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The Influence of Laser Processing Applications for Leather Laminates Comfort

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In this paper the investigations of moisture transfer through microporous membrane laminated leather are presented. To improve the comfort features, the leather was laser-processed using molecular gas CO_2 and laminated with microporous breathable PU membrane. The influence of microporous membrane and geometrical parameters of laser cutting perforation on the leather laminate comfort properties has been investigated. Lamination with microporous membrane increases leather resistance to water penetration, decreases the water vapour permeability and intensifies the water vapour absorption. Herewith laser cutting perforation is opening the cutting surface of holes, which is able to improve the vapour penetration and sorption. The water vapour permeability and absorption were directly dependent on perforation area.

Keywords: laminated leather, microporous membrane, water vapour permeability, absorption, perforation area.

1. INTRODUCTION

Laser processing technology is applied in many manufacturing industries. Metallic and nonmetallic materials are cut, welded, and surface treated by different types of lasers at different operating powers [1].

Laser processing is a prospective method for materials properties improvement based on the local heating caused by the optical absorption of laser radiation. Laser processing is used for modification of microstructure, physical, mechanical and other properties [2, 3]. One category of applications includes semiconductor annealing and etching, polymer curing, scribing/marking of integrated circuit substrates, etc. These applications require limited energy/ /power and they don't cause significant change of phase or state. The second type of application encompasses cutting, welding, fusion, heat treatment, etc., requiring substantial amount of energy to induce the phase transformations. The changes of parameters of the treated materials mainly occur due to the created in them thermal fields [4].

Laser cutting, marking and engravings are common popular process in clothing industry [1, 3]. The following applications are performed on the surface of various materials: textile, leather, plastic etc. For cutting non-conducting materials like leather, textile, carbon and plastics, the focused beam heats up the surface to boiling point and generates a hole. The hole influences a sudden increase in absorptivity due to multiple reflections and the hole deepens quickly [5]. Due to rapid energy delivery, heat-affected zones in the irradiated targets are strongly localized with minimal residual damage that can allow generation of well-defined microstructures with high quality and reproducibility [6]. Laser application is executed with very high accuracy.

Application of laser cutting in clothing materials enables the extraction of various forms of holes with a certain pattern or dent lines. The application of laser cutting processing enables to improve not only aesthetic but also comfort features of clothing materials.

Clothing industry frequently uses layered laminates, which give a complex of various attributions. Membranes used for the production of laminates have increased resistance to water, wind, micro-organisms, and penetration of various chemicals [7 – 10]. Improvement of the resistance caused unwanted effects of laminate properties, often make their comfort features worse, such as: water vapour permeability, water vapour absorption, desorption [11 – 13]. The application of laser processing technology enables to change the mechanical, transfer property and improve the comfort of individual layers as well as laminates [1, 14 – 15]. The goal of this investigation is to study the influence of laser cutting perforation parameters on moisture transport properties of leather laminates in the exothermic conditions in order to predict comfortability of leather goods.

2. EXPERIMENTAL

The object of this investigation is the lining leather (produced by" company "Odos Gaminiai"), used for footwear production. During the made processes of laminate, the bottom surface of leather is duplicated and glued up with a breathable microporous polyurethane membrane "Puratex" (produced by company "Freudenberg Nonwovens"). Settings as following: temperature (T_{pr} = 90 °C), pressure (p_{pr} = 35 kPa), time interval (t_{pr} = 20 s). Characteristics of the materials are presented in the Table 1. The cross-section of microporous membrane "Puratex" and boundary between leather and membrane are presented in Fig. 1.

To improve the features of the comfort, the leather was laser-processed using molecular gas CO_2 laser "Daimond G-100" (produced by company "Coherent"). Cutting process accomplished at this conditions: laser power – 60 W; cutting speed – 75 mm/s; wavelength – 10.6 μm; beam diameter – $2.3 \cdot 10^{-2}$ mm. The use of CO_2 laser produces drilled-through holes with three different diameters (Table 2). Two variants (i) of perforation digital plan with holes location in different perforation density ρ_1 and ρ_2 are chosen and then sent to the system for automatic machining.

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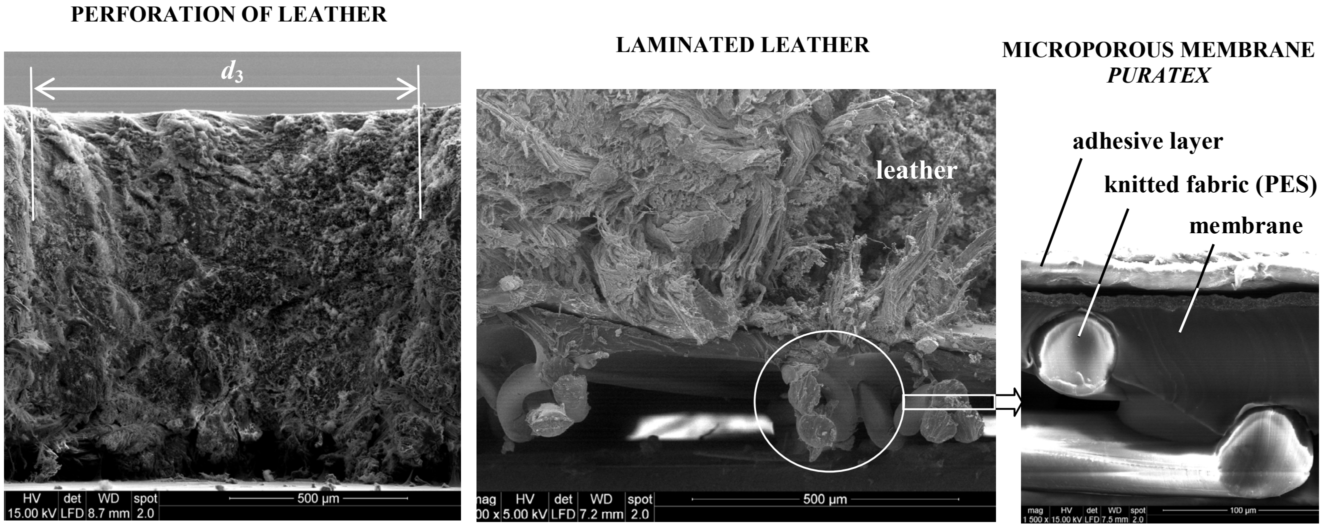

a b c

Fig. 1. Crossection of leather perforation hole (a), boundary between the leather and membrane of laminated leather (b) and breathable microporous polyurethane membrane "Puratex" (c)

Table 1. Characteristics of the materials

Materials	Thickness, mm	Density, mg/mm^3
Lining leather	1.13	0.46
"Puratex" membrane	0.21	0.30

Table 2. Parameters of the perforation and perforation area S_{perf}, m^2·10^{-6}

Samples of test	ρ_i, cm^{-2}		d_i, mm		
			0.5	0.7	1.0
Water vapour permeability	$i = 1$	0.83	1.37	2.69	4.71
	$i = 2$	3.64	5.10	10.39	20.41
Water vapour absorption	$i = 1$	0.83	1.57	3.46	6.28
	$i = 2$	3.64	7.07	13.46	28.26

Before the test all specimens were conditioned in standard atmosphere (temperature $T = 23$ °C ±2 °C, humidity $\varphi = 50$ % ±5 %) in accordance with the requirements of LST EN 12222:1997. The water vapour permeability was measured according to ISO 14268 at a constant temperature and relative humidity [16]. A sample of material was placed over a container, which contained up to half a solid silica gel desiccant. The whole set-up was kept upright in standard conditioned atmosphere. The prepared container was placed into the holder of device STM 473 and maintained in the dynamic conditions during all the test duration. Water vapour permeability was calculated using equation:

$$P_{VG} = \frac{M_2 - M_1}{S_b \cdot t}, \tag{1}$$

where P_{VG} is the water vapour permeability, g/(m^{2}h); M_1 presents the initial mass of the desiccant, g; M_2 gives desiccant mass after the test, g; S_{b} gives the surface area of the sample; t is the duration of the test, h.

The water vapour absorption was determined according to LST EN ISO 17229. In this case an impermeable material and the leather sample were clamped over opening of a cup, which holds 50 ml water [16]. Water vapour absorption was determined by its difference in mass before and after the test:

$$A_{VG} = \frac{M_2 - M_1}{S_b}, \tag{2}$$

where A_{VG} is the water vapour absorption, g/m^2; M_1 presents the initial mass of the sample, g; M_2 is the mass of sample after test, g; S_{b} is the sample surface area, m^2.

Water penetration and absorption were determined in accordance with the requirements of LST EN ISO 13518 standard. Water absorption was defined by the mass changes of the sample:

$$V_S = \frac{(M_1 - M_0)}{M_0} \cdot 100, \tag{3}$$

where V_S is the absorption of water, %; M_0 is the initial mass of sample; M_1 is the mass of the sample after the test.

Water penetration was defined according to the mass of water, which penetrated trough the sample during all test duration:

$$M_p = m_1 - m_0, \tag{4}$$

where M_p is the water penetration, g; m_0 is an initial mass of a piece of absorbing material, g; m_1 is the mass of a piece of absorbing material after the test, g.

3. RESULTS AND DISCUSSIONS

During the research it was found out that leather is especially susceptible to water – it gets wet trough in 20 s. Water absorption of this leather makes Vs = 91 %, and water penetration makes $M_{\text{p}} = 0.53$ g. In order to increase its resistance to water, this leather was laminated with a hydrophobic polyurethane membrane "Puratex". In this case, the dynamic test of water penetration shows that water does not penetrate through lining laminate even after (3 – 4) h of testing.

Increasing leather resistance to water reduces the permeability of water vapour. To improve permeability laminate leather was perforated with holes of three different diameters. The holes were perforated in two different locations of the surface in different density of material. It was found out that water vapour permeability P_{VG} of lining surface with the same perforation density of the leather laminate increases while the area of perforation increases (Fig. 2).

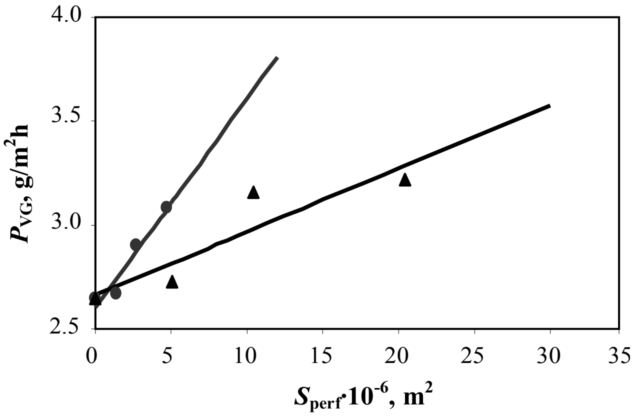

Fig. 2. Relation between the laminated leather water vapour permeability (P_{VG}) and the perforation area S_{perf}: ● – $\rho_1 = 0.83$ cm^{-2}, ▲ – $\rho_2 = 3.64$ cm^{-2}

It was found out that the relationship between the water vapour permeability P_{VG} and the perforation area of laminate leather can be defined according to the linear equation (determination coefficient $R^2 = 0.945$ and $R^2 = 0.829$):

$$P_{VG} = k_1 + k_2 \cdot S_{perf}, \quad (5)$$

where k_1 and k_2 are the water vapour permeability constants (Table 3), S_{perf} is the perforation area, m^2 (Table 2).

It was found that while the area of perforation holes increases, the water vapour permeability P_{VG} of laminated leather increases at different levels: at a lower perforation density ($\rho_1 = 0.83$ cm^{-2}) it increases by about 17 %, while at higher perforation density ($\rho_2 = 3.64$ cm^{-2}) – about 22 % (Fig. 2). In lower density perforations area makes 1 % of the working area, and in perforation area of higher density – up to 3 %. Therefore, the rate of water vapour permeability variation was assessed (3) as a tangent angle (Table 3). It was found out that at higher perforation density ($\rho_2 = 3.64$ cm^{-2}) the rate of water vapour permeability variation is about 3 times less than the perforations in the lower density ($\rho_1 = 0.83$ cm^{-2}).

Fig. 2 explains the fact, that leather perforation in diameter $d_1 = 0.5$ mm of holes water vapour permeability at selected perforation density varies about 2 %. In case the leather perforation with holes $d_2 = 0.7$ mm, this difference increases to 9 % and the perforation with $d_3 = 1.0$ mm holes – about 4 %. These results suggest that the water vapour flux intensity is influenced not only by the area of holes, but also by their location. Therefore, in order to increase water vapour permeability of laminate, it is necessary to select properly geometrical the parameters of perforation.

The results of the investigation proved that during leather perforation and lamination the characteristics of the water vapour permeability, as well as water vapour absorption A_{VG} changed (Fig. 3). It was found out, that the water vapour absorption of leather, which was laminated with microporous membrane "Puratex", increased about 12 % (Fig. 3). As the perforation area increases, the water vapour absorption A_{VG} of leather and laminated leather increases at different levels.

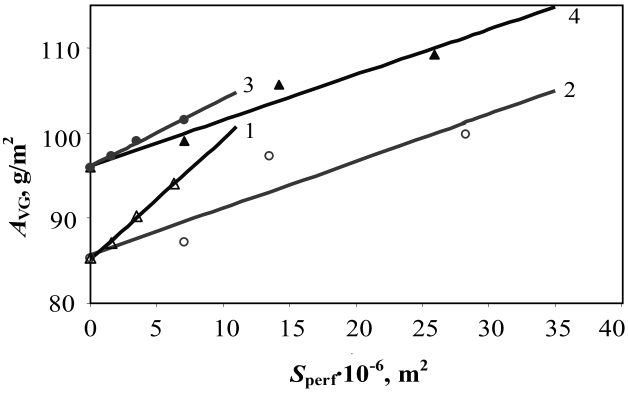

Fig. 3. Relation between the water vapour absorption A_{VG} and the perforation area S_{perf}: Δ and ● – $\rho_1 = 0.83$ cm^{-2}, ▲ – $\rho_2 = 3.64$ cm^{-2} (1 and 2 – leather; 3 and 4 – laminated leather)

After leather perforation was performed the water vapour absorption of the leather and leather laminate were increased as a linear function of perforation area:

$$A_{VG} = k_3 + k_4 \cdot S_{perf}, \quad (6)$$

where k_3 and k_4 are the water vapour absorption function (6) constants (Table 4).

The growth of the perforation area increased the leather water vapour absorption A_{VG} by 11 % at a lower density ($\rho_1 = 0.83$ cm^{-2}) and 17 % at higher density ($\rho_2 = 3.64$ cm^{-2}) (Fig. 3). In case of laminated leather, the water vapour absorption increased about 6 % at a lower density ($\rho_1 = 0.83$ cm^{-2}) and 14 % at a higher density ($\rho_2 = 3.64$ cm^{-2}).

The rate of water vapour absorption variation as the tgα results, provided in the Table 4, suggests that both leather and the laminate at greater density of perforations, absorb the vapour at the same speed (tg$\alpha = 0.51$). Lower perforation density has influence at a higher rate of water vapour absorption comparing to the terms of a higher density.

During the investigations it was found, that after the preforation was executed the leather surface area, which is absorbing the vapour, reduces up to 1 %, when $\rho_1 = 0.83$ cm^{-2}, and up to 3 %, when $\rho_2 = 3.64$ cm^{-2} (Fig. 4). Due to this reason the values of water vapour absorption of perforated leather should decrease. While the process of leather perforation is going on, the additional holes' area of cut surface on the leather thickness, therefore the water vapour penetration and absorption is able to proceed better.

It can have some influence on the increasing of the water vapour absorption values. Therefore the water vapour absorption dependence on area of cut surface was defined (Fig. 5):

$$A_{VG} = k_5 + k_6 (S_c)^2, \quad (7)$$

Table 3. Parameters of Eq. (3)

Material	ρ_i, cm^{-2}		tgα	k_1, g/(m^{2}h)	k_2, g/(m^{4}h)	Determination coefficient R^2
Leather laminate	$i = 1$	0.83	0.093	2.60	100453.04	0.945
	$i = 2$	3.64	0.028	2.61	100048.77	0.829

Table 4. Parameters of Eq. (4)

Material	ρ_i, cm^{-2}		tgα	k_3, g/m^2	k_4, g/m^4	Determination coefficient R^2
Lining leather	$i = 1$	0.83	1.38	85.16	$1.415 \cdot 10^6$	0.996
	$i = 2$	3.64	0.51	85.71	$0.549 \cdot 10^6$	0.842
Leather laminate	$i = 1$	0.83	0.79	96.09	$0.787 \cdot 10^6$	0.994
	$i = 2$	3.64	0.51	96.16	$0.534 \cdot 10^6$	0.955

Table 5. Parameters of Eq. (7)

Material	Density ρ_i, cm^{-2}		k_5, g/m^2	k_6, g/m^6	Determination coefficient R^2
Lining leather	$i = 1$	0.83	85.08	$1.28 \cdot 10^{10}$	0.994
	$i = 2$	3.64	85.58	$0.088 \cdot 10^{10}$	0.829
Leather laminate	$i = 1$	0.83	95.91	$0.803 \cdot 10^{10}$	0.999
	$i = 2$	3.64	96.44	$0.077 \cdot 10^{10}$	0.915

where k_5 and k_6 are the water vapour absorption function (7) constants (Table 5), S_c is the area of cut surface, m^2.

It is evident (Fig. 5), that as the hole diameter is increases, the area of cut surface increases about 3 %, when $\rho_1 = 0.83$ cm^{-2}, and even 14 % – when $\rho_2 = 3.64$ cm^{-2}. The values of water vapour absoption A_{VG} of leather icreasess 11 % and 17 % respectively.

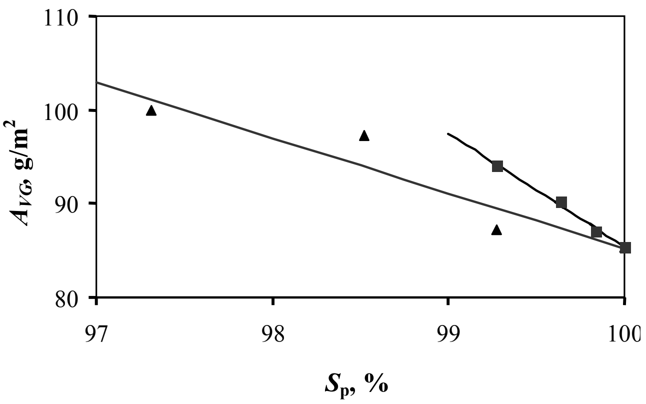

Fig. 4. Dependence of leather water vapour absorption A_{VG} on working surface area S_p: ■ – $\rho_1 = 0.83$ cm^{-2}, ▲ – $\rho_2 = 3.64$ cm^{-2}

This enables to make presumption, that water vapour absorption increases not only because of better penetration via the area of cut surface, but due to the surface structure changes, that appear during the laser perforation.

Laser treatment modifies the surface and microstructure of materials, and influences the physical, mechanical as well as other properties [2, 17]. The changes of parameters of the treated materials occur mainly due to the created in them thermal fields [4]. As it can be seen from Fig. 1, a, the cutting surface are always charred, if the laser is used to cut the leather. Surface treatment by laser cutting process can change the hydrophility [2, 3] of surface and this can have influence on the water vapour absorption. Therefore it can be assumed, that the absorption values increase, with increase of perforation area and this is related both with the increasing penetration and sorption via the area of cut surface in which can be the structural changes.

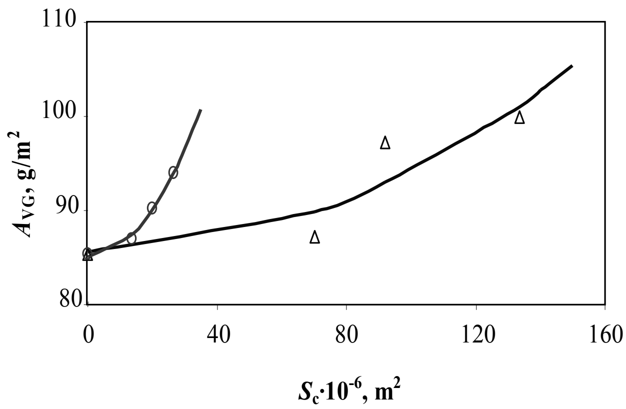

Fig. 5. Dependence of leather water vapour absorption A_{VG} on area of cut surface S_C: ○ – $\rho_1 = 0.83$ cm^{-2} and ∆ – $\rho_2 = 3.64$ cm^{-2}

CONCLUSIONS

Leather laminating with a breathable microporous polyurethane membrane "Puratex" allows producing leather laminate resistance to water penetration, but reduces the permeability of water vapour. To improve the features of the comfort, the leather were laser-processed using molecular gas CO_2.

Laser cutting perforation opening the cutting surface of holes is able to improve the vapour penetration and sorption. The water vapour permeability and water vapour absorption were directly dependent on perforation area. Its growth increases water vapour permeability of leather laminate by 17 % – 22 % and water vapour absorption by 6 % – 14 %.

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