 0.196 MPa, **Elastane fibre in weft, ***Elastane fibre in warp and weft

The specimens were tested using relaxometer device [15]. In order to investigate the influence of the loading we have used two different loads: maximal and minimal. Taking into account real conditions of garment manufacturing and wear process we used the maximal load of 5 N/cm. It corresponds to 0.5 % of breaking strength for the strongest fabrics that were used in this test. Suchlike force was applied taking into account the real conditions of garment wear process [16, 17].

The experiment consisted of four stages following each other (Fig. 2). The specimen was:

I. Loaded by 1 N/cm force (P_1 =1 N/cm);

II. Loaded by an extra load of 4 N/cm (P_2 = 5 N/cm);

III. Unloaded by 4 N/cm force (P_3 = 1 N/cm);

IV. Unloaded by 0.5 N/cm (P_4 = 0).

Duration of delayed recovery at each stage was 15 min.

At each experimental stage after delayed recovery we determined such characteristics of specimens as elongation at fixed load ε_n (%) and relative decrease of specimen's width Δb_n (%) at the same load.

However it was noticed that after specimen's loading (unloading) the direction of its deformation often disagrees with the direction of the force vector. Due to cutting angles in respect to warp direction the effect of unequal shear was in process. A non-uniformity extension of specimen edges was also determined, using the differences in specimen's edges lengths Δl_n (mm), as it is illustrated in Fig. 3.

For this reason we also introduced another characteristic of the tested fabrics such as shear angle α_n (deg). Besides, as it is evident from Fig. 3 the characteristic ε_n was calculated after measuring the longest edge of specimen.

Experiments were repeated for three times for each specimen cut in different direction. Variation coefficients of all tested specimens ranged up to 2.5 %.

RESULTS AND DISCUSSIONS

Elongation at fixed load. It is known that the largest deformations are in specimens, which are cut in bias direction (45°), because of the shear effect. This fact was confirmed by the fabrics M4 and M6 containing elastane fibre, as it is illustrated in Fig. 4.

As it was expected the largest elongation of tested fabrics was obtained at the second (II) testing stage when the maximal load of 5 N/cm was applied. Plastic deformation after (stages III and IV) were noticed for fabrics M4, M6 and M11.

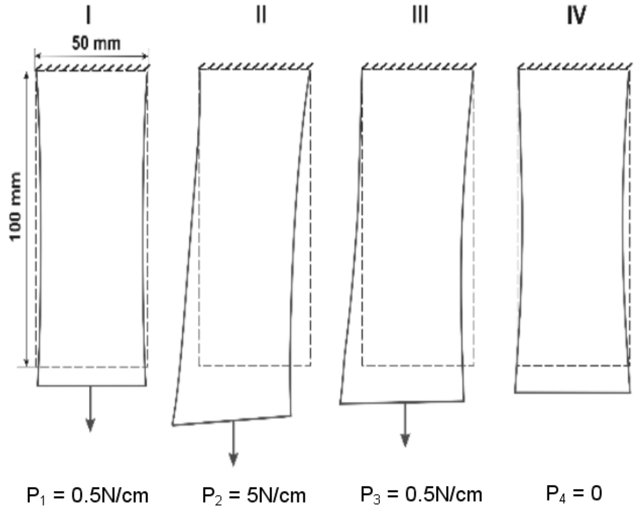

Fig. 2. Four stages of the experiment

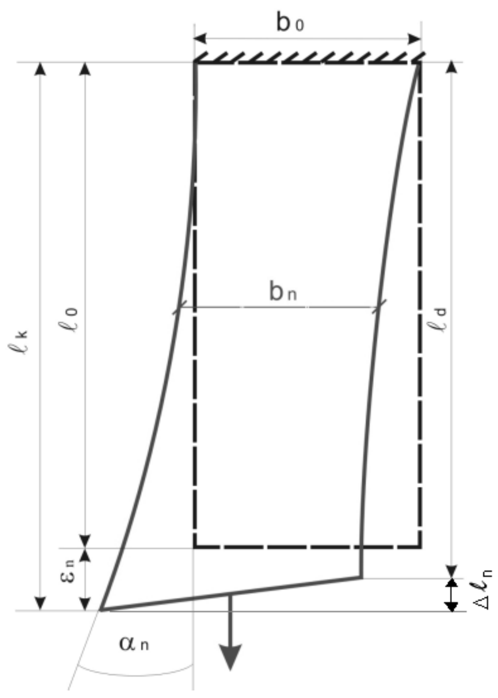

Fig. 3. Specimen's shape after stretching and measured parameters

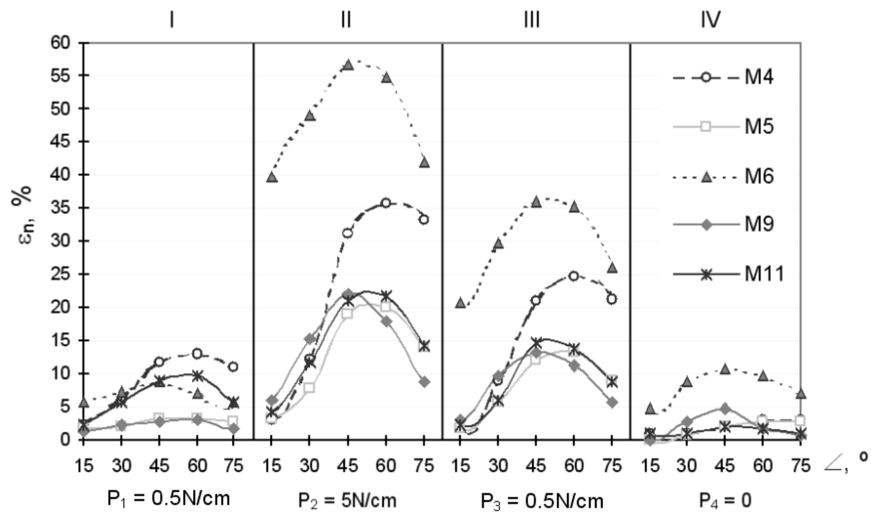

Fig. 4. The influence of loading conditions (I, II, III and IV stages) and cut directions of specimen upon the elongation ε_n

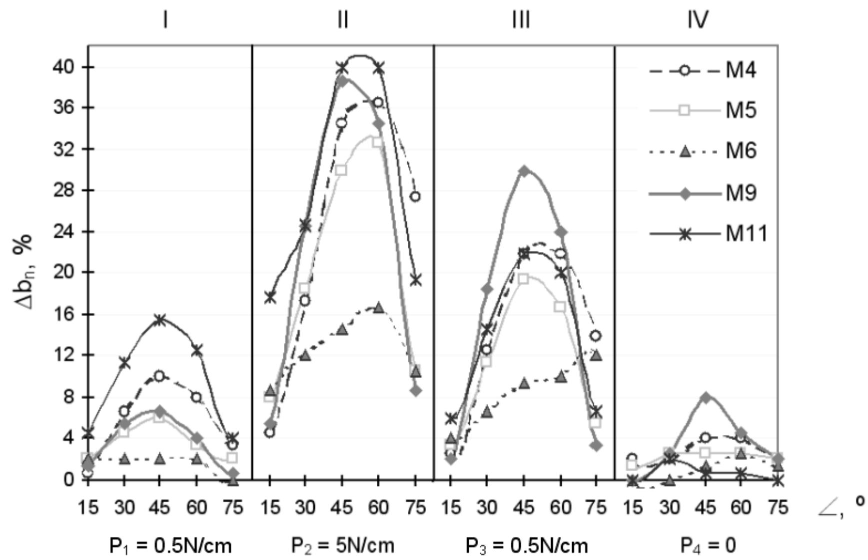

Fig. 5. The influence of loading conditions (I, II, III and IV stages) and cut directions of specimen upon the relative decrease of specimen's width Δb_n (%)

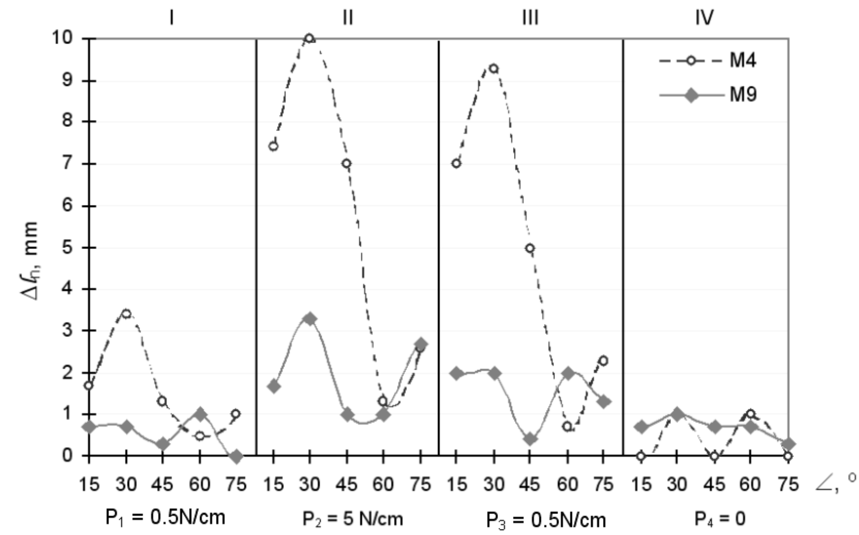

Fig. 6. The influence of loading conditions (I, II, III and IV stages) and cut direction of specimen upon the difference of specimen's edges length Δl_n

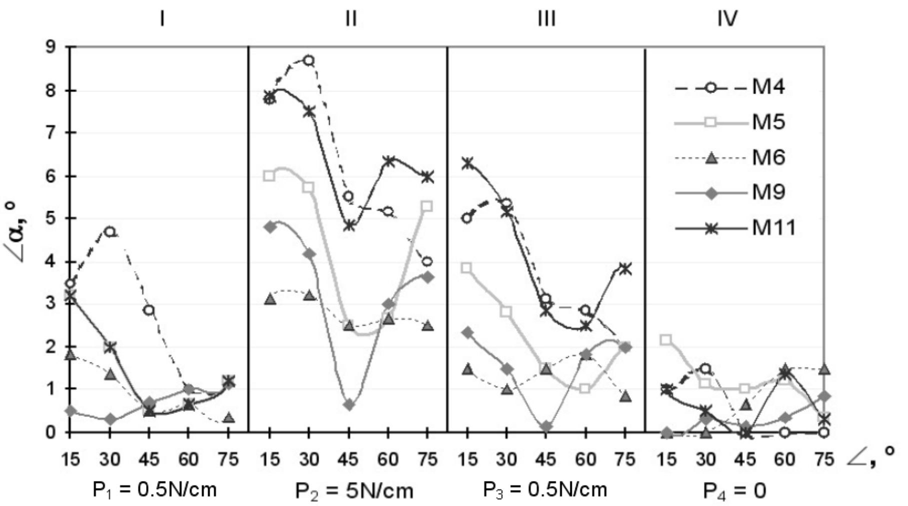

Fig. 7. The influence of loading conditions (I, II, III and IV stages) and cut direction of specimen upon the shear angle α_n

Fabric M6 had the largest elongation value when it was cut at an angle of 45° in all stages. Fabric M4 (with elastane fibre in weft direction) and laminate M5 had the largest elongation in specimens, which were cut at an angle of 60°. The most significant elongations for half-wool M11 fabric were obtained when specimens were cut at an angles of 45° and 60° in respect to warp direction. Laminates M5 and M9 had small elongations in all directions. The major reason of large shear stiffness of these materials is polymer that fills all spaces between the warp and weft threads. Polymers polyurethane and polyvinyl chloride were used to cover fabrics M5 and M9 (Table 1). Elongations of the tested fabrics were the smallest, when specimens were cut at an angle of 15° in respect to warp direction.

Changes of specimen width. The highest values of specimen shrinkage in width were obtained for loading force of 5 N/cm (Fig. 5). These specimens were cut at an angles of 45° and 60° in respect to warp direction. The largest alteration ($\Delta b_2 = 40$ %) in width has shown half-wool M11 fabric. The smallest changes were obtained for specimens that were cut at an angle of 15° and 75° in respect to warp direction. It was caused by the minimal deviations from warp or weft directions, therefore the obtained specimen's width had less difference comparing with its initial value. For example, the specimen's width Δb_n of fabric M6 (with elastane fibre in warp and weft directions) decreased only by 4.6 %.

Difference of edges length. All the tested fabrics had similar differences of specimen's edges length. Therefore the results of two fabrics M4 and M9, which had the most expressive values, are presented in Fig. 6. Maximal and minimal differences of edges length were determined especially when these fabrics were stretched by bigger force. The largest difference between vertical edges of specimen was noticed in fabric M4 with elastane only in weft direction ($\Delta l_2 = 10$ mm).

The smallest value of characteristic Δl_n was noticed for plain wave fabric with polymeric coating (laminate M9). After unloading (stage IV), differences between vertical edges Δl_n of specimens were small, about 1 mm.

Shear angle. It is known, that large deformations, (when obtained shear angle is bigger than 10°) may distort shear characteristics. The effect of shear was strongly expressed at the stage II when load of 5 N/cm was applied and, especially, for specimens that were cut at an angles of 15° and 30° in respect to warp direction, however the maximal shear angle didn't reach 10° [18, 19].

After unloading, the shear effect could be observed for most of the specimens in spite of their different cutting directions.

So, non-uniformity of textile fabrics deformations can be evaluated by two main characteristics: $\angle\alpha_n$ and Δl_n. Relation between these characteristics was determined for every tested fabric. No satisfactory correlation ($r = 0.67$) was obtained between these two characteristics. Such results point out the importance of both characteristics for evaluation the woven fabrics deformation non-uniformity during their tension. Taking into account the obtained results, we grouped the fabrics' deformation non-uniformity into three types:

a) when $\Delta l_n \to \max$, $\alpha \to 0$;
b) when $\Delta l_n \to 0$, $\alpha \to \max$;
c) when $\Delta l_n \to \max$, $\alpha \to \max$.

The first type of deformation includes these specimens that show the larger difference between vertical edges of specimen Δl_n during their tension, but shear angle $\angle\alpha_n$ is very small (Fig. 8, a). It means that specimen's shear isn't uniform, but deformation direction coincides with the tensile force vector. In our experiment, fabric M6 with elastane fibre in warp and weft directions had such properties.

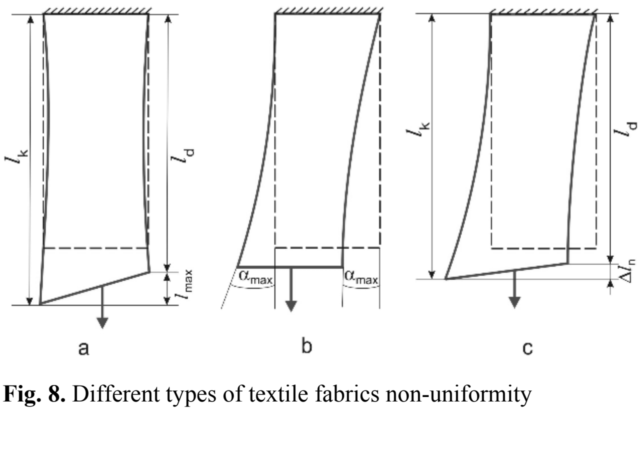

Fig. 8. Different types of textile fabrics non-uniformity

The specimens with bigger and uniform shear ability (Fig. 8, b) have the second types of deformation. Shear angle $\angle\alpha_n$ of specimen due to loading is almost maximum but the difference between vertical edges of specimen Δl_n is very small. Laminates M5 and M9 have shown this type of deformation.

The last type of fabrics deformation is distinguished by the largest values of both characteristic: Δl_n and $\angle\alpha_n$ (Fig. 8, c). It should be noted that for this group of deformation we received the best correlation between the vertical edges of specimen and shear angle ($r = 0.82 – 0.85$). Such type of deformation we received for fabric M4 (with elastane in weft direction) and half-wool fabric M11.

It was found that after unloading of tested specimens (IV stage) in many cases some dimensional changes of plastic deformations remains.

Thus nine cases of specimens' plastic deformation were identified. If at least one of the main characteristics is not equal to zero, then irreversible deformation of the specimen is obtained. It means that the specimen didn't receive its initial dimensional values. Detailed characteristics for each case are shown in Table 2.

Table 2. The characteristics of deformation types

Parameter	Evidence of deformation								
	1	2	3	4	5	6	7	8	9
ε	≠0	0	≠0	≠0	≠0	0	≠0	≠0	≠0
Δl	0	0	0	≠0	0	≠0	0	≠0	≠0
$\angle a$	0	0	≠0	≠0	0	0	≠0	0	0
Δb	≠0	≠0	0	≠0	0	≠0	≠0	≠0	0

It can be seen that in the case when $\varepsilon \neq 0$, the changes in specimen's width (type 2) and additionally in edges lengths (type 6) can be found.

In the case of flexible sheet materials, like woven fabrics, during their tension in bias direction buckling phenomenon which includes "in plane" tensile and shearing and out of plane (bending) deformations can be revealed. Under shear deformation of tested fabrics the buckling weave was observed in some cases. Fabrics M4 and M6 with high degree of extensibility buckling weave showed after their loading (I and II stages of test). It could be noted that for fabric M4 with elastane fibre only in weft the buckling wave aroused in most cases: in cut directions 15°, 30° and 45° (I stage) and 15° (II stage) while for fabric M6 with elastane fibre in warp and weft buckling wave was formed only in cut direction of 75° (I stage) and 60° (II stage). The buckling phenomenon for medium tensile fabric M11 was observed in cut direction 45° and 60° after loading (I stage) and unloading (II stage). Laminates M5 and M9 have shown buckling after loading (II stage) in cut directions 45° and 60°. For fabric M9 curling of vertical edges was observed instead of buckling phenomenon.

CONCLUSIONS

1. Weave structure of textile fabrics, existence of elastane fibre, polymeric coating and the direction of tensile force have influence on the degree of elongation, specimen width decreases and changes of specimen shape.
2. The smallest dimensional changes were noticed when woven fabrics were cut at an angle of 15° in respect to warp direction and loaded by a maximal force of 5 N/cm. The smallest elongation obtained in such conditions was 3 %, the smallest width decrease of the specimen was 4.6 %.
3. The largest non-uniformity of deformation was obtained when textile fabric had elastane fibre only in weft direction and specimens were cut at an angle of 30° in respect to warp direction and loaded by a maximal force of 5 N/cm. Difference of specimen's vertical edges length had the biggest value of 10 mm and shear angle had its biggest value of 8.7°.
4. After stretching three different types of deformation non-uniformity were determined:
   a) difference in specimen's edges lengths is maximal and specimen's shear angle because of the load is minimal (when $\Delta l_n \to \max$, $\alpha \to 0$);
   b) difference in specimen's edges lengths is minimal and specimen's shear angle because of the load is maximal (when $\Delta l_n \to 0$, $\alpha \to \max$);
   c) difference in specimen's edges lengths is maximal and specimen's shear angle because of the load is maximal (when $\Delta l_n \to \max$, $\alpha \to \max$).
5. Nine types of fabrics deformation were determined after unloading using four characteristics: shear angle, difference between vertical edges of specimen, width decrease. It was received that after unloading of tested specimens in any case their initial dimensions and rectangular shape didn't recover.

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