Donata Zubauskienė[1*],
Eugenija Strazdienė[2]

Effect of Friction in the Punch-to-Specimen Contact Zone upon the Punching Behaviour of Synthetic Leathers

DOI: 10.5604/01.3001.0010.1700

[1] **Department of Materials Engineering,**
Faculty of Mechanical Engineering and Design,
Kaunas University of Technology,
Studentų 56, LT-51424 Kaunas, Lithuania
* E-mail: zubauskiene@yahoo.com

[2] **Faculty of Arts and Creative Technologies,**
Vilnius University of Applied Sciences,
Didlaukio str. 82, Vilnius LT-08303, Lithuania

Abstract
Upholstery materials during their performance experience biaxial deformations, which are effected by friction in the contact zones: material-to-human skin, material-to-material, and material-to-inner parts of the furniture. The aim of this research was to define the effect of friction in the punch-to-specimen contact zone upon the tearing character and strength of non-perforated and perforated synthetic leathers under biaxial punching. Tests were performed with three different punches. The variation of friction coefficients in the punch-to-leather contact zone was achieved by the application of four different lubricants. Leather samples were investigated on the face (vinyl) and reverse (textile) sides. The results of the investigations confirmed that the maximal punching force P_{max} *increases with an increase in the punch size. The same tendency is valid in cases where different levels of friction act in the punch-to-specimen contact zone or whether the specimens were punched from both sides. Dependencies exist between area S of the punch-to-specimen contact zone during tearing and the average static* μ_{SA} *and dynamic* μ_{DA} *friction coefficients.*

Key words: *non-perforated leather, perforated synthetic leather, biaxial punching, friction, lubricants.*

Introduction

The variety of materials used in upholstery production is extremely large. Among them are different leathers, which are applied in cars, boats and aircraft seats, etc. Many scientists have studied the physical, mechanical and thermal properties of natural [1-3] and artificial leathers [3-5]. Perforated leather has small equally spaced holes, which is advantageous for use in heated leather seats [6, 7]. Perforated leather is usually thinner than ordinary leathers, therefore it is softer and more comfortable. Perforated leathers also have good absorption, but are still out-performed by most cloth seat fabrics [8].

Upholstery materials during their performance experience biaxial deformations, which are effected by friction in the contact zones: material-to-human skin [9-12], material-to-material [13, 14], and material-to-inner parts of the furniture: polyurethane [15] or metal [14]. The majority of such investigations are related to the clothing industry with the aim to increase comfort in contact with human skin, e.g. in medicine – for injured or disabled patients who are chained to a wheelchair [9, 11, 12], amd in sports – for athletes to reduce friction between clothing and weather conditions, e.g. snow [16].

New technologies are applied [17] in innovative textile material surface treatment, such as HeiQ's Glider, which helps the wearer feel more comfortable during summer sport [18]. A realistic skin model in combination with an objective friction test method allows to develop new textiles for sport and medical applications with an improved skin adapted surface and frictional properties [10]. Different lubricants are also applied in friction studies [19, 20]. S. N. Jawale *et al* applied lubricant to affect both yarn-to-metal and yarn-to-yarn friction [19]. Ujevic, D. *et al* analysed the uniaxial strength, burss ting strength and density of two artificial leathers designed for car seats: artificial leathers with woven and knitted fabrics on the reverse side [5].

It must be noted that a big part of textile materials during their exploitation are affected by forces perpendicular to their surfaces. As a result, the shell, i.e. spatial surface, with a biaxial state of deformation is formed. Up to now, two biaxial deformation test methods are well known and widely used for such investigations: the membrane and punch methods [21]. The deformational behaviour of textile materials during punching is investigated using a big variety of punches which can be different in shape and size. J. E. Rocher *et al* presented the results of bias tension, bending and friction tests performed in order to characterise the formability of two 3D fabrics punched with a double-curved punch with a triple point (tetrahedral punch) [22]. B. Vanleeuw *et al* used a double-dome shaped punch to measure full field displacements [23]. F. F. Wu *et al* investigated the size dependent plastic deformation of metallic glass under biaxial loading using the small punch (SP) test [24]. X. Zhang *et al* analysed the deformation and failure characteristics of four types (PE, three-layer, ceramic-coated, non-woven) of lithium-ion battery separators. Biaxial punching was performed with four punches of different size which were made of Teflon to reduce friction [25].

The main aim of this research was to define the effect of friction in the punch-to-material contact zone upon the tearing character and strength of non-perforated and perforated synthetic leathers under biaxial punching. Tests were performed with three punches different in size. The variation of friction coefficients in the punch-to-leather contact zone was achieved by the application of four different lubricants. Leather samples were investigated from both sides – the vinyl face and the back textile.

Materials and methods

For the investigations, two types of commercial synthetic leathers were selected: non-perforated L1 and perforated L2. They were vinyl coated on the face side and had a plain jersey background, the composition of which was cotton and polyester. Such man-made vinyl leathers are treated and dyed to resemble real leather and are used in upholstery, clothing, fabrics and for other uses where a leather-like finish is required. Both of the vinyl leathers investigated, L1 and

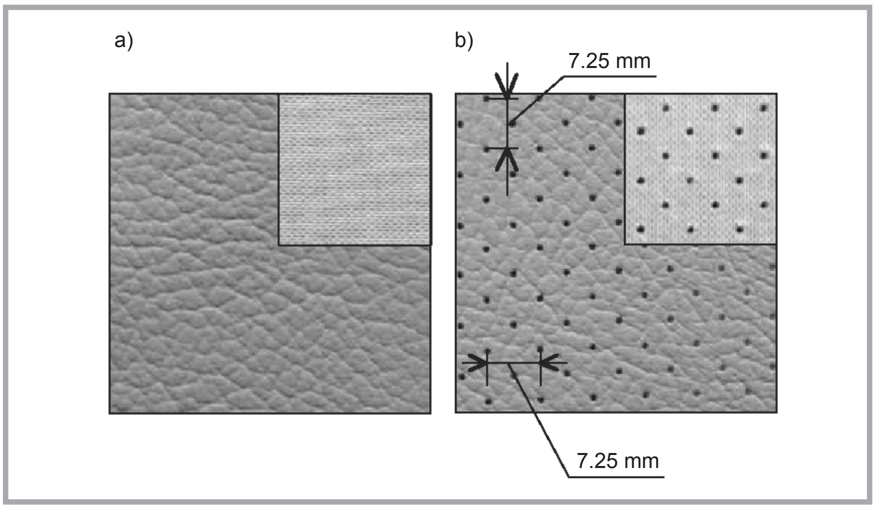

***Figure 1.** Samples of commercial non-perforated L1: a) and perforated L2, b) synthetic leathers investigated.*

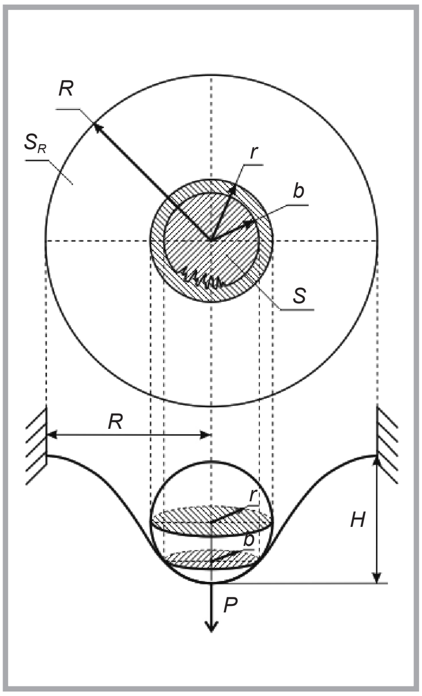

***Figure 2.** Principal scheme of area S of the punch-to-specimen contact zone during tearing calculation: R – radius of specimen work zone, r – radius of punch, b – radius of tearing zone, S_R – area of specimen work zone, S – area of tearing zone, H – punching height, P – punching force.*

L2, are commonly used for car interior installations – seats, front and lateral panels, etc. Perforated leather is often paired with other fabrics for adjustable temperature controlled car seats. The perforation diameter of L2 leather is 1.32 mm, density – 4 holes in cm^2, and the distance between the holes in the longitudinal and transverse directions – 7.25 mm (***Figure 1***). The characteristics of synthetic leathers L1 and L2 are presented in ***Table 1***.

Biaxial punching was performed with a special test unit attached to a standard tensile testing machine – Tinius Olsen (load cell – 500 N) (***Figure 2***). The tensile velocity of the upper clamp was 100 mm/min. For the investigations, ten specimens (180 x 180 mm) were cut from each sample of synthetic leather. The radius of the clamped specimens was $R = 60$ mm. Punching was performed from both sides of the specimens using punches of three different sizes: $r_1 = 9.0$ mm ($r_1/R = 0.15$), $r_2 = 23.5$ mm ($r_2/R = 0.39$) and $r_3 = 31.0$ mm ($r_3/R = 0.52$). Typical punching curves P/H until complete cracking were registered during the experiment. The variation coefficient of biaxial punching reached 6.73% when punched with the smallest punch r_1, and did not exceed 5% when punched with the others, r_2 and r_3. The variation coefficient was 4.17% and 3.08%, respectively. Friction testing was performed in accordance with the requirements of Standard DIN EN ISO 8295 [26]. Static F_S and dynamic F_D friction forces as well as static μ_S and dynamic μ_D friction coefficients were defined. The variation coefficient of the results obtained did not exceed 5%. For investigation of the friction phenomenon, four different types of lubricants were applied: A – pure water, B – commercial cleaner Arexons, which is developed for car seats and upholstery cleaning, polishing and protection, and is enriched with glycerine and natural waxes, C – industrial silicone, D – commercial leather cleaner and Turtle Wax conditioner, the ingredients of which are water, silicone, emulsifiers and additives.

***Table 1.** Characteristics of non-perforated L1 and perforated L2 synthetic leathers.*

Characteristics	Testing directions	Measurement units	Standards	Synthetic leathers	
				L1	L2
Thickness		mm	EN ISO 5084:2000	1.06	1.01
Reverse side (textile)		g/m^2		80-90	80-90
Surface density		g/m^2	EN 12127:1999	674.8	629.0
Uniaxial strength parameters	Longitudinal	P_{max}, N	LST EN ISO 13934-1:2000	342.8	170.0
		ε_{max}, %		23.9	23.4
	Transverse	P_{max}, N		282.8	118.4
		ε_{max}, %		127.6	50.6

All four types of lubricants were used not only to determine friction parameters but also to define and analyse the effect of friction between the punch and specimen upon the deformation behaviour of the synthetic leathers chosen. In all cases, lubricant was spread over metal surfaces with the help of a rubber brush. After each test, the surfaces were cleaned and an appropriate lubricant was re-applied.

The area S of the punch-to-specimen contact zone during tearing was defined according to the scheme presented in ***Figure 2*** and was calculated according to the equation $S = pb^2$, where: S – area of tearing zone, mm^2, b – radius of tearing zone, mm.

Results and discussion

During the investigations, punching was performed from both sides of the specimens taking into consideration the fact that products from synthetic leather, e.g. soft furniture, car seats, etc. experience external normal loading from both sides during production and, especially, during their performance and utilisation. ***Figure 3*** presents typical punching curves P/H (punching force/punching height) of synthetic leathers L1 and L2 when punched from both sides with r_1, r_2 and r_3 punches without the application of any lubricant. It was obtained that the maximal punching force P_{max} depends upon the punch radius r_1, r_2, r_3 (***Figure 5***).

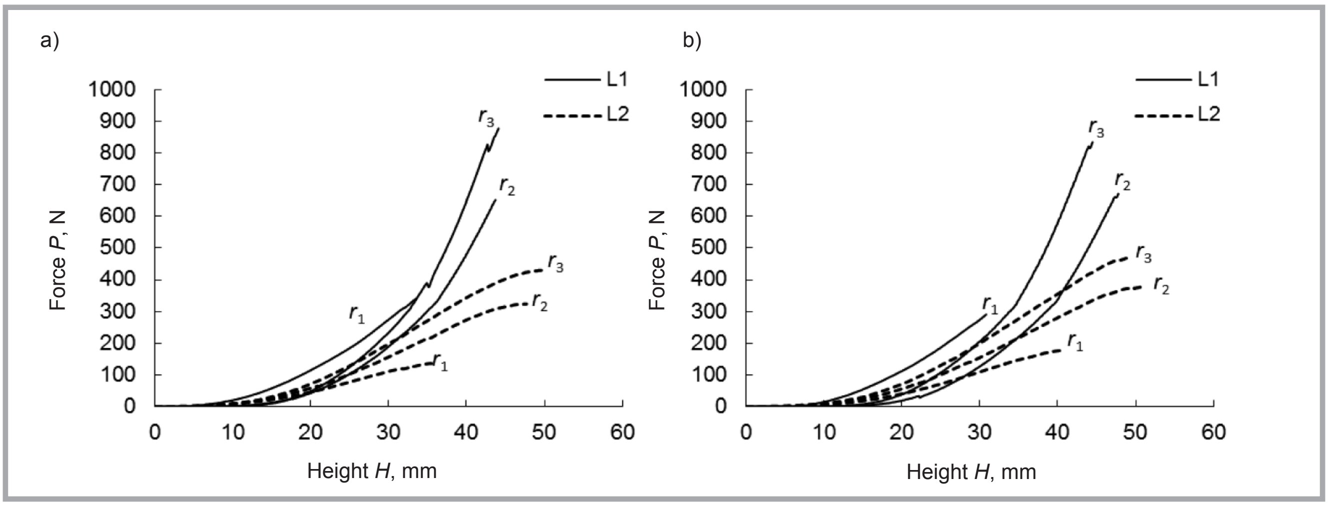

Figure 3. *Punching curves of synthetic leathers L1 and L2 when punched with r_1, r_2 and r_3 punches without the application of lubricants on the face vinyl side a) and back textile side b).*

These results confirm the tendencies obtained by other researches [25], the investigations of which were performed with PE, three-layer, ceramic-coated and non-woven materials. Also they confirm the same relationships obtained for knitted materials [21], which showed that punching strength characteristics were dependent upon the size of the punch, i.e. the punching force P_{max} increased and the punching height H_{max} decreased with an increase in ratio r/R. In [21], the decision was made to apply the universal ratio r/R for comparative analysis of the effect of the punch-to-material's contact area. From this standpoint all three investigations (including the current research) confirm the same tendency of P_{max} in respect to ratio r/R. In the current research P_{max} increased on average 2.72 times for non-perforated leather L1 and 2.90 times for perforated leather L2 when the punch radius increased from $r_1 = 9.0$ mm ($r_1/R = 0.15$) to $r_3 = 31.0$ mm ($r_3/R = 0.52$), (***Figure 4***).

Comparative analysis of the results obtained showed that synthetic leather L1 is nearly twice stronger but less deformable compared to perforated leather L2 due to increased stress concentration around perforated holes (***Figure 3*** and ***5***). Differences between the maximal punching forces of L1 when punched with r_1, r_2 and r_3 punches from the reverse and face sides were negligible and varied in the limits of standard error. Meanwhile the same differences for perforated leather L2 were more evident. P_{max} when punched from the back textile side was higher by 8.4% – 23.2% compared to the face side (***Figure 5***). It must be noted that no evident tendencies were obtained for punching heights H_{max} of non-perforated L1 and perforated L2 leathers.

In order to analyse the effect of friction in the contact zone of punch-to-leather upon the punching strength characteristics, four different lubricants A, B, C and D were applied. Punching results after their application are presented in ***Figures 7*** and ***8***, confirming the same linear dependencies between the maximal punching strength P_{max} and radius r/R: for lubricant A – $R^2 = 0.996$-1.000, for lubricant B – $R^2 = 0.981$-1.000, for lubricant C – $R^2 = 0.977$-0.999, and for lubricant D – $R^2 = 0.979$-1.000. For all four types of lubricants non-perforated leather L1 was nearly twice stronger when compared to perforated leather L2, and P_{max} was higher when punched from the back textile side on average by 8.4% – 36.3% compared to the face vinyl side (***Figure 6***).

It must be noted that for all four lubricants A, B, C and D, similar tendencies existed in respect to the maximal punching height H_{max}, unlike in the case where no lubricant was applied. Average values of maximal deformation H_{max} are higher for perforated leather L2 compared to L1 by 6.3% – 20.65%, increasing with an increase in the

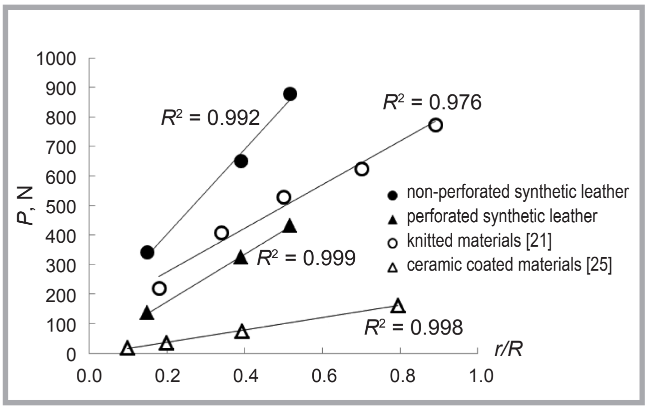

Figure 4. *Dependencies of maximal punching forces P_{max} upon ratio r/R for knitted materials [21], ceramic-coated materials [25] and non-perforated and perforated synthetic leathers (current research).*

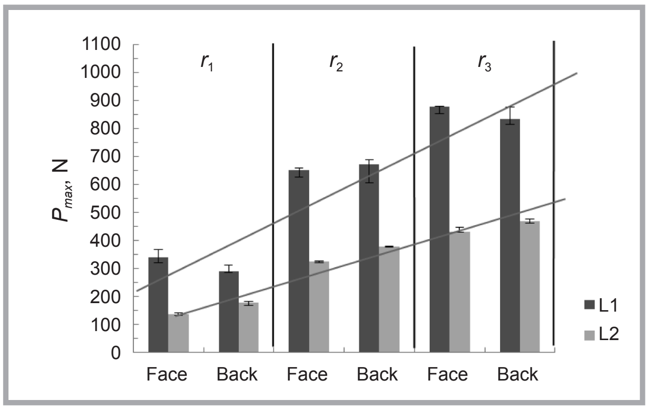

Figure 5. *Effect of the punch size upon the maximal punching force P_{max} for synthetic leathers L1 and L2 when punched from the face (vinyl) side and reverse (textile) side without the application of lubricants.*

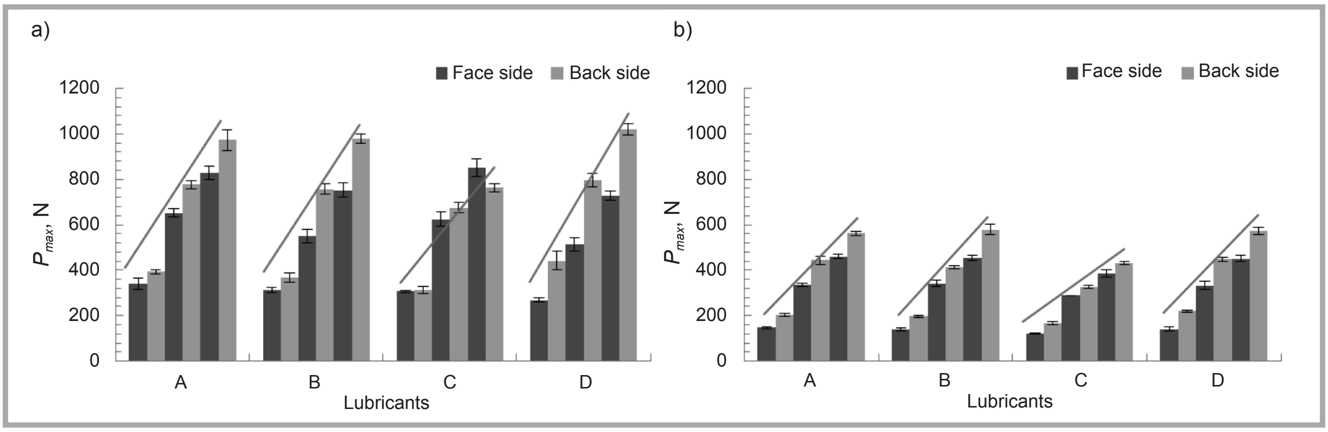

Figure 6. Maximal punching force P_{max} of synthetic leathers L1 a) and L2 b) when punched from the face and reverse sides with punches r_1, r_2 and r_3 after the application of lubricants:A – pure water, B – commercial cleaner Arexons, C – industrial silicone, D – commercial leather cleaner and Turtle Wax Professional.

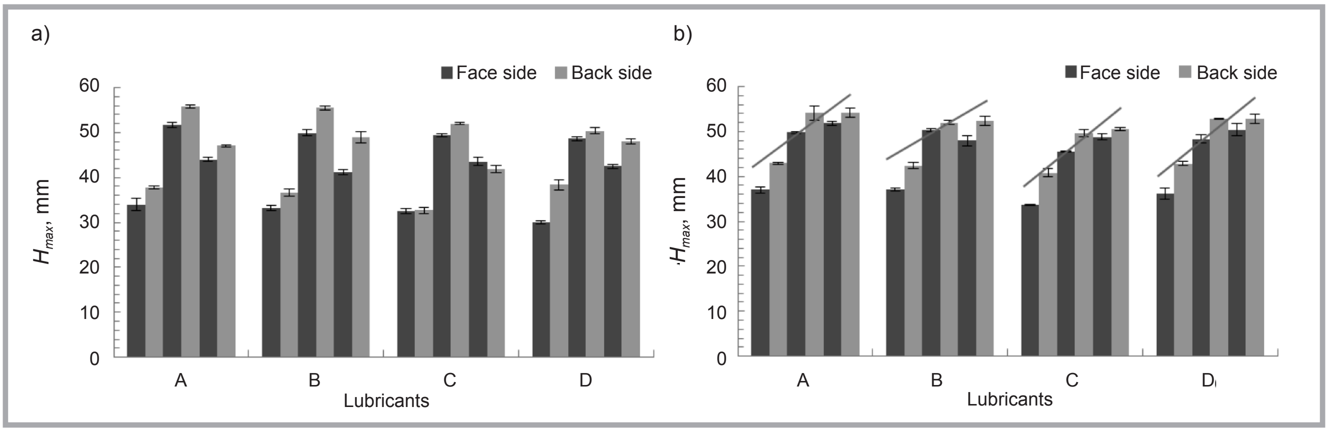

Figure 7. Maximal punching height H_{max} of synthetic leathers L1 a) and L2 b) when punched from the face and reverse sides with the punches r_1, r_2 and r_3 after the application of lubricants: A – pure water, B – commercial cleaner Arexons, C – industrial silicone, D – commercial leather cleaner and Turtle Wax Professional.

punch size. Especially a linear dependency between H_{max} and ratio r/R (R^2 = 0.883-0.935 for L2) is evident when leather samples are punched from the back textile side and almost in all cases H_{max} was higher by 4.6% on average, and 17.7% when punched from the reverse side than from the face side (***Figure 7***).

Comprehensive analysis of the effect of the lubricants applied in respect to the punching characteristics of samples without lubricants revealed that lubricant A (pure water) did not have any effect on the maximal punching force P_{max} of non-perforated leather L1 when punched from the face side (***Figures 8*** and ***9***), varying within the limits of standard error, whilst it increased by 23% when punched from the reverse side, i.e. the textile background. The maximal punching force P_{max} of perforated leather L2 after the application of lubricant A slightly increased: from the face side – by 6% on average, and from the reverse side – by 17% on average

Lubricant B (cleaner Smash leather treatment – Arexons) had more evident effect compared to pure water. It must be noted that P_{max} after the application of lubricant B on non-perforated leather L1's face (vinyl) side decreased on average by 13%, but increases on average by 19% when the same lubricant was applied on the textile (back) side. Furthermore these tendencies of increasing and decreasing become more significant with an increase in the punch radius. In the case of perforated leather L2, P_{max} increased on both the face (4%) and reverse (14%) sides (***Figures 8*** and ***9***). Pure silicone – lubricant C decreased the strength of non-perforated leather L1 by 6% when punched from the face side, but had almost no effect when punched from the reverse side. It also decreased the strength of perforated leather L2 by 11% when punched from the face side, and it is the only lubricant which decreased (by 10.8%) the strength of perforated leather L2 from the reverse side. The most significant effect can be observed with lubricant D (commercial leather cleaner and conditioner Turtle Wax Professional). The maximal punching force P_{max} of non-perforated leather L1 when punched from the face side decreased by 20% and increased by 31% when punched from the textile (reverse) side. In the case of perforated L2 leather, it decreased by 3% and increased by 21%, respectively. Thus it is evident that lubricants A, B and D have a more significant effect upon P_{max} when they are applied from the textile (reverse) side in respect to the case where no lubricant was applied, i.e. P_{max} decreases when samples are punched from the vinyl side and increases when they are punched from the textile side. The punching behaviour of samples is different when pure silicone is applied – P_{max} slightly decreased in all cases.

It can be seen that all four lubricants show a different effect upon the punching behaviour of investigated leathers L1 and L2 from the face vinyl side, as well as from the reverse textile side. Thus the effect of friction in the punch-to-specimen contact

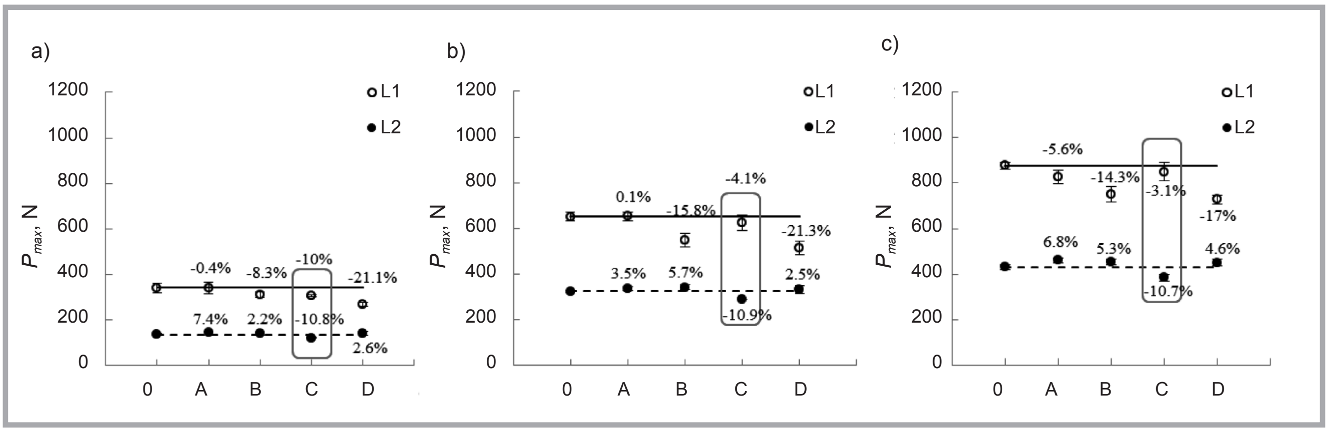

Figure 8. *Maximal punching force P_{max} of synthetic leathers L1 and L2 when punched from the face side with the punches r_1 a), r_2 b) and r_3 c) after the application of lubricants: A – pure water, B – commercial cleaner Arexons, C – industrial silicone, D – commercial leather cleaner and Turtle Wax Professional.*

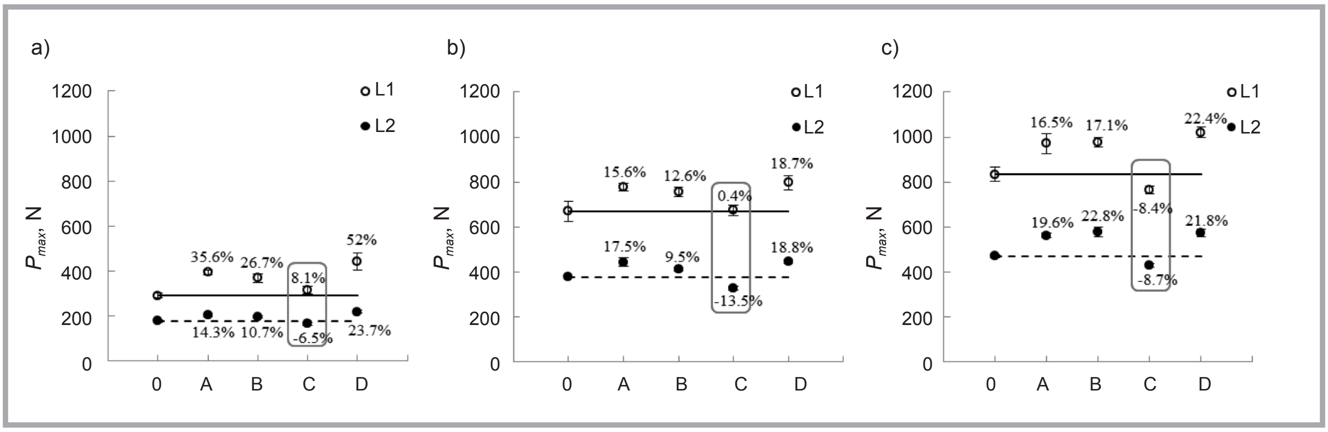

Figure 9. *Maximal punching force P_{max} of synthetic leathers L1 and L2 when punched from the reverse side with punches r_1 a), r_2 b) and r_3 c) after the application of lubricants: A – pure water, B – commercial cleaner Arexons, C – industrial silicone, D – commercial leather cleaner and Turtle Wax Professional.*

zone was investigated during the next research stage. The results of static F_S and dynamic F_D friction forces, as well as static μ_S and dynamic μ_D friction coefficients are presented in ***Table 2***. It can be seen that static friction parameters compared to dynamic are evidently higher on the face (vinyl) side. In certain case this difference reaches even 68.6%. However, on the reverse (textile) side the friction process is smoother, and this difference does not exist or varies in the limits of standard error.

The differences in friction parameters between leathers L1 and L2 were analysed from two standpoints: (1) in respect to longitudinal and transverse directions, and (2) in respect to the face and reverse sides. In all cases of lubricants applied, friction characteristics on the face side of non-perforated leather L1 were higher compared to perforated leather L2. Here the case without a lubricant can be exceptional, because the difference in the longitudinal direction was very significant, i.e. 44.7%-58.5% compared to the rest. Meanwhile the difference in the transverse direction became opposite as the friction parameters of perforated leather L2 became higher by 1.5%-6.3% on average. Friction characteristics from the reverse side maintain the same tendencies for all lubricants, although the difference between leathers L1 and L2 is a bit lower, except the cases where no lubricant or industrial silicone – lubricant C – was applied. Friction characteristics of leather L2's reverse side, in contrast to the face side in the longitudinal direction, were higher by even 41.0% and 46.2%, respectively. The assumption can be made that the four lubricants applied – A, B, C and D, make the values of static μ_S and dynamic μ_D friction coefficients lower (from face side), e.g. by 27.6-53.85% in leather L1's longitudinal direction and by 15.69-59.42% in leather L2's transverse direction.

During punching, the part of the specimen which is in contact with the punch obtains its shape (***Figure 2***). The rest part of the specimen from the point where it loses contact with the punch up to the clamp obtains the shape of a concaved curve. Earlier investigations proved that the specimen tearing line is always located below the top of the shell formed, i.e. in the place where the specimen loses contact with the punch [21], and that it can extend along the whole perimeter (***Figure 10.a***) or be localised in one place (***Figure 10.b***). The results obtained during the testing performed with non-perforated and perforated synthetic leathers L1 & L2 did not contradict these findings (***Figure 10***). On one hand the position of the tearing line depends on whether the sample was punched from the face (vinyl) or reverse (textile) side. On the other hand, it depends on the size of the punch, i.e. the bigger the punch used, the further from the centre the tearing line was located and the bigger the area S (mm^2) of the punch-to-leather's contact zone during tearing. In most of the cases, the tearing line is perpendicular to the transverse direction of the specimens tested [21].

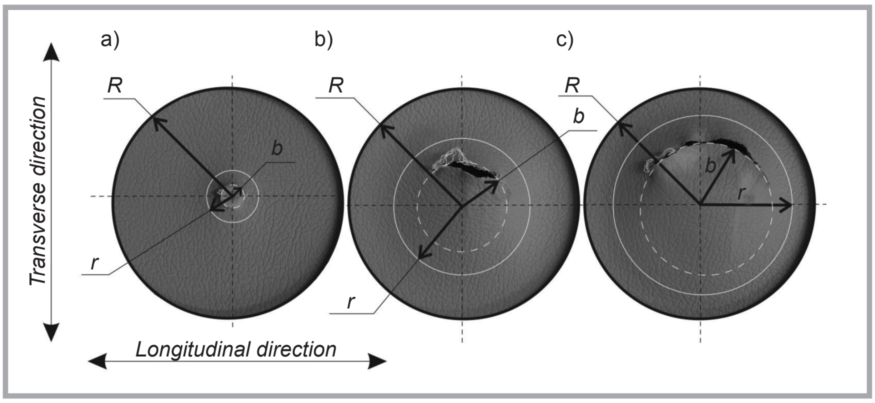

Figure 10. *Examples of synthetic leather L1's tearing lines when punched from the face side with punches r_1 a), r_2 b) and r_3 c).*

The areas S of the punch-to-leather contact during tearing were defined according to the scheme presented in ***Figure 2***. The results of the calculations are presented in ***Figure 11***, from which it can be seen that bigger contact areas S during tearing are characteristic for perforated leather L2 for all types of lubricants when punched from both the face and reverse sides. A comparison of the face and reverse sides show that bigger areas belong to the reverse (textile) side, especially evident in the case of perforated leather L2. The effect of lubricants A, B, C and D is more evident when they were applied from the face (vinyl) side (***Figure 11.a***). After their application, the areas S of the punch-to-leather contact zones during the tearing of leathers L1 and L2 decrease by 25.9-61.2% in the case of lubricants A and B and by 24.1-96.5% in the case of lubricants C and D. The same tendency is not valid when the leather samples were punched from the reverse (textile) side as the area S became bigger compared to that when no lubricant was applied (***Figure 11.b***).

Table 2. *Friction characteristics of non-perforated and perforated synthetic leather L1 & L2.*

Material	Direction	Face side				Reverse side			
		F_S	μ_S	F_D	μ_D	F_S	μ_S	F_D	μ_D
without lubricant									
L1	Long	1.79	0.91	1.26	0.65	0.44	0.23	0.47	0.24
	Trans	1.33	0.68	0.95	0.48	0.45	0.23	0.50	0.26
L2	Long	0.99	0.50	0.53	0.27	0.62	0.32	0.49	0.25
	Trans	1.36	0.69	1.00	0.51	0.50	0.26	0.40	0.20
lubricant A									
L1	Long	0.99	0.51	0.74	0.38	0.62	0.32	0.64	0.33
	Trans	1.02	0.52	0.84	0.43	0.70	0.36	0.78	0.40
L2	Long	0.90	0.46	0.70	0.36	0.59	0.30	0.63	0.32
	Trans	1.00	0.51	0.84	0.43	0.58	0.30	0.59	0.30
lubricant B									
L1	Long	1.02	0.52	0.92	0.47	0.50	0.25	0.54	0.28
	Trans	0.93	0.47	0.77	0.39	0.79	0.40	0.82	0.42
L2	Long	0.72	0.37	0.49	0.25	0.46	0.23	0.46	0.24
	Trans	0.79	0.40	0.61	0.31	0.66	0.34	0.68	0.35
lubricant C									
L1	Long	1.22	0.62	0.74	0.38	0.26	0.13	0.23	0.12
	Trans	1.20	0.61	0.57	0.29	0.66	0.34	0.67	0.34
L2	Long	0.90	0.46	0.57	0.29	0.37	0.19	0.33	0.17
	Trans	0.55	0.28	0.48	0.25	0.43	0.22	0.35	0.18
lubricant D									
L1	Long	1.15	0.59	0.58	0.30	0.38	0.20	0.42	0.22
	Trans	1.19	0.61	0.55	0.28	0.51	0.26	0.51	0.26
L2	Long	0.85	0.43	0.52	0.27	0.41	0.21	0.41	0.21
	Trans	0.86	0.44	0.27	0.24	0.51	0.26	0.49	0.25

The main aim of this research was to define the effect of friction in the punch-to-material contact zone upon the tearing character and strength of non-perforated and perforated synthetic leathers under biaxial punching. Thus it was defined that for both non-perforated and perforated leathers L1 & L2 there is no difference in the dependencies between areas S and static μ_S and dynamic μ_D friction coefficients in the longitudinal and transverse directions (***Table 3***). Meantwhile a clear difference exists between coefficients μ_S and μ_D. The determination coefficient R^2 of μ_D dependency is higher and for non-perforated leather L1 varies in the limits of 0.65 ÷ 0.98, and for perforated leather L2 in the limits of 0.29 ÷ 0.87.

It must be noted that punching is a biaxial process during which friction acts simultaneously in both the longitudinal and transverse directions. Taking this into account together with the research results of other investigators [27, 28], the decision was made to use the average values of these coefficients in two main directions. The results of the dependencies (determination coefficients R^2) between the area S of the punch-to-leather contact during tearing and average values of static μ_{SA} and dynamic μ_{DA} friction coefficients are presented in ***Table 4***. These results confirm an obvious difference in the effect of static μ_{SA} and dynamic μ_{DA} friction coefficients. The determination coefficient R^2 of the μ_{DA} dependency is significantly higher (***Figure 12***). For non-perforated leather L1 it varies in the limits of 0.79 ÷ 0.98, and for perforated leather L2 – in the wider limits of 0.25 ÷ 0.94. It is important to mention that these dependencies are valid for individual punches r_1, r_2 and r_3. The same dependency for the research results of all three punches is weaker: determination coefficient R^2 does not reach 0.5.

Further investigations revealed that linear dependencies exist between the maximal punching force P_{max} and punch-to-leather contact areas S during tearing (***Figure 13***). In the case of non-perforated leather L1 for all three punch sizes and both the face and reverse sides, they are as follows: without lubricant $R^2 = 0.615$, for lubricant A – $R^2 = 0.869$, for lubricant B – $R^2 = 0.772$, for lubricant C – $R^2 = 0.737$ and for lubricant D – $R^2 = 0.753$. In the case of perforated leather L2 these dependencies are even stronger: without lubricant $R^2 = 0.919$, for lubricant A – $R^2 = 0.923$, for lubricant B – $R^2 = 0.891$,

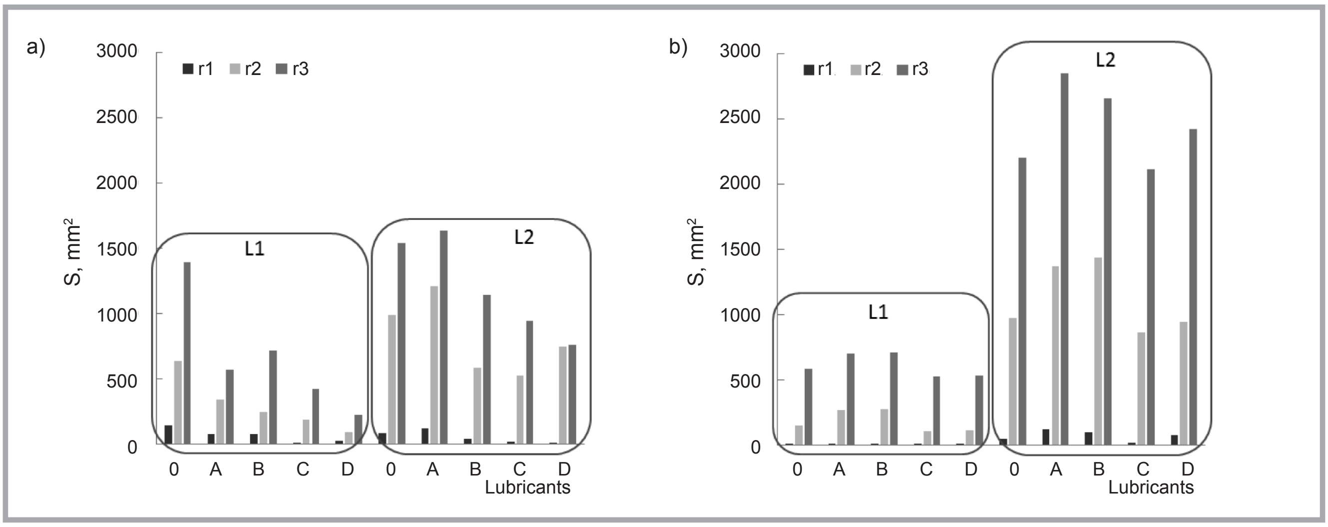

Figure 11. *Areas S of punch-to-leather contact zones during the tearing of non-perforated and perforated leathers L1 & L2 when punched with punches* r_1*,* r_2 *and* r_3 *without any lubricant (0) and with all lubricants (A-D) from the face a) and reverse b) sides.*

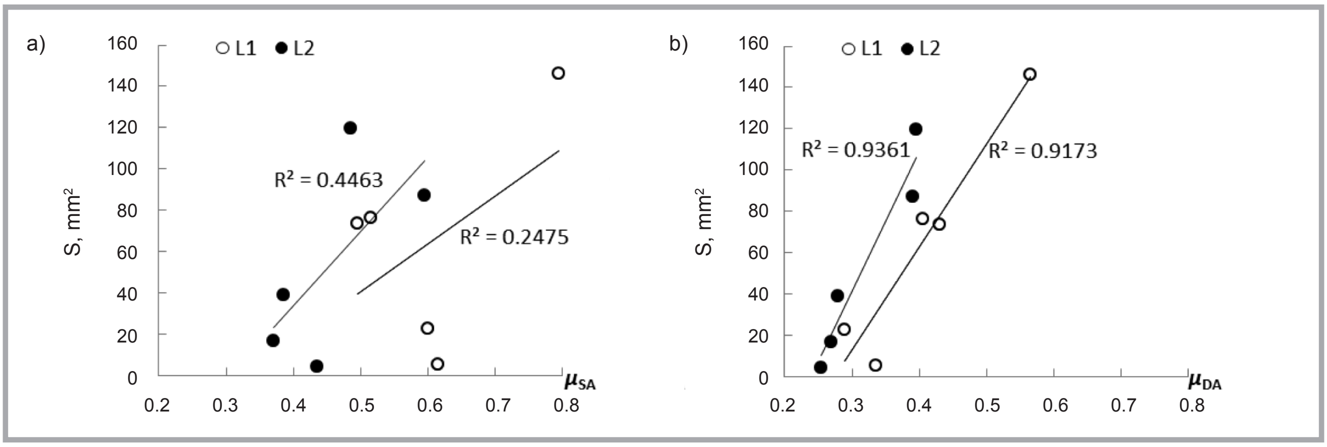

Figure 12. *Dependencies between the area S of the punch-to-leather contact zone during tearing and the average a) static* μ_{SA} *and b) dynamic* μ_{DA} *friction coefficients of non-perforated and perforated synthetic leathers L1 & L2 when they were punched with punch* r_1*.*

for lubricant C – R^2 = 0.819 and for lubricant D – R^2 = 0.807.

Conclusion

The results of the current investigations have confirmed the dependency between the maximal punching force P_{max} and the radius r of the punch for non-perforated and perforated synthetic leathers. P_{max} increased on average 2.72 times for non-perforated leather L1 and on average 2.90 times for perforated leather L2 when the punch radius increased from r_1 = 9.0 mm (r_1/R = 0.15) to r_3 = 31.0 mm (r_3/R = 0.52). The same tendency is valid in cases where different levels of friction act in the punch-to-specimen contact zone or whether the specimens were punched from the face (vinyl) or reverse (textiles) side. Comparative analysis has shown that non-perforated leather is nearly twice stronger, but less deforma-

Table 3. *Dependencies (determination coefficients* R^2*) between the area S, mm² of punch-to-leather contact during tearing and the static* μ_S *and dynamic* μ_D *friction coefficients in the longitudinal and transverse directions.*

Material code	Punch size	Longitudinal direction				Transverse direction			
		Face side		Reverse side		Face side		Reverse side	
		μ_S	μ_D	μ_S	μ_D	μ_S	μ_D	μ_S	μ_D
L1	r_1	0.40	0.78	0.70	0.68	0.03	0.91	0.50	0.71
	r_2	0.60	0.85	0.69	0.71	0.16	0.82	0.50	0.69
	r_3	0.63	0.98	0.72	0.73	0.13	0.74	0.44	0.65
L2	r_1	0.19	0.44	0.15	0.70	0.44	0.78	0.70	0.76
	r_2	0.28	0.51	0.10	0.51	0.53	0.60	0.90	0.87
	r_3	0.20	0.29	0.08	0.62	0.49	0.87	0.68	0.79

Table 4. *Dependencies (determination coefficients* R^2*) between the area S, mm² of the punch-to-leather contact during tearing and average values of static* μ_{SA} *and dynamic* μ_{DA} *friction coefficients.*

	L1				L2			
	Face side		Reverse side		Face side		Reverse side	
	μ_{SA}	μ_{DA}	μ_{SA}	μ_{DA}	μ_{SA}	μ_{DA}	μ_{SA}	μ_{DA}
r_1	0.25	0.92	0.94	0.97	0.45	0.94	0.54	0.94
r_2	0.45	0.93	0.94	0.98	0.56	0.79	0.55	0.90
r_3	0.45	0.97	0.91	0.96	0.49	0.94	0.43	0.92

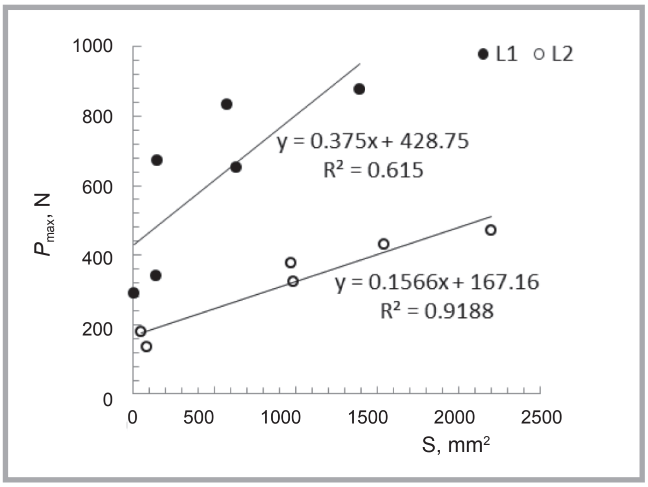

***Figure 13.** Dependencies between the area S of the punch-to-leather contact zone during tearing and P_{max} when no lubricant was applied from the face and reverse sides of non-perforated and perforated synthetic leathers L1 & L2.*

ble compared to perforated leather due to increased stress concentration around perforated holes. The surfaces of synthetic leathers on the face and on the reverse sides differ because it has a textile background coated with a vinyl layer. Thus punching characteristics from both sides are different not only taking into account the size of the punch but also in respect to the contact friction.

It was also obtained that for non-perforated and perforated synthetic leathers dependencies exist between the area S of the punch-to-leather contact zone during tearing and the average static μ_{SA} and dynamic μ_{DA} friction coefficients, i.e. the tearing area increases with an increase in friction. An especially strong relationship was obtained in the case of dynamic friction μ_{DA}. It must be noted that static friction parameters compared to dynamic are evidently higher from the face vinyl side. In certain cases this difference reaches even 68.6%. But from the reverse textile side the friction process is smoother, and this difference does not exist or varies in the limits of standard error.

References

1. Sureshkumar P S, Thanikaivelan P, Phebe K, Kaliappa K, Jagadeeswaran R and Chandrasekaran B. Investigations on structural, mechanical, and thermal properties of pineapple leaf fiber-based fabrics and cow softy leathers: an approach toward making amalgamated leather products. *Journal of Natural Fibers* 2012; 9(1): 37-50.
2. Tsaknaki V, Fernaeus Y and Schaub M. Leather as a material for crafting interactive and physical artifacts. *Research Gate* 2014; 05: 5-14.
3. Turk M, Ehrmann A and Mahltig B. Water-, oil-, and soil-repellent treatment of textiles, artificial leather, and leather. *Journal of the Textile Institute* 2014; 106 (6): 1-10.
4. Schwarz I G, Kovacevic S and Kos I. Physical-mechanical properties of automotive textile materials. *Research Gate* 2015; 11.
5. Ujevic D, Kovacevic S, Wadsworth L C, Schwarz I and Sajatovic B B. Analysis of artificial leather with textile fabric on the backside. *Journal of Textile and Apparel, Technology and Management* 2009; 6 (2): 1-9.
6. Prestige Sunroofs. Are Perforated Leather Seats Better. *Leather Seats and Trims*, 2014. http://prestigesunroofs.com.au
7. Popely R. What's the difference between perforated leather and regular leather? *I'm Just Wondering*, September 16, 2012. http://ask.cars.com
8. McMullan A and Mealman M. An investigation of automotive seat fabric sound absorption. *SAE Technical Paper*, 2001; 2011-01-1454: 1-6.
9. Vilhena L and Ramalho A. Friction of human skin against different fabrics for medical use. *Lubricants* 2016; 4 (6): 1-10.
10. Derler S, Schrade U and Gerhardt L C. Tribology of human skin and mechanical skin equivalents in contact with textiles. *Wear* 2007; 263: 1112-1116.
11. Rotaru G M, Pille D, Lehmeier F K, Stampfli R, Scheel-Sailer A, Rossi R M and Derler S. Friction between human skin and medical textiles for decubitus prevention. *Tribology International* 2013; 65: 91-96.
12. Tasron D N, Thurston T J and Carre M J. Frictional behaviour of running sock textiles against plantar skin. *Procedia Engineering*, 2015; 112: 110-115.
13. Bertaux E, Lewandowski M and Derler S. Relationship between friction and tactile properties for woven and knitted fabrics. *Textile Research Journal*, 2007; 77 (6): 387-396.
14. Das A, Kothari V K and Vandana N. A study on frictional characteristics of woven fabrics. *Autex Research Journal*, 2005; 5 (3): 133-140.
15. Takuya S, Tsuneaki Y, Soo K I and Yuji E. Frictional properties of electrospun polyurethane nanofiber web. *Tribology Online* 2010; 5 (6): 262-265.
16. Nachbauer W, Mossner M, Rohm S, Schindelwig K and Hasler M. Kinetic friction of sport fabrics on snow. *Lubricants* 2016; 4 (7): 1-8.
17. Dong Y, Kong J, Mu Ch and Lu X. Materials design towards sport textiles with low-friction and moisture-wicking dual functions. *Materials and Design* 2015; 88: 82-87.
18. Phillipp M. Reduced textile friction for cotton, synthetics and blends: GLIDER by HeiQ. *Textile Intelligence Inside* 2014: 1-3.
19. Jawale S N and Patil U J. Yarn friction and its importance, theory, factors, measurement. *The Indian Textile Journal*, 2011.
20. Gerhardt L C, Lottenbach R, Rossi R M and Derler S. Tribological investigation of a functional medical textile with lubricating drug-delivery finishing. *Colloids and Surfaces* 2013.
21. Strazdienė E, Gutauskas M V, Paprečkienė L and Williams J T. The behaviour of textile membranes in punch deformation process. *Materials Science* (*Medžiagotyra*) 1997; 5 (2): 50-54.
22. Rocher J E, Allaoui S, Hivet G, Blond E. Experimental testing of two three-dimensional (3D)-non crimp fabrics of commingled yarns. *13th Autex World Textile Conference* 2013: 1-6.
23. Vanleeuw B, Carvelli V, Barburski M, Lomov S V and van Vuure A W. Quasi-unidirectional flax composite reinforcement: deformability and complex shape forming. *Composites Science and Technology* 2015; 110: 76-86.
24. Wu F F, Zhang G A and Wu X F. Extrinsic size effects on performance of Zr-based metallic glass under biaxial loading. *Journal of Material Science* 2012; 47: 2213-2217.
25. Zhang X, Sahraei E and Wang K. Deformation and failure characteristics of four types of lithium-ion battery separators. *Journal of Power Sources* 2016; 327: 693-701.
26. DIN EN ISO 8295 (2004 10) Plastics. Film and sheeting. Determination of the coefficient of friction.
27. Fontaine S, Marsiquet C and Renner M. Adhesion, roughness and friction characterization on time-dependant materials: example with fibrous structures. *SEM Annual Conference and Exposition on Experimental and Applied Mechanics* 2006; 4: 1948-1953.
28. Ezazshahabi N, Latifi M and Tehran M A. Analysis of frictional behavior of woven fabrics by a multi-directional tactile sensing mechanism. *Journal of Engineered Fibers and Fabrics* 2015; 10 (3): 129-135.

Received 07.11.2016 Reviewed 14.03.2017