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THE IMPACT OF STRUCTURE PARAMETERS ON FABRIC EALASTICITY

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Introduction

As it is well known, a weave type, yarn density, yarn float and length, surface and other parameters describe the structure of woven fabrics [1, 2]. According to these parameters, fabric quality as well as its suitability for one or other clothing is judged. In addition, textile fabrics differ not only in structure but also in other properties: thickness, weight, strength, stiffness, lustre, air permeability, etc [3-8]. These properties greatly affect appearance, functionality and usage of a garment. Many authors have examined fabric structure and its impact on various fabric parameters. Weave patterns greately affect fabric physical properties. A plain weave has the highest weave interlacing coefficient, sufficient breaking strength in the warp and weft directions and elongation at break in the warp direction than a diced weave [3]. A plain weave has the highest load resistance, the consequence of higher breaking force is lower elongation at break [5]. A twill weave has lower breaking force and higher elongation at break than a plain weave [8]. Fabric elongation also depends on the presence of elastics yarns. The anisotropy of material deformation can be reduced by polyurethane yarns in the weft and warp direction [9]. Gorjanc and Bukošek presented an investigation into the behaviour of fabrics with elastane yarn while stretching. They studied a viscoelastic part in a stress-strain curve and fabric with elastine behaviour after one hour of stretching above the yield point. By increasing elastane count (dtex), both elongation and recovery percentages in the warp direction increased whereas in the weft direction - only recovery percentage increased. Fabric recovery was affected by thread density and float size as compared with elastane count [10]. Ogulata et al. researched elongation and recovery properties of fabrics with elastane. An attempt was made to predict elongation and recovery test results in the warp and weft directions at different testing points using regression and ANN models and to compare predicted results with each other [11]. The interrelation between elasticity of stretch fabrics and cutting and fashioning techniques was discussed in the work [12]. Qadir et al. studied the impact of different elastane denier and draft ratios on weft yarn. The increase of elastane denier resulted from the increase of elastane percentage, resulting in higher elasticity. Deformation of specimens in the cross direction depended not only on fabric elasticity but also on other structural characteristics [14].

A few authors elaborated different integrated structure factors, linear density, warp and weft density, and fabric weaves. Milašius developed an integrated structure factor taking into account a weave matrix. In their later works, V. Milašius and A. Milašius [15], proposed factors for the weft and warp directions, and one for unbalanced weaves. It is particularly important that Milašius suggested a new integrated structure factor that affects mechanical properties of woven fabrics and their end use [16-17]. The weave factor can be used for both balanced and unbalanced weave structures without any variable experiments [16]. E. Kumpikaitė [18–20] at al. checked how this factor correlates with tensile properties of fabrics woven from yarns produced using traditional spinning technologies. Kumpikaitė and Sviderskytė analysed the dependence of woven fabrics breaking force and elongation at break on different weave factors. In this case the structure of woven fabrics becomes more rigid, i.e. factor j increases. Elongation at break increases as well. They found high correlation between the weave factor and fabric elongation. As weave rigidity of woven fabrics increased, the weave factor P_1 decreased, and fabric elongation at break increased. The integrated fabric structure factor *φ,* which evaluates all fabric structure parameters, also showed similar dependence tendencies [17]. Abromavičius' et al. experimental results showed the impact of a weave on fabric tensile properties. More clear dependencies of elongation in the warp direction on the weave factors Pa and Pm were observed. Fabric elongation more depended on the factor Pa. Other weave factors had no big impact on elongation [21]. It was confirmed by the previous works of Kumpikaite [18-20].

Banerjee et al. in their paper [8] did not find any correlation between the weave factors Pa, Pm and tensile properties of fabrics, woven from cotton yarns.

Barburski and Masajtis studied a new way of modelling the behaviour of woven fabrics structure after mechanical loading. They analysed the behaviour of woven fabrics structure subjected to different static loads, methods for testing expected mechanical properties studied fabric design and techniques, analysed fabric structure subjected to deforming strengths, fabric properties with respect to the basic parameters of fibres and yarns [23].

The new test could be used to measure tensile properties in various directions with one sample simultaneously under the same initial conditions [24]. The results confirmed that measuring orthotropic tensile properties of symmetrical structure fabrics was possible. Anisotropic deformation of materials reduced by a polyurethane thread in the weft and warp direction.

The aim of this work was to analyse fabric structure parameters, warp and weft yarns and their impact on fabric elasticity.

Experimental

Woven fabrics of different structures were selected for elasticity analysis. They were selected according to their structure. This choice was defined by fabric elasticity, which depends on elastic yarns twisted in one or in both principal directions. The basic characteristics of the analysed samples were determined by applying standard methods presented in Table 1. Seven samples were used: with an elastic thread (Fig. 1 a); an assembled thread (Fig. 1 b) and with a thread covered with other threads (Fig. 1 c, d). Additionally, three samples without elastane were chosen for comparison.

A thread is a key design element of a complex multistage material therefore for fabric structure analysis such characteristics as the linear density of warp and weft threads and the outline of conventional diameters were used.

The linear density of threads was determined in accordance with LST EN 1049-2.

Various filling factors were estimated in the analyzed samples, too. The linear filling factor shows which fabric part is filled with threads (e_{weft} – weft direction), (e_{warp} – warp direction). If the warp or weft index is $e \geq 1$ then the threads of the analyzed samples are very tight or not situated in one row, covering each other.

Most of the selected samples were twill weave fabrics. This weave has a characteristic twill line, which is composed of homogeneous floats of yarns inclined at the angles of different size oblique to the vertical direction. The oblique angle θ was measured with accuracy $\pm 1^0$.

The fabric structure factor φ was calculated by comparing the density of the analyzed samples with the theoretical standard density of woven fabrics. S. Brierley found [25] that the maximum fabric density is 1. Therefore, the tested fabric structure factor is always $\varphi < 1$. Most of textile fabrics for garment sewing have moderate stiffness and elasticity and their structure factor ranges from 0.7 to 0.8. The structure factor of thin and flexible woven fabrics is from 0.5 to 0.6 [26].

The breaking force P and elongation at break of yarns pulled out from the samples was determined using a Zwick tensile testing machine according to the standard LST EN ISO 2062:2010 [27].

Rectangular shape specimens (working zone - 50×150 mm) were used for the extension test. The samples were cut at the angles of 15°, 30°, 45°, 60° and 75° with respect to the warp direction. The samples were deformed by force 5 N/cm corresponding to the loads which reflect actual conditions of production and wear. It made up 17 % of the weakest material force at break. Several types of materials elongation curves were determined. Elongation ε of the sample was calculated as a percentage of its initial size. Three repeats per sample were carried out and averages were calculated. The result of the test was that the coefficients of variation ranged from 0.2% to 15.5%.

Before the test the samples were conditioned in standard atmospheric conditions of 65% RH and 20 °C.

Results and discussions

The main characteristics of the threads of the examined woven fabric and filing factors are presented in Table 2.

The values of the angle θ in twill wave fabrics are presented in Table 3. The results in Table 4 show that the linear rates of the warp are greater than 1 and therefore if e_{weft} > 1 or e_{warp} >1 then the fabric cover factor in the smallest element of the fabric thread area in proportion with the whole element area is equal to unity, $e_{surface} = 1$. In this case the results of the fabric straight line (e_{weft}, e_{warp}) and surface active ($e_{surface}$) factors are not counted.

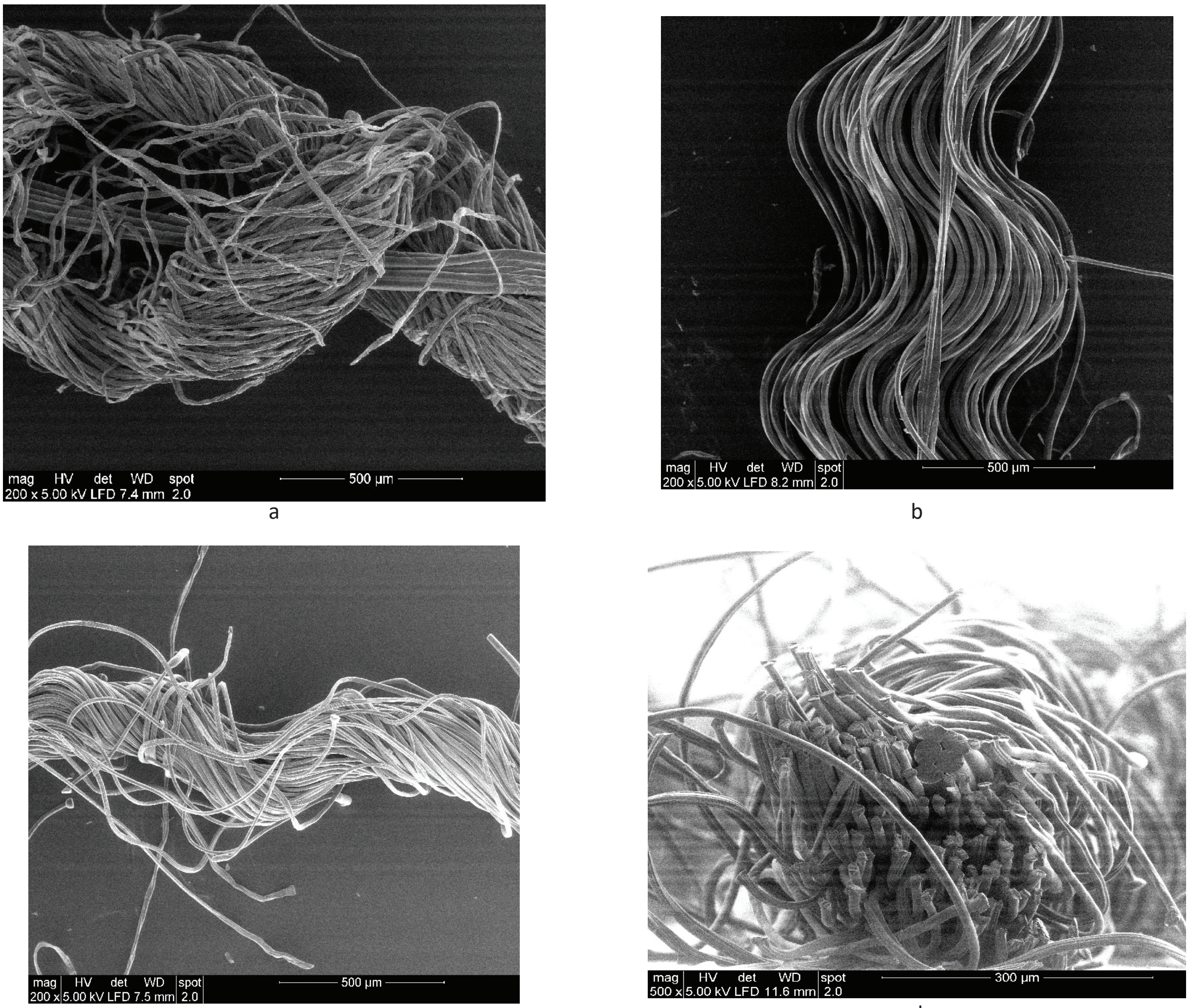


Fig. 1. The warp thread with elastane yarn twisted with staple spun in fabric M6 (a); the weft thread with assembled elastane yarn with continuous filament yarns in fabric M8 (b); the weft thread with double covered continuous filament yarn in fabric M9 (c and d)

Table 1. *Characteristics of the investigated woven fabrics*

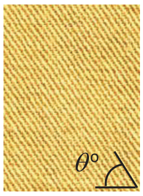
Fabric code	Content, %	Elastane yarn	Weave	Surface density, g/m^2	Thickness, mm	Density, cm^{-1}	
						warp	weft
M1	CV (60) / CO (38)+ EL (2)	twist with every second weft yarns	1/3 twill	309	0.9	30	20
M4	CV (50) / PA (48) +EL (2)	assembled with weft yarns	1/2 twill	184	0.5	48	28
M6	CV (96) +EL (4)	twist with warp and weft yarns	1/2 twill	359	0.9	34	24
M7	WO (97) + EL (3)	twist with weft yarns	3/1 twill	279	0.7	40	30
M8	CV (50) / PES (48) + EL (2)	assembled with weft yarns	1/2 twill	251	0.8	37	18
M9	PES (97) +EL (3)	twist with warp and every second weft yarns	pointed twill	281	0.7	31	27
M10	PES (96) +EL (4)	twist with warp and weft yarns	plain	294	0.7	25	21
M11	Wool (60) / PES (40)	-	1/2 twill	203	0.5	28	24
M12	CO (40) / Flax (60)	-	plain	228	0.4	20	12
M13	CO (50) /CV (50)	-	1/2 twill	217	0.4	42	18

*CV-viscose, WO-wool, PES-polyester, EL-elastane, CO-cotton

Table 2. *Characteristics of warp and weft threads*

Fabric code	Thread construction [28]		Linear density, tex		Linear filling factor		Surface cover factor
	warp	weft	warp	weft	e_{warp}	e_{weft}	$e_{surface}$
M1	Carded ring-spun	Staple spun; Folded twist	69	38 43	1.52	0.75 0.80	1
M4	Staple spun	Filament assembled	18	22	1.20	0.77	1
M6	Folded twist	Folded twist	47	44	1.31	0.90	1
M7	Worsted spun	Single-covering	32	31	1.31	0.96	1
M8	Staple spun	Filament assembled	37	42	1.42	0.74	1
M9	Folded twist	Continuous filament; Double-covering	37	35 39	1.07	0.91 1.00	1
M10	Folded twist	Folded twist	50	53	0.96	0.83	0.993
M11	Folded twist fibre blend	Folded twist fibre blend	37	37	0.92	0.79	0.983
M12	Carded ring-spun	Composite	50	100	0.63	0.55	0.836
M13	Folded twist	Staple spun	35	42	1.21	0.57	1

Table 3. *The oblique angle of the twill line*

Fabric code	Oblique angle θ, °	Twill weave sample
M1	56	
M4	60	
M6	56	
M7	50	
M8	63	
M9	30	
M11	55	
M13	53	

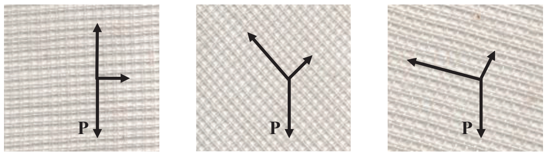


Fig. 2. Vectors of the extension force *P* subject to weft and warp thread orientation in specimens cut at different angles (experimental data)

This indicates that, in the analyzed fabrics, threads of one or another type are situated very tightly or cover each other and therefore the surface cover of these fabrics is highest, i.e. 100 %, except for fabric M12, which has less density. It is obvious that the normal fabric filling characteristics are not sufficient to qualify the analyzed fabrics and therefore an integrated fabric structure factor [17] was introduced which evaluates the structure and technological properties of the fabric.

According to the integrated fabric structure factor φ, the fabrics used in this work can be classified into having high, average and low stability [24].

It is interesting to note that for plain weave fabrics M10 (the highest value) and M12 (the lowest value) the values of the limitary factor were received. Fabric M10 has practically the same linear density and structure, the density of polyester warp and weft threads differs only by 16 %.

One can expect that the elongation of threads with elastane yarns should be higher when these yarns are covered with other fibres in comparison with assembled yarns. However, parameter analysis of the tested woven fabrics threads did not prove it (Table 4). The highest level of elongation was observed in polyester weft threads in fabric M8 with assembled elastane yarn. Twisted threads of the same fabric M10 with elastane yarn extended less –12 %. This was affected by different linear thread density and finishing, i.e. threads in fabric M10 were thinner and colored while threads in fabric M8 were thicker and not colored. In addition, the adhesion between the assembled less stretched fibers was weaker compared to covered fibers and, because stretching of separate fibers teared them off causing a higher break level. Of course, thread extensibility largely depended on elastane yarn extension.

Table 4. *Breaking characteristics of threads of the tested woven fabrics*

Fabric code		Warp		Weft	
		break force, N	elongation at break, %	break force, N	elongation at break, %
M1	→ – → +	7.41	7.04	4.036 4.39	5.97 8.17
M4		2.93	5.9	4.5	26.91
M6		5.54	15.34	4.2	8.47
M7		2.75	12.14	2.34	14.58
M8		5.8	6.62	11.43	33.04
M9	→ + → – → +	6.04	30.77	 4.25 5.67	 15.5 20.05
M10		8.35	31.86	9.04	29.04
M11		4.34	21.77	4.46	24.96
M12		3.33	5.2	6.78	9.73
M13		5.22	9.42	5.024	4.41

Here: + threads with elastane yarn, – threads without elastane yarn.

Although threads without elastane stretched less than threads with elastane, threads elongation in fabric M11 was more or less the same as of threads with elastane yarn. Fabric M11 was made from folded twist fibre blend. The warp thread was slightly thicker than the weft thread but the weft thread stretched by 13 % more than the warp thread. The threads of the both types were made from the same raw material – polyester and wool.

Due to the received results (Table 4), the weft threads in fabrics M4, M8, M10 and M12 were stronger than the warp threads because their raw material was flax (M12), synthetic polyamide and polyester (M4, M8) or their linear density was higher than in the threads of the same raw material (M10).

The largest thread breaking force *P* was determined for polyester threads: the weft of assembled threads with elastane yarn in fabric M8 and the weft and warp of twisted threads with elastane yarn in fabric M10. In this case assembled threads were stronger by 21 %. The lowest thread breaking force was determined for the warp and weft threads in fabric M7. Elastane yarns wrapped with woollen yarns stretched more by 17 % than spun yarns.

It has already been known that fabrics stretch even under small loads but because of the specific structure of some samples deformation is non-uniform. This may be related to the fact that not all threads of a sample fit into the clamps when those samples are cut at a specific angle to the warp direction, and the discrepancy between the deformation direction and the force vector direction appeared (Fig. 2).

Type 1 elongation curve is specific to fabrics with elastane yarn only in weft threads (Fig. 3). In this case the greatest fabric elongation was in the samples cut at the angles of 45° and 60° to the warp direction ε_{max} = 57 %. The asymmetry of the warp in respect to the direction was affected by a twill weave and elastane yarn in weft threads.

Type 2 elongation curve is specific to stretch fabrics with elastane yarn in weft and warp threads (Fig. 4). The maximum weft elongation at the bias of samples cut from stretch woven fabrics with elastane yarn was ε_{max} = 52.5 %.

Type 3 elongation curve is specific to fabrics without elastane yarn (see Fig. 5). Elongation of these fabrics was minimal, ε_{min} = 4.1 %, and samples stretched because of the shear phenomenon when the angle between the warp and weft threads changed.

Analysing break results in samples it was determined that at the time of break or erosion of a thread with the main non-stretching component, elastane, continued to stretch further sometimes even without breaking at all. Fig. 7 illustrates examples of the threads consisting of two different components strain till break.

It has also been known that because of the peculiarities of the characteristics of non-stretching fabrics the highest level of elongation is achieved by having the bias of the fabric cut at the angle of 45 degrees. The very same rule applies to fabrics with elastane yarn in both directions (see Fig. 8), but characteristic values were higher than in elastane yarn, especially in the bias stretching direction.

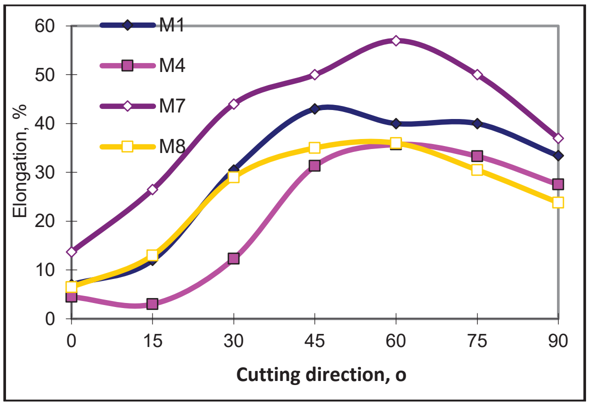


Fig. 3. Type 1 elongation curve

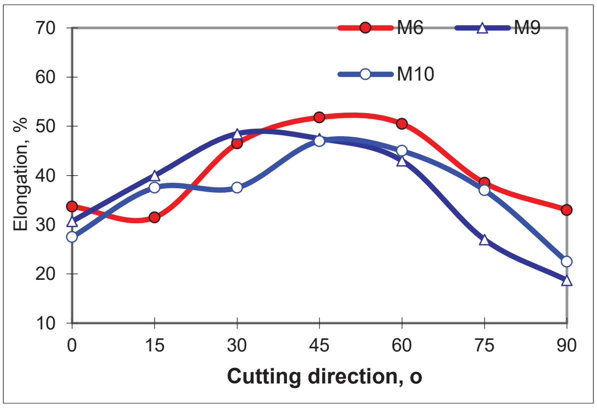


Fig. 4. Type 2 elongation curve

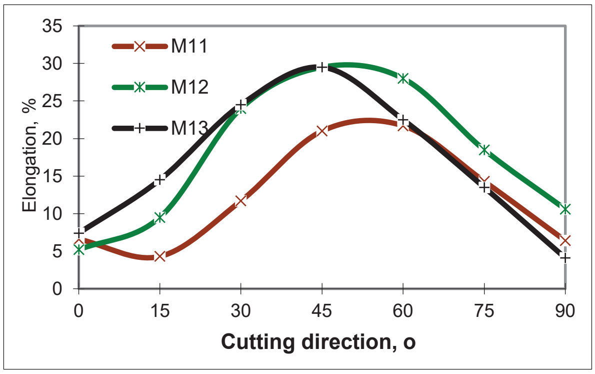


Fig. 5. Type 3 elongation curve

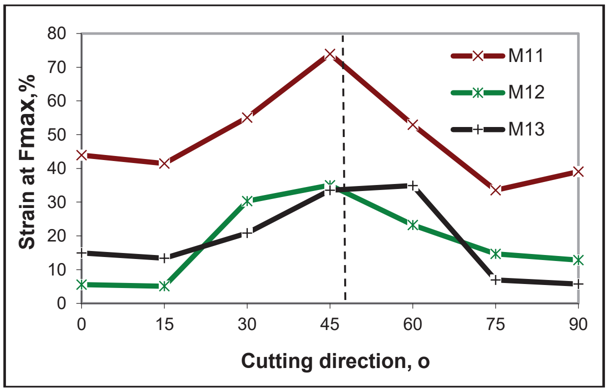


Fig. 6. Elongation of woven fabrics without elastane yarn

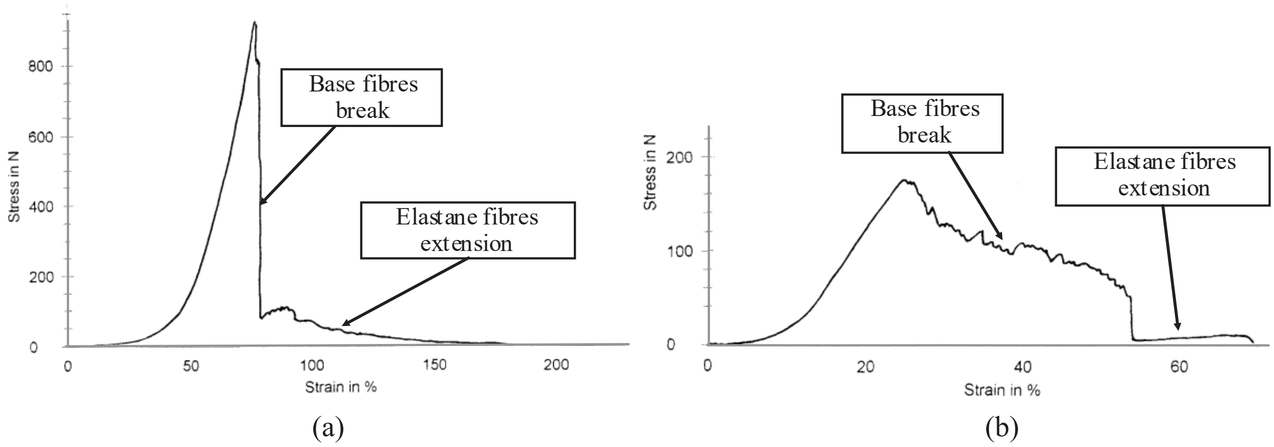


Fig. 7. Types of curves of the tested samples when break occurs instantaneously (a) or after some period of time (b)

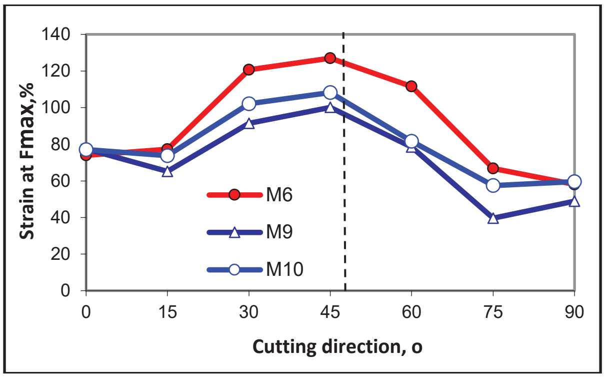


Fig. 8. Elongation of woven fabrics with elastane yarn in both directions

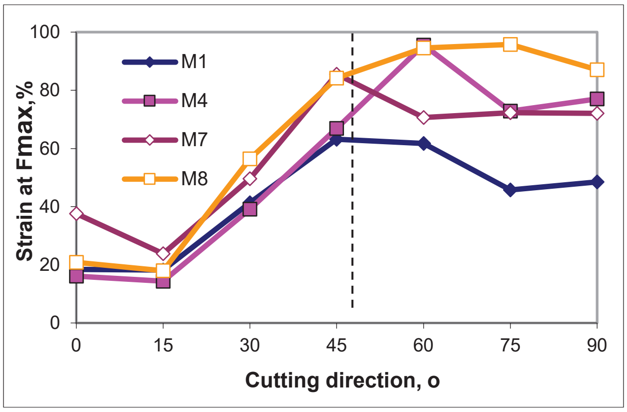


Fig. 9. Elongation of woven fabrics with elastane yarn in the weft direction

Elongation values for fabric M11 were higher (Fig. 9) as it was noted that yarn stretched mainly due to its structure and raw material.

Analysing elongation at break of fabrics with elastane only in the weft direction it was noticed that it was higher in the direction that matched best with the twill weave angle. Accordingly, the lowest level of elongation at break was found in the samples cut at a 15 degree angle to the warp (Fig. 10).

The match of elongation, obtained using two different methods, was not very adequate because of different methods, different speed of nippers, different initial stress that cause great inadequacies in test results. Elongation at break in stretch fabrics was considerably higher than those in suiting fabrics.

The ability of fabrics to stretch is especially important sewing parts of a garment together.

It is essential that parts sewn to a garment recovered their original shape. Garment elongation and deformation should be present along various directions during its exploitation. Elastane yarn extends deformation possibilities of woven fabrics. Woven fabrics with elastane yarn increase the level of comfort by providing more freedom to move and crumples less.

Conclusions

It was determined that elongation of woven fabrics with elastane yarn is higher than of those without it. Elongation depends on the direction of the angle at which the sample was cut Elongation of the analyzed fabrics is affected by the following: thread density, raw materials, yarn thickness. The oblique angle of the twill has a big impact..

Elongation of the analysed fabrics under small loads depends on the orientation of elastic yarn in the specimens. Woollen fabrics with a 1/3 twill weave and with elastane yarn stretches most only in weft yarns, and fabrics without elastane yarn stretches least.

It was found that elongation at break of woven fabrics with elastane yarn in both directions shows the highest elongation in the bias direction (45 degrees) and lowest – in the warp and weft directions. A similar tendency was observed in woven fabrics without elastane yarn. It should be noted that elastane yarn in the warp and weft directions considerably increases ultimate elongation.

It was also found that elongation at break of woven fabrics with elastane yarn only in the weft direction was highest, it streched most at the cutting angle of 45, 60, 75 and 90 degrees. Most of these fabrics broke almost instantaneously. Only wool fabrics showed high results of ultimate elongation at the cutting angle of 60 and 75 degrees.

In both cases it was established that extensibility of woven fabrics with elastane yarn was higher than of those without elastane yarn. The results of different fabric analysis methods moderately correlated with each other.

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Summary

THE IMPACT OF STRUCTURE PARAMETERS ON FABRIC ELASTICITY

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Fabric deformation properties considerably depend on its structure. Garment elasticity is an important factor that allows a garment wearer to move freely. Fabric deformation depends on the structure parameters of yarrn and fabric. It has been known that elongation at break of fabric with elastane yarn is higher than of ordinary fabric. The aim of this work was to analyse elongation at break parameters of the and warp and weft yarn in fabrics. Ten commercially produced samples of woven fabrics were used in the experiment. Some samples were with elastan yarn in the warp and weft directions or only in the weft direction. Elongation at break was measured applying a standard method. The results showed that elongation at break of the main elastic component or another component may occur simultaneously when an elastic component or elastane yarn may reach fabric ultimate elongation.

Keywords: *woven fabric, elastane, structure parameters, elongation properties, elasticity.*

Santrauka

STRUKTŪROS PARAMETRŲ ĮTAKA AUDINIŲ PASLANKUMUI

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Audinių deformacinės savybės didele dalimi priklauso nuo audinių struktūros. Drabužių deformacija yra svarbus veiksnys, užtikrinantis laisvo judėjimo sąlygas dėvėtojams. Audinių deformacijos priklauso nuo siūlų ir audinio struktūros parametrų. Yra žinoma, kad audiniai su elastaniniais verpalais turi didesnę trūkimo ištįsą nei įprasti audiniai. Šio darbo tikslas buvo išanalizuoti audinius sudarančių metmenų ir ataudų siūlų struktūros ištįsos parametrus. Eksperimentui buvo naudojama dešimt komerciškai pagamintų audinių. Kai kuriuose audiniuose elasto pluoštas yra metmenų ir ataudų arba tik ataudų kryptimi. Bandinių ištįsa buvo nustatoma standartiniu metodu. Iš tyrimų rezultatų matyti, kad bandinių ištįsos metu pagrindinis elastingo komponento trūkis gali vykti tuo pačiu metu su kitu sudedamuoju siūlu, kai elastano komponentas, arba elastano siūlai, gali ištįsti iki galutinės audinio ištįsos.

Prasminiai žodžiai: *audiniai, elastanas, struktūros parametrai, ištįsos savybės, paslankumas*.

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