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Analysis of Pre-tension Level upon Biaxial Behaviour of Fused Systems

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The effect of uniaxial pre-tension level upon the regularities of fused two-layer systems biaxial behaviour is analysed in this research work. Initial pre-tension of 0.0 %, 0.4 %, 0.8 %, 1.2 %, 1.7 % and 2.1 % was applied in longitudinal and transverse directions separately. Cotton fabric (100 %) of plain weave was used as a base material for the investigated systems. Biaxial punching was performed with three types of interlinings: woven, nonwoven and knitted, which differed not only in surface density, but in the density of adhesive layer, i. e. 52 and 76 dots/cm^2. The samples of fused systems were punched from the side of the base cotton fabric in order to maintain the same friction force between the punch and the specimen. The results of the investigations have shown that not only punching strength $P_{\max}$, N, and punching height $H_{\max}$, mm, differ with the increase of pre-tension level in longitudinal and transverse directions, but also different number of punching force peaks is characteristic for the investigated two-layer systems, which is related to the structure of applied interlining.

Keywords: fusing interlining, two-layer system, biaxial deformation, punching, initial pre-tension.

1. INTRODUCTION

In earlier investigations the method for pull-on ease level measurement of furniture upholstery and the definition of its deformational behaviour regularities in respect to three different levels of initial uniaxial pre-tension were analysed [1]. The values of initial pre-tension of upholsteries pattern in transverse direction were: 0.0 %, 1.4 % and 2.7 %. The problem lies in the fact that the variety of upholstery materials differ by their strength properties and deformational behaviour in longitudinal and transverse directions. Thus, it is not right to design upholstery patterns with the same ease values for all applied materials. The result of such practice is evident – furniture coverings of low quality, which experience significantly high residual deformations during its exploitation. It means that mechanical characteristics of each applied material must be taken into the account individually. Many researchers explore such undesirable deformation as bagging which is meaningful not only for garment fabrics but also in soft furniture production, as well [2 – 5].

In this research the upgraded method for the analysis of pre-tension level upon biaxial behaviour of fused systems is presented. Significant number of research is done analysing the behaviour of textiles in uniaxial tension and biaxial loading [6 – 7], e. g. woven fabrics [8 – 11] and knitted materials [11 – 14]. Fused textile systems are used not only to perfect the functionality of clothing [15], but for technical purposes, as the reinforcement of auto window glass [16], architectural fabrics, which consist of a woven base cloth with an impermeable coating providing water-proofness and weave stability [17], cellular woven fabrics, which can be used as technical textiles subjected to bursting and impact forces [18], as well. Other researchers investigated the interactive effects between warp and weft in biaxial tension [6, 8, 19]. Several researchers have analysed the effect of pre-tension (pre-stress) [10, 20 – 22] upon the behaviour of composite systems with concrete, glass, fibers, etc. [23 – 25] and have found out that pre-stressing is even more advantegeous in the case of high strength fabrics. The limit of proportionality, the modulus of rupture and cracking stresses considerably increase for them with the increase of pre-stressing. Meantime there is no information concerning the effect of pre-tension upon biaxial behaviour of fused multilayer textile systems, which are often used in interior product and soft furniture production. Testing method which is presented in this research is aimed to solve this problem. The basis of it comes from our previous investigation of furniture upholsteries behaviour in situ conditions [1], which was not comfortable from the standpoint of specimen preparation and the reliability of obtained testing results. This method was perfected and the main aim of this research is to evaluate the effect of two perpendicular pre-tension directions and the levels of pre-tension upon fused two-layer textile systems performance behaviour under biaxial punching.

2. MATERIALS AND METHODS

For the investigations of pre-tension level upon biaxial behaviour of fused systems 100 % cotton fabric M1 of plain weave was used as basic layer. For the second layer five types of 100 % PES fusing interlinings of woven (W1 and W2), knitted (K1 and K2) and nonwoven (N1) structures were applied. It can be seen (Table 1) that fusing interlinings differed not only by the density of adhesive dots per cm^2, i. e., 52 and 76, but also by their surface density, i. e. from 36 g/m^2 up to 53 g/m^2.

In this research woven interlinings were of cross twill 2/2 weave structure, which is characterised as having equal length of yarn floats along warp and weft directions, what creates a homogeneous structure leading to higher fabric elasticity in bagging deformation. The twill 2/2 structure

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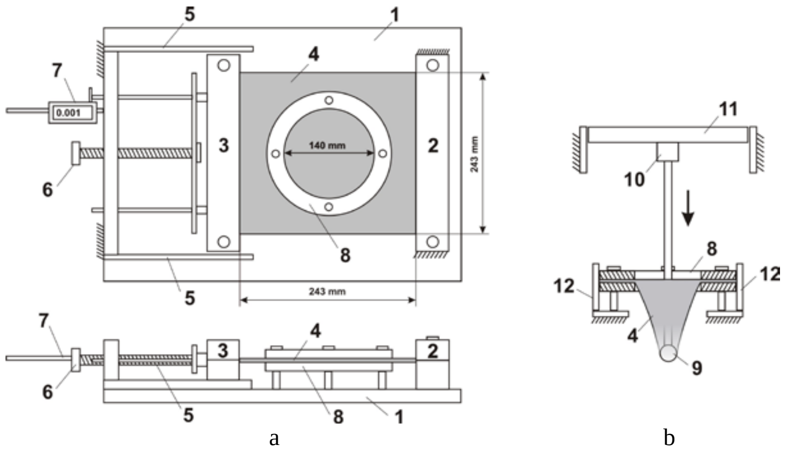


a b

Fig. 1. The device for specimens initial pre-tension (a) and the device for specimens biaxial punching (b): 1 – the platform; 2 – fixed clamp; 3 – moving clamp; 4 – the specimen; 5 – the guides of moving clamp; 6 – threaded drive for specimens pre-tension; 7 – strain gauge; 8 – circular shaped clamps; 9 – the punch; 10 – the tensometer; 11 – standard drive of tensile testing machine; 12 – fixed holder

deforms easier and recovers from bagging deformation faster than the other weave types [3]. Specific tensile strength of the base fabric M1 in warp direction was $f = 0.065$ N/tex, in weft direction was $f = 0.057$ N/tex.

For the biaxial deformation interlinings were fused with the base material M1. Fusing conditions for all samples were: temperature 140 °C, duration 16 s, pressure (1 – 3) bar (5 – 35 N/cm^2). Eighteen samples of each fused system of (250 × 320) mm were cut in longitudinal and transverse directions. Tested samples were kept in standard atmosphere conditions (20 °C ±2 °C and 65 % ±4 % humidity) for 24 h according to the requirements of standard ISO 139:2005.

Table 1. Characteristic of investigated materials (components of fused systems)

Material code		M1	W1	W2	N1	K1	K2
Surface density, g/m^2		136	44	53	50	50	36
Thickness, mm		0.31	0.30	0.31	0.26	0.39	0.16
Adhesive density, $dots/cm^2$		–	52	76	52	52	76
Yarn density, cm^{-1}	warp/ course	25	36	24	–	7	13
	weft/ wale	19	15	14	–	13	20
Material structure		Woven, plain weave	Woven, cross twill 2/2		Non-woven	Knitted, closed pillar stitch	

The scheme of specimen pre-tension is presented in Fig. 1. First of all, the specimen 4 is fixed in special device for uniaxial pre-tension with the help of clamps 2 and 3. Certain level of pre-tension is applied by thread drive 6. The displacement of moving clamp 3 is controlled by a digital gauge 7. After that stretched specimens were clamped into flat circular shaped clamp 8, which is placed into special holder 12 and mounted on a standard tensile testing machine Tinius Olsen (load cell – 500 N). The drive 11 pulls down the punch 9, which breaks the stretched specimen 4 at the velocity of 100 mm/min. Tension meter 10 records breaking force P_{max}, N; while strain gauge – maximal punching height H_{max}. Coefficient of variation did not exceed 19.09 %. The samples of fused systems were punched from the side of the main cotton fabric in order to maintain the same friction force between the punch and the specimen.

During these investigations the specimens were pre-tensioned by 0.0 %, 0.4 %, 0.8 %, 1.2 %, 1.7 % and by 2.1 %. Such pretention levels were chosen to make them more close to the testing conditions of earlier performed research work [1]. In order to obtain more evident dependencies in respect to the earlier obtained results, the number of pre-tension steps was increased from three to five.

Uniaxial tension tests were performed with the same standard tensile testing machine. Tensile velocity was 100 mm/min. Fifteen specimens of each tested sample (separate components and their fused systems) of (50 × 200) mm were tensioned in longitudinal and transverse directions. Average values of samples tensile strength F_{max} and elongation at break ε_{max}, were defined. Variation coefficient of all fusing interlinings and their systems did not exceed 5.87 %, except for woven W2 and knitted K1 interlinings, which varied in the limits of 8.06 % – 23.97 %.

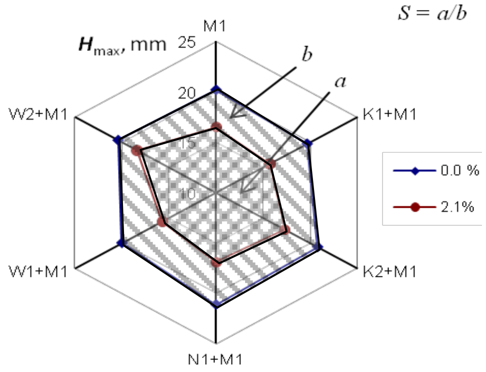


Fig. 2. Complex criterion S for the evaluation of tested samples total deformability

During the research the evaluation of the effect of pre-tension level upon total deformability of all tested samples was performed on the basis of complex criterion S (Fig. 2). It was calculated as the ratio between the area of polar diagram b, which was outlined by punching height H_{max} values of non-tensioned samples and by the area a, which was outlined by tested samples punching heights H_{max} at each pre-tension level.

3. RESULTS AND DISCUSSION

At the first stage of investigation uniaxial behaviour of M1 fabric and its two-layer fused systems was analysed. Their strength and extension characteristics are presented in Table 2. Uniaxial testing results show that high elongation anisotropy is characteristic for basic cotton material M1 and woven interlinings and low elongation anisotropy for nonwoven and knitted interlinings.

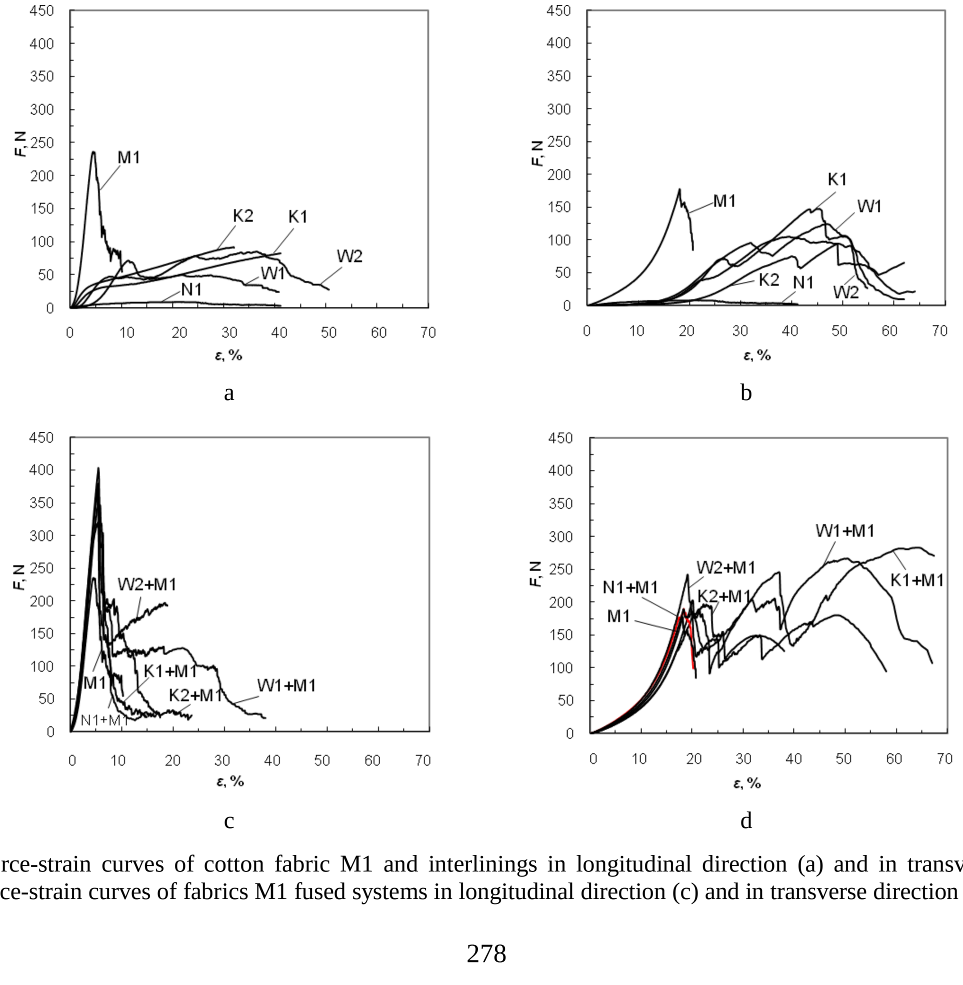
Table 2. Strength and extension characteristics of investigated two-layered systems and their separate components

Material code	Surface density, g/m^2	Strength and extension parameters				Coefficient of anisotropy c_a
		warp/course		weft/wale		
		F_{max}, N	ε_{max}, %	F_{max}, N	ε_{max}, %	
M1	136	235.8	4.5	177.6	18.1	0.25
W1	44	46.7	7.9	42.6	24.4	0.32
W2	53	71.0	11.4	95.6	32.0	0.36
N1	50	8.3	22.2	9.2	31.2	0.71
K1	50	82.0	41.1	71.4	26.3	0.64
K2	36	92.3	31.9	75.0	40.1	0.80
W1+M1	181	358.4	5.6	189.2	18.3	0.31
W2+M1	184	403.5	5.5	242.3	19.0	0.29
N1+M1	178	367.6	5.4	190.6	18.4	0.29
K1+M1	184	379.6	5.4	203.2	20.1	0.27
K2+M1	168	317.2	5.2	196.6	22.2	0.24

It must be noted that tension characteristics after fusing two-layered systems with all investigated interlinings (woven, nonwoven and knitted) became highly anisotropic and very close. Uniaxial strength F_{max} varied from 21.39 % to 21.91 %; breaking elongation ε_{max} varied from 7.27 % to 17.53 %.

It must be noted that uniaxial behaviour of separate materials differed significantly, but after fusing strength parameters became close to the parameters of the basic material M1 (Table 2). In the case of two-layered system with nonwoven interlining breaking force and elongation is slightly higher than those of basic material M1. The same can be observed with woven interlinings and their systems, where breaking characteristics of woven interlining W2 is higher compared to W1. It can be explained by significant difference in the density of adhesive dots per cm^2 of those two interlinings, meanwhile surface density g/m^2 and yarn density cm^{-1} of them differed negligibly (Table 1).

Analysis of tension process of fused systems up to the first breaking point allows to state that strength and extension characteristics for all systems differ insignificantly (Fig. 3, c, d). Meantime, interesting view can be observed analysing further tension process where the systems with woven interlinings show different behaviour. The results of uniaxial tension in transverse direction – the same as in longitudinal direction – show that strength characteristics of single nonwoven interlining are very low and significantly differ from the basic material M1 (Fig. 3, c). Nevertheless, strength and extension characteristics of two-layer system composed of those two materials became the same as those of the rest investigated systems. Two-layer systems with woven interlinings show the second breaking point which is higher compared to the first one (system W1+M1).



a

b

c

d

Fig. 3. Typical force-strain curves of cotton fabric M1 and interlinings in longitudinal direction (a) and in transverse direction (b); typical force-strain curves of fabrics M1 fused systems in longitudinal direction (c) and in transverse direction (d)

The same phenomenon takes place in the case of knitted interlinings and their systems. The difference is that the third breaking point appears (system K1+M1), which is higher compared to the first and to the second one.

Breaking character of specimen pre-tensioned in transverse direction does not differ significantly from the ones pre-tensioned in longitudinal direction. In this case the strongest is also basic material M1, which breaks at comparatively small elongations (Table 2). The weakest is nonwoven interlining N1. Meantime breaking characteristics of woven and knitted interlinings in transverse direction is higher by 20 % – 75 % compared to longitudinal direction. Analysing tension curves up to 20 % of elongation we can see that breaking character of the systems is very similar. The second and the third breaking points appear after the first and they are higher. The first peak point is related with the breaking of basic material M1, the second – with the breaking of interlining material and the third – with the breaking of the last threads.

Fig. 3 shows that woven interlining W2 strengthens basic material M1 in longitudinal and transverse directions most of all. Meantime knitted interlining K2 makes M1 fabric the most deformable in the main directions. It must be noted that tensile behaviour of all tested interlinings differs essentially, but this difference disappears for their fused systems. In general after fusing the strength of M1 fabric in longitudinal direction increased by 25.7 % – 41.6 %, deformability increased by 13.5 % – 19.6 %. Less significant effect was observed in transverse direction: the increase of strength was 6.1 % – 26.7 %, the increase of elongation was 1.1 % – 18.5 %.

At the second stage of investigation punching behaviour of non-tensioned two-layer systems was analysed. Fig. 4 shows that there is no significant difference in the behaviour of all investigated systems up to the first breaking point. Punching height H_{max} varied from 0.99 % to 4.55 %, while punching force P_{max}, N, increased from 3.28 % to17.15 % in respect to punching strength and height of base fabric M1. These results confirm the remarks made by Kovacevic, S. et al that the fabric which has the highest bursting strength, has the lowest anisotropy [8]. In our case anisotropy coefficients of all fused systems are very close, thus their bursting strengths are very close, as well.

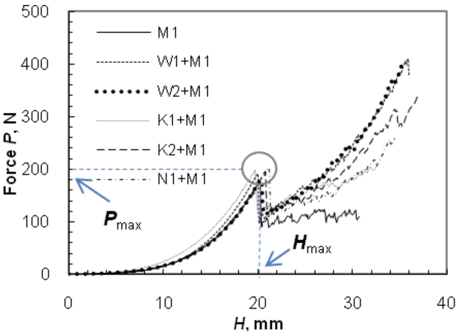
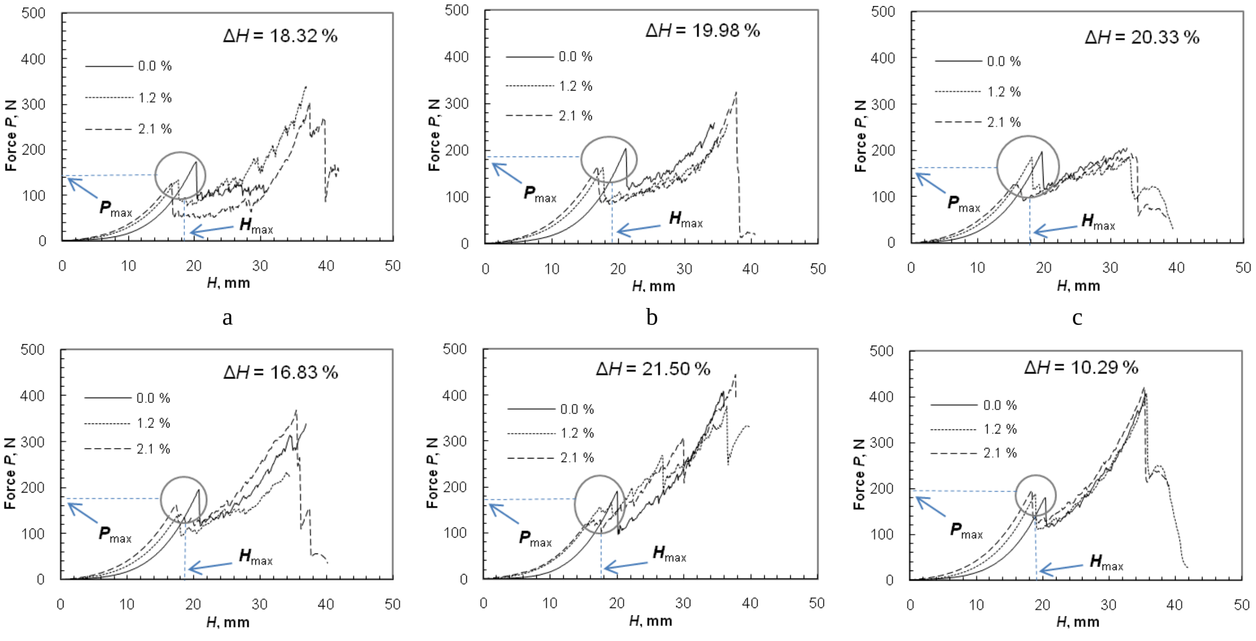


Fig. 4. Punching curves of non-tensioned base fabric M1 and its fused two-layer systems

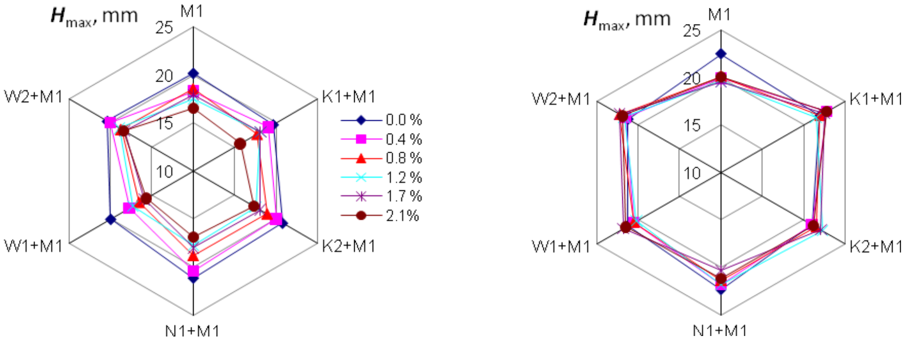
The attention can be pointed to the system K1+M1 with knitted interlining and the system W1+M1 with woven interlining punching heights H_{max}, mm, of which are lower compared to the other fused systems. The same phenomenon was observed for uniaxial breaking in both directions (Fig. 3, c, d). The results of uniaxial and biaxial tension of base fabric M1 and its systems formed with woven, knitted and nonwoven interlinings allow to summarize that behaviour of two-layer fused systems in both types of tension up to first breaking point becomes very close even though interlinings of different structure were used. Significant differences appear in further process, because the second breaking point reveals and the variation of second breaking results becomes very wide.



a b c

d e f

Fig. 5. Punching curves of 0.0 %, 1.2 % and 2.1 % pre-tensioned samples in longitudinal direction for base fabric M1 (a) and its systems: N1+M1 (b), K1+M1 (c), K2+M1 (d), W1+M1 (e), W2+M1 (f), where ΔH describes the change of punching height H_{max} of the first break between non-tensioned and pre-tensioned samples



a

b

Fig. 6. The effect of initial pre-tension upon the changes of punching height H_{max} (mm) in longitudinal (a) and transverse (b) directions

At the third stage of investigation the effect of pre-tension direction and its level upon punching strength P_{max} and punching height H_{max} of tested two-layer samples was analysed. In the case of longitudinal pre-tension punching height H_{max} of the first breaking point decreased from 10.29 % to 21.50 % when pre-tension was increased from 0.0 % up to 2.1 % (Fig. 5). Different results were obtained for pre-tension in transverse direction. The main difference is that the decrease of punching height during breaking is not as high as in the case of longitudinal pre-tension and changed from 3.75 % to 13.17 %.

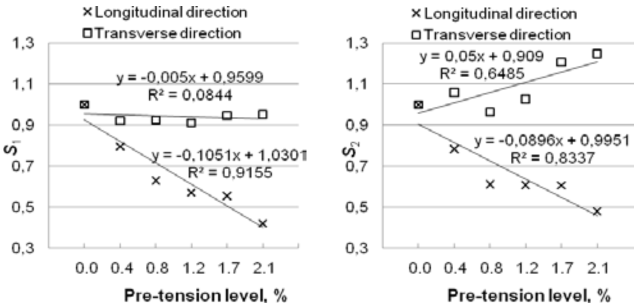
The effect of initial pre-tension becomes evident when the difference between tested systems deformability in longitudinal and transverse directions is compared (Fig. 6). Punching height H_{max} of the first break of base material M1 and of all its fused systems decreases when initial pre-tension is increased from 0.0 % to 2.1 % in longitudinal direction (Fig. 6, a).

It can be seen that deformability of W2+M1 system fused with woven interlining W2 is the lowest because, its punching height H_{max} at all levels of pre-tension starting with 0.0 % and ending by 2.1 % have changed only by 10.29 %. It can be explained by the fact that strength properties of this system in uniaxial tension are also the highest between tested ones (Table 2). Whereas in transverse pre-tension only the behaviour of base material M1 can be distinguished. For fused two-layer systems the effect of pre-tension is insignificant and is smaller compared to all longitudinal pre-tension levels by 39 % (Fig. 6, b).

Fig. 6 illustrates the effect of initial pre-tensions level upon deformability of each tested fused system and base material M1. The last step of analysis was to define the dependency between the level of initial pre-tension and total deformability of all investigated fused systems. For this purpose complex criterion S of total deformability was used, which was calculated on the basis of polar diagram areas: $S = a/b$, where a is the area of any pre-tension level except 0.0 %; b is area determined by tested systems deformability without pre-tension.

Fig. 7, a, shows the dependencies between the criterion of total deformability S_1, which was defined on the basis of the changes of punching height H_{max} and the levels of initial pre-tension in longitudinal and transverse directions.

Fig. 7, b, illustrates the same dependencies of total strength criterion S_2, which was defined on the basis of the changes of punching force P_{max}. It is evident that the most significant effect of pre-tension is experienced in longitudinal directions. The decrease of tested systems deformability can be described by linear dependency ($R^2 = 0.834 \div 0.916$). Different results are obtained for transverse pre-tension. It does not have any effect for total deformability criterion S_1 ($R^2 = 0.084$). Meantime total strength criterion S_2 slightly increases ($R^2 = 0.649$) with the increase of pre-tension from 0.0 % up to 2.1 %.



a

b

Fig. 7. The changes of total deformability criterion S_1 (a) and total strength criterion S_2 (b) in respect to the levels of initial pre-tensions in longitudinal and transverse directions

The investigations, performed by the other researchers have shown that there is no significant difference between uniaxial and biaxial deformations of woven, nonwoven and knitted systems [8]. Meantime the novelty of this work is the investigation of pre-tension effect of differently composed systems, which revealed the difference between pre-tension direction, e. g. breaking height H_{max} when initial pre-tension was increased from 0.0 % to 2.1 % decreased by 47.88 % in longitudinal direction and by 28.51 % in transverse direction.

4. CONCLUSIONS

The method to evaluate the effect of pre-tension direction and level upon biaxial behaviour of two-layer materials was developed. After fusing uniaxial behaviour of two-layer systems up till the first break became very close for the investigated materials (F_{max} varied between 21.39 % and 21.91 %, ε_{max} varied between 7.27 % and 17.53 %), even though fusing interlinings of different structure (woven, nonwoven and knitted) and characteristics were used. The same can be said about biaxial punching of the same two-layer systems the behaviour of which became even more close ($P_{\max}$ varied between 3.28 % and 17.15 %, $H_{\max}$ varied between 0.99 % and 4.55 %). Breaking height $H_{\max}$ of two-layer textile system decreased by 47.88 % when initial pre-tension was increased from 0.0 % to 2.1 % in longitudinal direction. Meantime this decrease became less by 28.51 % when the same initial pre-tension was applied in transverse direction.

Concerning breaking character of two-layer systems it was observed that for fusing interlinings that had several breaking maximums in uniaxial tension, the same tendency remains in their fused systems uniaxial tension even though base material of fused system had only one very clear breaking point. Moreover – the same tendency becomes characteristic for the process of biaxial loading, e. g. punching.

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