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The Investigation of Soft Furniture Upholstery Deformational Behaviour

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Textile materials, which are different in fibre content, weave type, density and thickness, as well as multi-layered synthetic leathers, are used in soft furniture upholstery production. Deformation - relaxation behaviour, which depends on mechanical properties of such materials differs significantly, also. From this standpoint substantial problem exists in soft furniture production, because the dimensions of its upholstery patterns, i.e. initial pretention must be adjusted taking into account the differences of applied materials mechanical properties. Otherwise external view and quality of upholstery may be unacceptable due to obvious visual material excess on soft furniture surfaces, which is called pull-on ease. The aim of this investigation was to determine the dependencies between three different levels of soft furniture upholstery pre-tension and corresponding values of pull-on ease. New testing method presented in this study allows defining soft furniture upholstery deformational behaviour and its regularities in respect to the initial dimensions of upholstery patterns.

Keywords: upholstery, uniaxial tension, biaxial deformation, pre-tension.

INTRODUCTION

Up to date the problems of fitting woven and knitted fabrics to three-dimensional surfaces were analysed from the standpoint of their mechanical and physical properties [1]. The investigations were performed aiming to find out the relationships between the parameters of uniaxial and biaxial behaviour [2] and seeking to define the effect of materials anisotropy level upon the shapes of spatial objects obtained under biaxial loadings [3]. Other investigations showed that pre-tension is an effective method to improve the quality of the shaped composite parts [4]. Tensile properties of multilayered materials [5, 6] and fused textile systems [7], stress relaxation of fused systems [8], deformational behaviour of upholstery fabrics under static load [9], mechanical properties of upholstery fabrics for vehicles [10], comfort index of chairs [11] and other topics are widely discussed by the researchers. Still the problem of practical application remains. From this standpoint the problem exists in soft furniture production, i. e. the dimensions of soft furniture upholstery patterns must be adjusted in respect to different mechanical properties of used materials. Otherwise external view and quality of upholstery may be unacceptable due to obvious visual material excess on soft furniture surfaces, which is called pull-on ease.

The aim of this investigation was to develop new method for pull-on ease level measurement directly on the furniture and on the basis of it to define the regularities of upholsteries deformational behaviour in respect to three different levels of its initial uniaxial pre-tension.

EXPERIMENTAL

Investigations were performed with seven textile materials (woven and knitted) and two types of synthetic leather most often used in soft furniture industry. Their characteristics are presented in Table 1. Thickness and surface density of the investigated upholstery materials were defined according to the requirements of standards EN ISO 5084:2000 Textiles – Determination of thickness of textiles and textile products and EN 12127:1999 Textiles – Fabrics – Determination of mass per unit area using small samples [13], respectively.

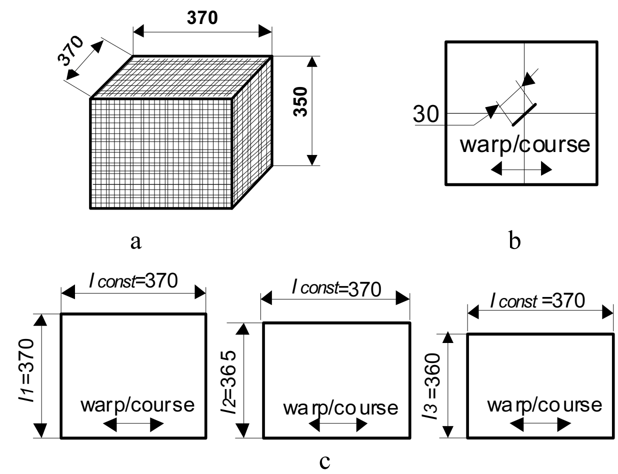

Fig. 1. Characteristics of pouffe construction: a – pouffe dimensions; b – the placement of hanging hook pricks (top view of pouffe); c – the principle of top patterns width reduction (measurements in mm)

One of the main criterions of soft furniture quality is the optimal strain of its upholstery, i. e. it must cover the furniture close to its surface without material additional ease, which appears while pulling the upholsteries covering on the surface of furniture. The level of this easiness is mainly determined by the mechanical properties of used materials. Therefore it is important to define the relationship between the mechanical characteristics of used materials and upholsteries pull-on ease values. For this purpose the furniture of the simplest geometrical shape –

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Table 1. Characteristics of investigated upholstery materials

Material code	Thickness, mm	Surface density, g/m^2	Strength parameters				Coefficient of anisotropy c_a	Material composition
			warp/course		weft/wale			
			P_{max}, N	ε_{max}, %	P_{max}, N	ε_{max}, %		
W1	0.61	297.3	850	13.4	675	11.1	0.83	one layer: woven
W2	2.25	532.0	1150	43.1	900	31.7	0.74	two layer fused system: (face side – woven; back side – woven
W3	2.52	486.7	1154	31.6	375	25.0	0.79	one layer: woven
W4	1.26	384.0	1150	21.5	950	30.8	0.70	two layer fused system: face side – woven; back side – woven
W5	1.12	291.0	1025	28.8	1400	37.3	0.77	two layer fused system: (face side – woven; back side – nonwoven
W6	1.22	372.0	1125	24.4	1025	25.3	0.96	two layer fused system: face side – woven; back side – woven
L1	1.12	597.0	750	14.5	625	28.9	0.50	synthetic leather: face side - PU, PVC; back side – woven
L2	1.08	576.0	420	33.7	210	132.9	0.25	synthetic leather: face side - PU, PVC; back side – knitted
K1	0.73	180.0	330	77.1	450	60.1	0.78	one layer: knitted

Notes: P_{max} – force at break, N; ε_{max} – elongation at break, %.

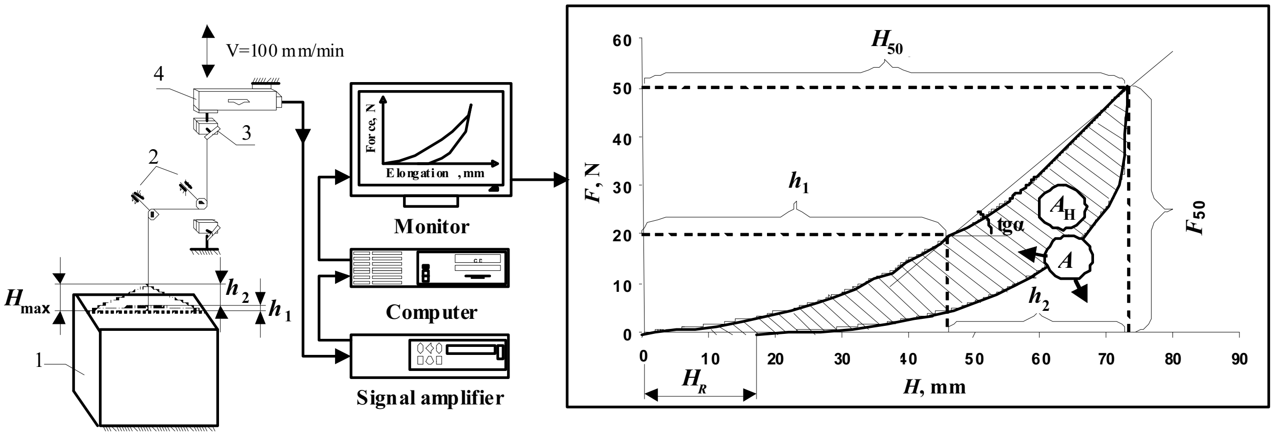


Fig. 2. Principal scheme of pouffe hanging and the method of hanging process energy A, hanging hysteresis A_H and hanging height H_{50} recording at the force of F_{50}, N: 1 – pouffe; 2 – rotating deflectors; 3 – the grip of tensile testing machine; 4 – force sensor

pouffe – was selected for testing (Fig. 1, a).

In order to define the regularities of pull-on ease value changes three types of upholstery coverings were prepared for each tested material. In this research the dimensions of upholsteries top pattern, i. e. initial pre-tensions, were changed according to the scheme presented in Figure 1, c. It can be seen that dimensions were changed only in transverse (weft/wale) direction, i. e. the width of the pattern was decreased two times by 5 mm. Thus, the investigated width values in (weft/wale) at the top part of upholstery coverings were $l_1 = 370$ mm, $l_2 = 365$ mm and $l_3 = 360$ mm, while the length in grain (warp/course) direction remained constant $l_{const} = 370$ mm.

The essence of upholsteries pull-on ease level measurement is based on direct furniture hanging. Thus, the pouffe with pulled on samples of different upholstery coverings were hanged with the hook at the geometrical centre of the top pattern according to the scheme presented in Figure 1, b. The distance between hanging hook pricks was 30 mm. The diameter of hooks cross-section was 5.0 mm. The hysteresis of hanging force A_H was recorded with the help of QMat software. Hanging force for all samples was constant and equal to $F_{const} = 50$ N, because this was the level at which pouffe started to lose its contact with the base surface (Fig. 2). Such parameters as hanging height H_{50}, mm and its constituent parts h_1, mm and h_2, mm corresponding to the values of pull-on ease and materials deformability, i. e. its elongation ($H_{50} = h_1 + h_2$), were defined from $F_{50} – H_{50}$ (hanging force – hanging height) curves, which were recorded by a standard tensile testing machine TINIUS OLSEN H10 KT according to standard EN ISO 13934 – 1:2000 Textiles – Tensile properties of fabrics – Part 1: Determination of maximum force and elongation at maximum force using the strip method [12]. At the confidence level of 95 % the mean values of H_{50}, h_1, h_2 were within the range of 6.8 %.

During the investigations the whole cycle of pouffe hanging and recovery was performed for three levels of upholsteries pre-tension during which the values of hanging process energy A, Nmm hanging hysteresis A_H, Nmm and residual deformation H_R, mm were defined (Fig. 2).

RESULTS AND DISCUSSION

Hanging heights H_{50}, mm at $F_{const} = 50$ N for three different widths of pouffe top patterns are presented in Table 2. Initial results of the investigation showed that H_{50} for the initial pattern width $l_1 = 370$ mm varied in the range of 75.3 mm ÷ 98.4 mm (Δ = 23.1 mm); for the second step l_2 = 365 mm – in the range of 72.9 mm ÷ 95.9 mm (Δ = 23.0 mm) and for the third step of pattern width reduction l_3 = 360 mm – in the range of 67.5 mm ÷ 81.9 mm (Δ = 14.4 mm).

In the case of l_1, which represented no uniaxial pre-tension, i. e. no reduction of upholstery patterns width, the highest H_{50} value was obtained for W3 fabric (98.4 mm) and the lowest - for L1 synthetic leather (75.3 mm). At this step of pattern width reduction the behaviour of W2, W3, W4 and W5 materials was similar, their H_{50} values varied from 95.0 mm to 98.4 mm (Table 2). This is related to the similarity of these materials breaking elongation values ε_{max} in warp (from 21.5 % to 43.1 %) and weft (from 25.0 % to 37.3 %) directions, as well as very close breaking elongation anisotropy coefficients, which varied from 0.70 to 0.79 (Table 1).

When the width of upholstery top patterns was reduced by 5 mm (l_2 = 365 mm) – first step of uniaxial pre-tension - the highest H_{50} value was obtained for W4 fabric (95.9 mm) and the lowest – for the same L1 synthetic leather (72.9 mm). Maximal hanging heights of these materials have declined by 0.8 % and 3.2 %, respectively. For the rest of investigated materials this decline was also very different: starting with 1.1 % for W6 and ending by 9.7 % for W5 sample. Further reduction of upholstery top patterns width by 10 mm (l_3 = 360 mm) – second step of uniaxial pretention – showed similar results: highest H_{50} value was obtained for W3 fabric (81.9 mm) and the lowest – for the same L1 synthetic leather (67.5 mm). Total maximal hanging heights of these materials have declined by 16.8 % and 10.4 %, respectively. For the rest of investigated materials the decline of total maximal hanging height H_{50} varied in a wide range starting with 5.5 % (W1) and ending with 23.4 % (W5).

It is evident from the experimental results that there is no clear dependency between uniaxial strength characteristics of investigated upholstery materials and their biaxial behaviour parameters obtained by pouffe hanging method when materials significantly different in structure are analysed. Still some regularities can be found in the group of synthetic leathers because in all three uniaxial pre-tension cases H_{50} values of synthetic leather L2 (breaking elongation anisotropy coefficient 0.25) were from 1.33 % to 5.69 % higher compared to those of leather L1 (breaking elongation anisotropy coefficient 0.50). Meantime the values of uniaxial extension of synthetic leather L2 were higher compared to the values of synthetic leather L1 (Table 1) in course direction by 43.02 % and in wale direction – by 459.86 %, respectively. This example proves earlier obtained findings [2] that highly stretchable and anisotropic materials (synthetic leather L2 in analysed case) in biaxial loading may experience the state close to the uniaxial tension. Hence the main loading in the presented testing falls upon less deformable course direction of synthetic leather L2 making its hanging height H_{50} values more close to uniaxial extension values in course direction compared to wale direction which reached even 459.86 %. All this shows that besides uniaxial strength characteristics, the anisotropy of strength parameters is of significant importance for predicting the behaviour of materials in real exploitation conditions, which usually are described by biaxial loadings.

At the second stage of experiments the effect of pouffe top patterns width reduction upon soft furniture upholsteries pull-on ease h_1 values was investigated. The analysis of pouffe hanging process up to F_{const} = 50 N allowed to notice that two zones – I and II - are characteristic for recorded deformation curves, as it is presented in Figure 3. The first zone (I) is characterised by the hanging height h_1, mm which is related to the maximal value of pull-on ease. Meantime, the second zone (II) is characterised by the hanging height h_2, mm which is related to upholstery materials deformability, i.e. materials elongation under acting forces (Fig. 3). Also it was noticed that in the second zone (II) the shape of deformation curves at all three stages of uniaxial pre-tension l_1, l_2 and l_3 remained almost unchanged and was very close to linear behaviour. Mean stiffness values tgα of all tested upholstery materials in second zone (II) varied in the range of 1.07 ÷ 1.32 (Table 2). As it could be expected, close relationship exists between material stiffness tgα and its deformability in the second zone (II) (Fig. 4).

It must be noticed that two analysed zones (I and II) of fabrics biaxial deformation are also characteristic to its behaviour in uniaxial stretching, which occurs when tensile loads are applied on the fabric and which were described in several research works [14, 15].

Table 2. The effect of pouffe top patterns width reduction, i.e. pre-tension, upon its behaviour characteristics in hanging process

Material code	Hanging height H_{50}, mm			Material stiffness tg$a$				Material deformability h_2, mm (II zone)				Pull-on ease h_1, mm (I zone)		
	l_1	l_2	l_3	l_1	l_2	l_3	mean	l_1	l_2	l_3	mean	l_1	l_2	l_3
W1	84.8	81.5	80.1	1.22	1.22	1.20	1.22	24.5	24.5	25.0	24.67	60.3	57.0	55.1
W2	95.0	92.4	80.6	1.10	1.07	1.12	1.10	27.2	28.0	26.9	27.37	67.8	64.4	53.7
W3	98.4	91.6	81.9	1.20	1.09	1.14	1.14	24.9	27.6	26.3	26.27	73.5	64.0	55.6
W4	96.7	95.9	76.5	1.13	1.14	1.14	1.13	26.6	26.3	26.4	26.43	70.1	69.6	50.1
W5	97.4	88.0	74.6	1.15	1.15	1.18	1.16	26.2	26.1	25.4	25.91	71.2	61.9	49.2
W6	89.2	88.2	72.9	1.18	1.12	1.16	1.15	25.4	26.7	26.0	26.02	63.8	61.5	46.9
L1	75.3	72.9	67.5	1.24	1.31	1.32	1.29	24.2	23.0	22.7	23.26	51.1	49.9	44.8
L2	79.0	77.3	68.4	1.15	1.23	1.19	1.19	26.1	24.5	25.1	25.23	52.9	52.8	43.3
K1	88.6	80.4	79.0	1.20	1.22	1.21	1.21	25.0	24.5	24.8	24.77	63.6	55.9	54.2

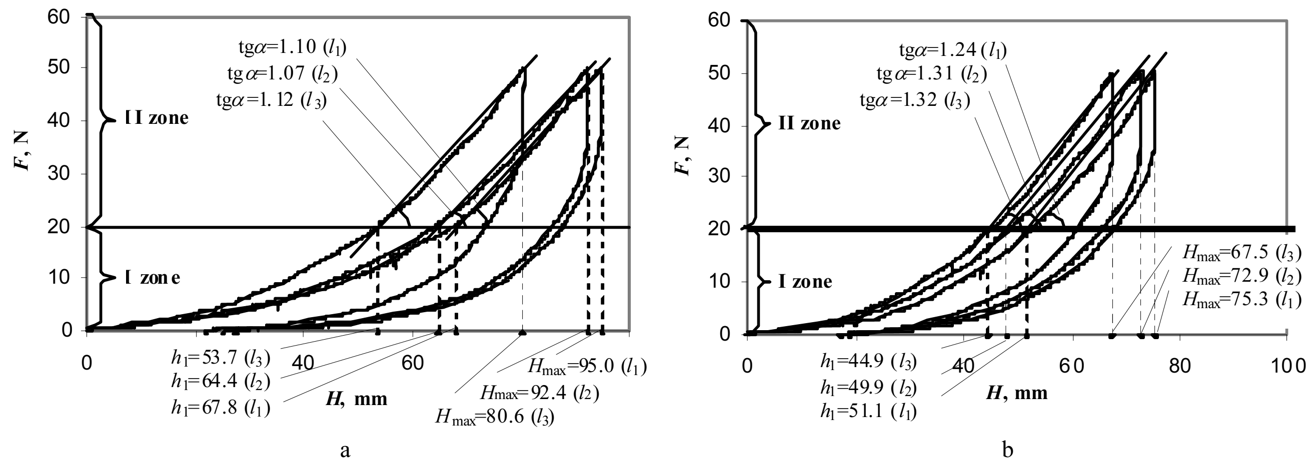


Fig. 3. Characteristic samples of pouffe upholsteries top patterns pull-on ease h_1 dependency upon its width changes: a - two layer fused woven system W2; b - synthetic leather L1; when l_1 = 370 mm, l_2 = 365 mm, l_3 = 360 mm

The first zone reflects the inter-fibre friction, inter-yarn friction and decrimping of the yarns, which results in relatively high elongation, though the overall tensile stress remains quite small. After the reconfiguration of fibres and yarns the second zone (II) starts where decrimping of the yarns becomes dominant until they reach a point of yarn lock at which contact forces between the intersecting yarns become high enough and can no longer move relatively to one another. Due to this, material stiffness tgα in the second zone (II) increases significantly in the case of uniaxial tension, as well as in the case of biaxial deformation.

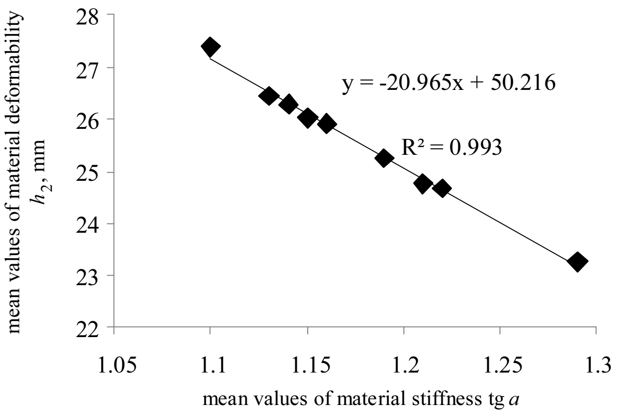
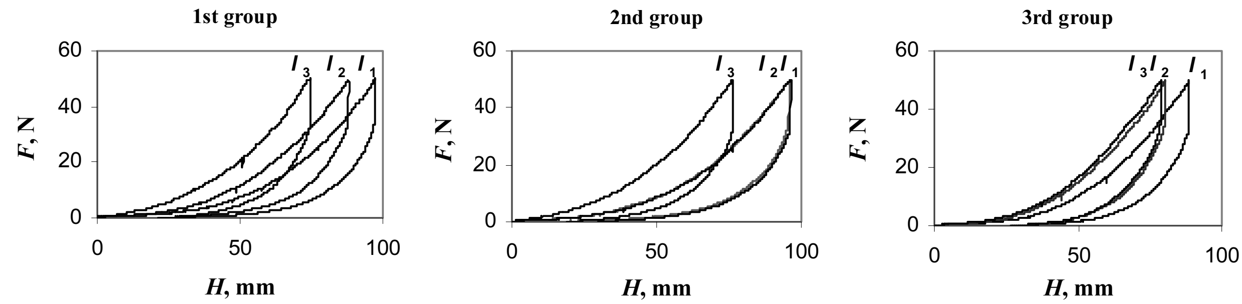


Fig. 4. The dependency between mean values of tested upholstery materials stiffness tgα and its deformability h_2 in the second zone (II)

Thus, further analysis can be performed on the basis of hanging height h_1, which is related to the maximal values of pull-on ease. The characteristic samples (upholstery materials W2 and L1) of pouffe top patterns pull-on ease dependency upon its width changes are presented in Figure 3. Woven material W2 presents the case when the effect of upholstery top patterns width reduction is significant – 15.16 % (Fig. 3, a) and synthetic leather L1 presents the case when this effect is less meaningful – 10.36 % (Fig. 3, b).

It can be seen from Figure 5 that with the reduction of pattern width in 5 mm ($\Delta_{1\text{-}2} = l_1 - l_2$) the value of the pull-on ease expressed through the hanging height h_1 decreases in the range of 0.19 % ÷ 13.61 %. Further decrease of top pattern size ($\Delta_{2\text{-}3} = l_2 - l_3$) has much more significant effect upon the pull-on ease change because it decreases in the range of 2.67 % ÷ 27.82 %. Total decrease of pull-on ease ($\Delta_{1\text{-}3} = l_1 - l_3$) for pattern size reduction in width by 10 mm falls in the range of 8.62 ÷ 30.90.

Analysing this phenomenon from the side of materials properties it must be noted that one of the lowest pull-on ease h_1 value is characteristic for synthetic leather L1. It is little effected (only by 12.33 %) by dimensional changes of the top pattern. Meantime the other sample of synthetic leather L2 acts in a different way. Though the pull-on ease h_1 values for initial width l_1 of pouffe top pattern are almost the same for both materials, i. e. 51.1 mm and 52.9 mm, but the effect of pattern size reduction is different. Pull-on ease h_1 value of synthetic leather L2 reduces more significantly – by 18.15 %. It can be explained by different behaviour of these materials in uniaxial tension. It is evident from Table 1, that synthetic leather L2 is much weaker and stretchable. Its anisotropy coefficient is 0.25, while the same coefficient for L1 is 0.5. The analysis of the effect of upholstery top patterns width reduction from l_1 = 370 mm to l_3 = 360 mm for its pull-on ease h_1 value showed that all investigated materials can be grouped into three groups (Fig. 5, a). The first group is composed of materials W3 and W5, deformational changes of which are equal at both stages of top patterns width reduction – $\Delta_{1\text{-}2}$ and $\Delta_{2\text{-}3}$. The second group is composed of materials W2, W4, W6, L1 and L2, deformational behaviour of which is more significant at the second stage of top patterns width reduction $\Delta_{2\text{-}3}$ (from 9.98 % to 27.82 %) compared to the first stage $\Delta_{1\text{-}2}$ (from 0.19 % to 5.01 %). It must be stated that the dimensions of upholstery patterns made of materials, which belong to the second group must be reduced even more in order to lower pull-on ease h_1 value, i. e. to produce soft furniture, in this case – pouffe, of high quality. The third group is composed of W1 and K1 investigated materials, deformational behaviour of which is opposite to the behaviour of materials from the second group. Their pull-on ease h_1 values significantly change at the first stage of top patterns width reduction $\Delta_{1\text{-}2}$ (from 5.47 % to 12.11 %) and less at the second stage $\Delta_{2\text{-}3}$ (from 2.67 % to 3.15 %).



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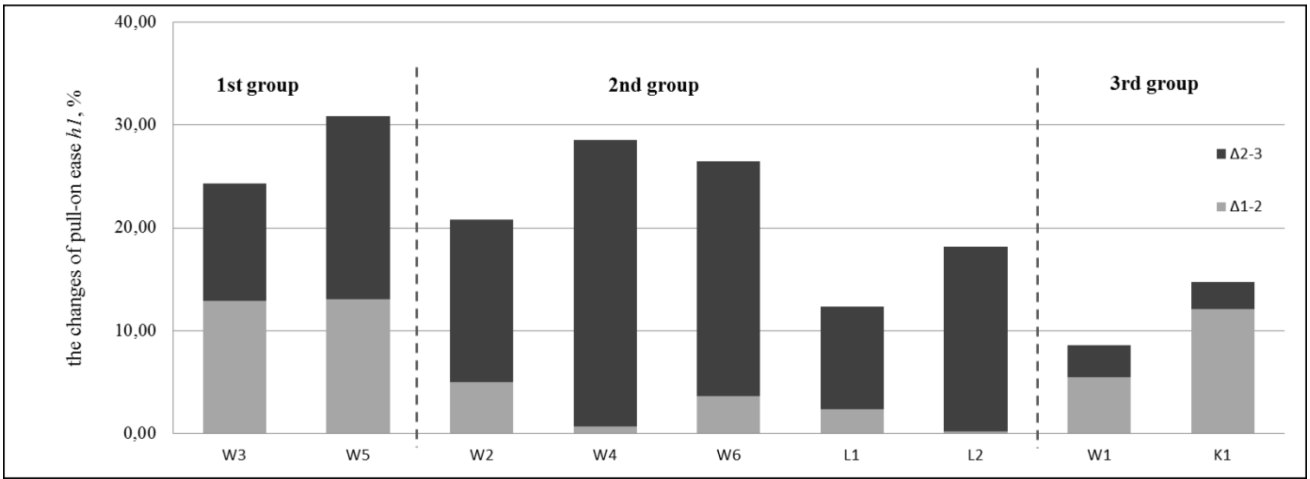

$\Delta_{1\text{-}2}$	mm	9.5	9.3	3.4	0.5	2.3	1.2	0.1	3.3	7.7
	%	12.93	13.06	5.01	0.71	3.61	2.35	0.19	5.47	12.11
$\Delta_{2\text{-}3}$	mm	8.4	12.7	10.7	19.5	14.60	5.1	9.5	1.9	1.7
	%	11.43	17.84	15.78	27.82	22.88	9.98	17.96	3.15	2.67
total $\Delta_{1\text{-}3}$	mm	17.9	22.0	14.1	20.0	16.9	6.3	9.6	5.2	9.4
	%	24.35	30.90	20.80	28.53	26.49	12.33	18.15	8.62	14.78

b

Fig. 5. Generalized grouping of tested materials in accordance to their behaviour in hanging process (a), corresponding changes of tested materials pull-on ease values h_1 at different levels of top patterns pre-tension l_1, l_2 and l_3 (b)

Interesting facts can be observed analysing the differences between knitted material and woven fabrics. Though knitted material K1 is significantly weaker and stretchable compared to woven ones, its pull-on ease value h_1 for initial top pattern size is not the highest. Meantime, as it can expected, the effect of pattern size reduction for this material is significant (14.78 %) like for the most knitted materials. These results correspond to the findings obtained by the other researchers who have also noticed the same effect of pre-tension level upon the behaviour of high stretchability knitted materials [16]. Woven fabric W1 is interesting from this side also, because it is very thin and not strong (Table 1). Despite this, pull-on ease value h_1 of this material wasn't the highest and due to its low stretchability in uniaxial tension (13.4 % in warp and 11.1 % in weft direction) the effect of pattern size reduction for it was the lowest (8,62 %). The other woven fabrics were very similar in uniaxial tension behaviour, i.e. they were stronger and less deformable, thus their behaviour in biaxial hanging process was close and they can be characterised by the highest initial pull-on ease values.

The analysis of hanging process energy A have shown that its value changes are very similar at both stages of top patterns pre-tension: at $\Delta_{1\text{-}2}$ it changes in the limits of 0.55 % – 6.17 % and at $\Delta_{2\text{-}3}$ in the limits of 0.59 % – 7.26 % (Table 3).

Table 3. The effect of pouffe top patterns width reduction upon its hanging process energy A and hanging and recovery cycle energy A_H

Code	Hanging process energy A, Nmm			Hanging and recovery cycle energy A_H, Nmm		
	l_1	l_2	l_3	l_1	l_2	l_3
W1	1188.2	1161.7	1190.1	755.0	754.2	772.1
W2	1390.5	1382.9	1283.6	904.5	918.3	828.0
W3	1249.8	1346.2	1248.4	755.3	873.3	811.3
W4	1300.5	1309.4	1245.1	801.1	850.6	820.2
W5	1262.8	1239.9	1198.9	813.3	782.6	810.7
W6	1238.7	1279.4	1196.2	755.2	839.9	763.8
L1	1150.5	1079.5	1061.4	683.7	603.0	624.7
L2	1229.5	1164.9	1171.8	749.5	690.4	732.1
K1	1182.1	1170.3	1190.1	761.6	763.6	772.1

The highest changes are experienced by synthetic leather L1, meantime the lowest – by stretchable knitted material K1 and the thinnest woven fabric W1. Bigger differences were obtained for the values of hanging process hysteresis A_H. At the first step of pre-tension $\Delta_{1\text{-}2}$ it was 0.11 % – 15.62 % and at the second step $\Delta_{2\text{-}3}$ it was 1.11 % – 9.83 %. Thus, it can be stated that the limit of hanging force which is equal to 50 N does not have significant effect upon the changes of hanging process energy A and hanging and recovery cycle energy A.

The other investigated characteristic was residual deformation H_R, which did not show any regularities at different levels of top patterns pre-tension and varied in wide limits. Still it can be noticed that the lowest changes were characteristic for knitted material K1 and synthetic leather L2. It means that from the standpoint of pouffe quality initial pre-tension of its upholstery will not have significant effect upon residual deformations during its exploitation.

CONCLUSIONS

Special method was developed to record soft furniture upholstery pull-on ease variations employing standard tensile testing machine. The experimental results have revealed that the values of upholstery pull-on ease depend on tensile properties of the tested materials though direct correlation between uniaxial tension properties and pouffe hanging process characteristics was not observed. This phenomenon can be explained by the fact that developed method can be classified as biaxial loading when maximal stresses, unlike the uniaxial tension, distribute between two main acting directions (warp/course and weft/wale). This difference in behaviour is clearly illustrated by the samples of woven fabric W1, which was very thin and not strong compared to the rest of wovens, but its pull-on ease value wasn't the highest. The same was observed with knitted material K1 because its pull-on ease value wasn't the highest though the material was very stretchable and not as strong as the rest tested woven fabrics.

Also it was found out that two zones are characteristic for hanging process curves. The first zone is characterised by the hanging height h_1, mm which is related to the maximal value of pull-on ease. Meantime, the second zone is characterised by the hanging height h_2, mm which is related to upholstery materials deformability, i. e. materials elongation under acting forces. Also it was noticed that in the second zone the shape of deformation curves at all three stages of uniaxial pre-tension l_1, l_2 and l_3 remained almost unchanged and was very close to linear behaviour.

The analysis of the effect of upholstery top patterns width reduction from $l_1 = 370$ mm to $l_3 = 360$ mm for its pull-on ease h_1 value showed that all investigated materials can be grouped into three groups. The first group is composed of materials, deformational changes of which are equal at both stages of top patterns width reduction – $\Delta_{1\text{-}2}$ and $\Delta_{2\text{-}3}$. The second group is composed of materials, deformational behaviour of which is more significant at the second stage of top patterns width reduction $\Delta_{2\text{-}3}$ and the third group is composed of materials, deformational behaviour of which is opposite – their pull-on ease h_1 values significantly change at the first stage of top patterns width reduction $\Delta_{1\text{-}2}$.

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