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Influence of Sampling Location on Physical and Mechanical Properties of Full Grain Leather

Utjecaj mjesta uzorkovanja na fizikalna i mehanička svojstva koža punog prirodnog lica

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Abstract

Full grain leather refers to the strongest and most durable part of the cattle hide, consisting of the grain layer and the part of the underlying corium, and has not been sanded or buffed to remove any imperfections, that means it displays the more natural characteristics of leather. Leather quality changes with sampling location, depending on variation present in the leather fibrous structure. Leather properties were also affected by tanning and finishing processes utilized during production. Full grain leather, instead finishing, sometimes go only through an ironing process for the desired sheen is obtained. Therefore, with the purpose of analysing the influence of the leather processing level, and sampling location on their quality, in this paper, the physical and mechanical properties of differently (synthetic and chromium) tanned finished and non-finished cattle full grain leathers, sampled from the bend, shoulder and belly of side leather cuts were evaluated. Their applicability for footwear uppers were assessed by measuring leather thickness, mass per unit area, apparent density, tensile strength and percentage elongation at break, all according to the standardised test methods.

Keywords: full grain cattle leather, sampling, physical and mechanical properties, leather testing, footwear

Sažetak

Koža punog prirodnog lica predstavlja najčvršći i najotporniji dio kože goveda. Sastoji se iz epidermisa i dijela dermisa, a nebrušenog je lica čime se zadržava karakterističan izgled prirodnog lica i ističe prirodan izgled kože. Njezina kvaliteta ovisi o mjestu uzorkovanja te mikro- i makrostrukturnim različitostima u pojedinim dijelovima kože. Vrsta štave i dovršne obrade također znatno utječu na svojstva gotovih koža. Za kožu punog prirodnog lica, umjesto dorade, ponekad je zadovoljavajuće provesti samo postupak glačanja za postizanje željenog sjaja. Stoga je u ovome radu, a u svrhu definiranja utjecaja stupnja obrade kože i mjesta uzorkovanja na njezinu kvalitetu, provedena analiza fizikalnih i mehaničkih svojstava različito (kromno i sintetski) štavljenih koža, uzorkovanih iz leđnog, vratnog i okrajinskog dijela polovica koža. Pritom je prema normiranim metodama vrjednovana njihova primjenjivost za izradu gornjišta obuće ispitivanjem debljine, plošne mase, prividne gustoće, prekidne čvrstoće i prekidnog istezanja.

Ključne riječi: goveđa koža punog prirodnog lica, uzorkovanje, fizikalna i mehanička svojstva, ispitivanje kože, obuća.

1. Introduction

Close examination of cattle hide cross-section shows that it consists primarily of long fine collagen fibres and fibre bundles interweaving in three-dimensional densely packed fibrous structure that gives hide-based materials many of their unique physical qualities. These properties include flexibility, a relatively high tensile strength with particular resistance to shock loads, resistance to tearing, puncturing and abrasion, low apparent density, good heat insulation and water vapour permeability. They also include mouldability, resistance to wind and liquid water, and an ability to be stretched and compressed without distorting the surface [1].

Cattle hide is made up of a few layers (Figure 1, left). Epidermis is a thin outer layer, consisting of: the grain, the outermost surface of the hide, comprised of tight, dense fibres; and the grain and corium junction, where the tight, other layer of the leather blends into the looser fibres of the corium. Dermis (or corium) is a layer within cattle hides that is comprised mainly of collagen fibres. These are looser and more open than in the grain leather. The corium is usually the thickest layer within hide. Thus, after splitting a hide, parts of the corium might be present in either top grain or genuine leather products. The subcutaneous fatty layer (or the flesh) is the layer of the hide that consists mainly of muscle and fatty tissues [2, 3].

The hide of mature cattle is generally between 4 and 6 mm thick. The grain layer occupies about one sixth the total thickness. The hairs are straight, relatively coarse and spaced equidistant through the grain layer. The corium fibre bundles are relatively large (0.1 mm in diameter) and interweave at a fairly high angle relative to the surface. Such a hide is highly suited for sole leather, harness, saddlery, or mechanical belting leather but is far too thick for shoe uppers unless it is split into two layers. The upper or outer layer consisting of the grain layer and part of the underlying corium can be split to 1 mm thick for upholstery leather or from 1.3 to 2 mm for the shoe uppers [4].

Leather quality and properties vary based on from where in the hide the final leather comes from. When considering grades and leather quality, it is key to understand how the leather is prepared, cut and finished. Therefore, when refer to the way the leather has been split and surface treated than distinguish following grades (Figure 1, right):

- Full grain leather,
- Top grain leather,
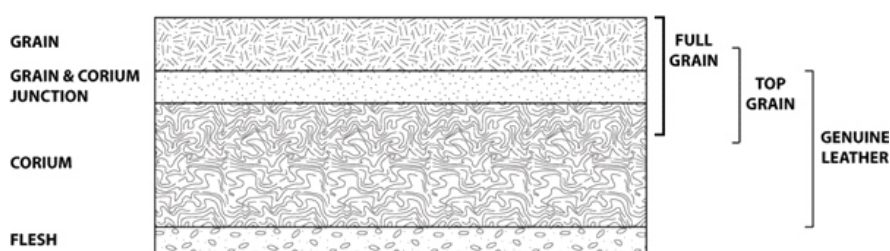- Genuine leather (corrected leather),
- Split grain leather.

Full grain leather cut consisting of the grain layer and the part of the underlying corium and refers to the strongest and most durable part of the cattle hide, which is just below the hair and has not been sanded or buffed to remove any imperfections, that means it displays the more natural characteristics of leather. The grain has densely packed and tightly interlinked collagen fibres that are finer. This results in a surface that is strong, durable, and can withstand tough use. This makes it good for saddlery, footwear and furniture. Top grain leather cut is very similar to full grain, except that it has the very top layer sanded

Figure 1. Cattle hide cross-section (left) and types of leather cuts grades (right) [2]

and/or buffed to remove imperfections and irregularities in the finish. Given its softness and flexibility, it is often used in high leather goods, including handbags, wallets and shoes. Genuine leather can come from any layer of the hide and

undergoes treatment to the surface to provide more uniform appearance. It can be sanded or buffed, then dyed or stamped/embossed. Split grain leather is a layered cut of leather from within the lower levels of the top grain area of the hide. It is usually a lower layer of the hide, above the flesh [2,5].

The strength of the full grain leather is dependent not only on its total thickness but also on the age of the animal and on the proportion that is corium tissue and the frequency with which the corium fibres interweave and cross over each other, a prerequisite for strength. The leather prepared from a young calfskin will have a grain layer of about 0.16 mm deep and the fineness of the corium fibres permits frequent interweaving through the corium. In the full grain leather prepared from mature cattle hide may have grain layer as deep as 0.6 mm. The large size of the corium fibres affects the frequency with which they can interweave in the remaining layer of corium tissue [3, 4].

Three-dimensional interweaved fibrous structure is not random throughout the leather. There is, parallel to the grain surface, a predominating direction in which the majority of the fibres run (Figure 2). This directional run profoundly affects the physical and mechanical properties of the leather. It is well known that the strength of the leather is greater and the elongation less in the direction parallel with the main run of the fibres.
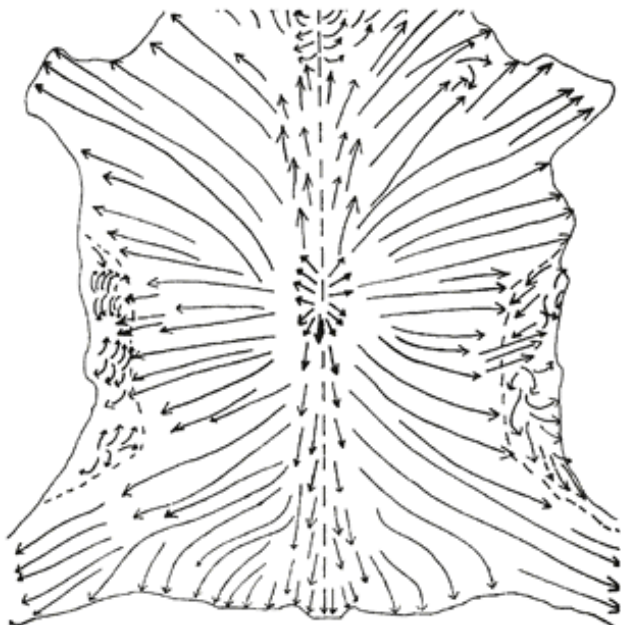

Figure 2. Direction of fibre run through the hide [4]

Leather properties changes with sampling location, depending on variation present in the leather interweaved fibrous structure. Along the line of the backbone the leather is thickest and the natural fibre networks most compact and dense. In the central bend region, which originally covered the back of the cattle, the fibrous structure is particularly compact with the interweaving at a high angle. In the belly region, the fibre networks is looser with fibre bundles running at a far lower angle of weave. These structural differences result in the leather in the belly region being weaker, softer and more stretchable [4]. Therefore, some parts of the same leather have different properties.

Leather quality is also affected by tanning and finishing processes utilized during production. The process of making full grain leather features three main stages: preparation, tanning and crusting. Crusting process is when the leather is thinned, tanned again and lubricated. Colouring process often comes in, but the main aim of crusting is to dry and soften the leathers. A fourth step may also be added where the leather is given a surface coating or finish (oiling, brushing, padding, spraying, buffing, embossing and glazing). Full grain leather, however, sometimes will skip this stage as it is not needed. Instead finishing, this leather will only go through an ironing process, which will use varying degrees of pressure and heat until the desired sheen is obtained [1, 6 - 8].

Although the tanner is bound by the natural structure of the hide, his skill lies in bringing about, by chemical and mechanical processing, limited

changes to the structure in order to produce a range of leathers with differing properties. If in the final dry leather processing allows fine spaces to remain between the fibrils and between fibre bundles than the leather will have a full, soft and flexible handle. Conversely if the processing causes the fibrils and fibres to adhere on drying, then the leather will be firmer and far less flexible [4, 9].

Depending on the selection of tanning agents, vegetable, mineral and synthetic tanning agents are most commonly used, as well as their different combinations. The type of the tanning material used also influence leather properties [10]. Chrome tanned leather has better physical and mechanical properties than vegetable tanned leather. Vegetable and synthetic tanned leather compared to chrome tanned leather contains besides more bounded tanning substances, unbound non-tanning substance also, they are heavier and contained thicker fibres [11]. Chrome-tanned leather is highly versatile, largely due to the low level of tanning agent needed to achieve the desired stability. Waste chrome from leather manufacturing, however, poses a significant disposal problem.

It is known, that big difference existing in the dimensional stability of chrome tanned leathers and chrome free leathers, and that leather differs in its susceptibility against heat and water depending on the type of tanning and the climate exposed [12, 13], which also significantly affects both physical and mechanical properties.

Therefore, with the purpose of analysing the influence of the leather processing level, and sampling location on their quality, in this paper the physical and mechanical properties of differently tanned finished and non-finished cattle full grain leathers, sampled from the bend, shoulder and belly of side leather cuts, were evaluated and their applicability assessed.

2. Experimental
2.1. Materials

The investigation was carried out on four cattle full grain leather samples for footwear uppers:

- L1 – chrome free, synthetic tanned and re-tanned, drum dyed in cyan, waterproofed and antimicrobial treated, slightly lubricated, vacuum dried, stretched and softened leather. Three side of non-finished leather cuts from one batch (L1-1 to L1-3) were tested.

- L2 - chrome free, synthetic tanned and re-tanned, antimicrobial treated, slightly lubricated, vacuum dried, stretched and softened, lining leather of surface treated with slightly beige pigmented casein and polyurethane polymerization binders. Two side of finished leather cuts from one batch (L2-1 and L2-2) were tested.

- L3 – chromium tanned and re-tanned, drum dyed in black, waterproofed and antimicrobial treated, slightly lubricated, vacuum dried, stretched and softened leather. Three side of non-finished leather cuts from one batch (L3-1 to L3-3) were tested.

- L4 - chromium tanned and re-tanned, waterproofed, slightly lubricated, vacuum dried, stretched and softened wet blue leather. Three side of non-finished leather cuts from one batch (L4-1 to L4-3) were tested.

2.2. Methods

After the sampling of bend (Bd), shoulder (Sh) and belly (Bl) from each side leather cut according to the EN ISO 2418 [14] (Figure 3) and conditioning according to the EN ISO 2419 [15] at temperature: 23 ± 2 °C and air relative humidity: 50 ± 5%, leather quality was assessed by determination of the following physical and mechanical properties:

- Leather thickness according to the EN ISO 2589 [16] using thickness gauge model 2000-U (Richard Hess MBV GmbH, Germany) with circular pressure foot of diameter 10 mm under a specified pressure of 49,1 kPa. Five measurement were taken, distributed across the sample and results obtained expressed as the arithmetic mean and range to the nearest 0.01 mm.

- Leather apparent density and mass per unit area according to the EN ISO 2420 [17]. The principle consists in an accurate measurement of the thickness and diameter of a disk of leather and calculation of the apparent density by dividing the mass by the volume, as well as mass per unit area by dividing the mass by the area. Used apparatus consists of steel press knife, thickness gauge, balance (+/- 0,001 g) and vernier callipers for measuring diameter. From the sample three test pieces were cut and results obtained expressed as the arithmetic

mean and range to the nearest 0.001 mm.

The apparent density, Da, in kg/m3 were calculated using equation 1, and the mass per unit area, ma, in g/m2 were calculated using equation 2:

$$D_a = \frac{1{,}273 \cdot 10^6 \cdot m}{t \cdot d^2} \qquad (1)$$

$$m_a = \frac{1{,}273 \cdot 10^6 \cdot m}{d^2} \qquad (2)$$

where:

t - is the mean thickness of the test piece, in mm,

d - is the mean diameter of the test piece, in mm,

m - is the mass of the test piece, in g.

- Leather tensile strength and percentage elongation at break according to the EN ISO 3376 [18]. From the sample, six test pieces were cut by applying a press knife in standard dimensions to the grain surface - three test pieces with the longer side parallel to the backbone and three test pieces with the longer sides perpendicular to the backbone. The width of each test piece was measured using vernier callipers, and thickness in accordance with EN ISO 2589. Breaking (highest) force, F, in N, and percentage elongation at break, Eb, were measured using strength tester Tensolab 3000 (Mesdan S.p.A., Italy) with gauge length of 50 mm and elongation rate of 100 mm/min, and the tensile strength, Tn, in MPa calculated using equation 3:

$$T_n = \frac{F}{w \cdot t} \qquad (3)$$

where:

F - is the highest force recorded, in N,

w - is the mean width of the test piece, in mm,

t - is the mean thickness of the test piece, in mm.

The test results include the mean breaking force, percentage elongation at break and tensile strength of the test samples calculated for the test pieces with the longer edge cut parallel to the backbone and perpendicular to the backbone, as well as the average values calculated for both directions.
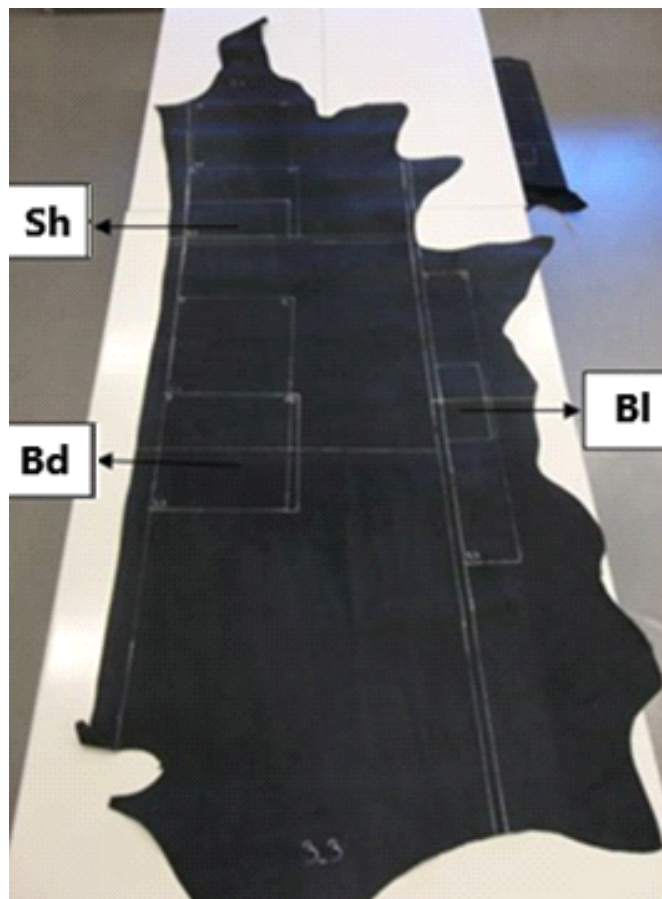

Figure 3. Sampling locations for bends (Bd), shoulders (Sh) and bellies (Bl) of full grain leather L3 side [19]

3. Results and discussion

Results obtained by investigation of differently tanned finished and non-finished cattle full grain leathers, sampled from the bend, shoulder and belly of side leather cuts, are presented in Tables 1 – 7 and Figures 4 - 9.

3.1. Leather physical properties

Values of thickness, mass per unit area and apparent density calculated for sampled areas of each tested leather side cut separately, and as an average values for all side leather cuts from one batch of leather samples L1 – L4 were presented in Tables 1 – 3. The influence of sampling location, type of tanning agent used and the leather processing level on the results obtained were analised.

Table 1. Thickness of full grain leather samples (L1 - L4) calculated for bends (Bd), shoulders (Sh) and bellies (Bl) of each leather cut (Th1 - Th3) as an arithmetic mean of five measurements, alongside with average values calculated for each sampled area of all leather cuts from one batch (Th) with corresponding coefficient of variation (CV)

Leather sample	Sampling location	Thickness				
		T_{h1} (mm)	T_{h2} (mm)	T_{h3} (mm)	T_h (mm)	CV (%)
L1	Bd	2.14	2.18	2.28	2.20	2.68
	Sh	2.06	2.06	2.03	2.05	0.58
	Bl	1.98	1.85	1.98	1.93	3.26
L2	Bd	1.30	1.23	-	1.27	2.96
	Sh	1.33	1.28	-	1.30	1.63
	Bl	1.25	1.22	-	1.24	1.21
L3	Bd	1.57	1.72	1.62	1.64	3.66
	Sh	1.65	1.71	1.54	1.63	4.26
	Bl	1.73	1.64	1.79	1.72	3.48
L4	Bd	1.34	1.17	1.46	1.33	8.97
	Sh	1.27	1.10	1.31	1.23	7.27
	Bl	1.25	1.05	1.41	1.24	11.91

Table 2. Mass per unit area of full grain leather samples (L1 - L4) calculated for bends (Bd), shoulders (Sh) and bellies (Bl) of each leather cut (ma1 - ma3) as an arithmetic mean of three measurements, alongside with average values calculated for each sampled area of all leather cuts from one batch (ma) with corresponding coefficient of variation (CV)

Leather sample	Sampling location	Mass per unit area				
		m_{a1} (g/m²)	m_{a2} (g/m²)	m_{a3} (g/m²)	m_a (g/m²)	CV (%)
L1	Bd	1554.331	1574.344	1588.148	1572.275	0.88
	Sh	1544.844	1541.900	1499.195	1528.646	1.36
	Bl	1369.503	1360.085	1324.861	1351.483	1.42
L2	Bd	958.960	929.489	-	944.224	1.56
	Sh	1017.776	975.343	-	996.559	2.13
	Bl	907.471	870.106	-	888.789	2.10
L3	Bd	1201.865	1329.396	1240.548	1257.270	4.25
	Sh	1222.031	1326.836	1199.259	1249.376	4.45
	Bl	1345.319	1264.855	1347.329	1319.168	2.91
L4	Bd	980.135	874.290	1024.463	959.629	6.56
	Sh	957.417	864.909	958.026	926.784	4.72
	Bl	948.131	701.278	977.678	875.696	14.15

Table 3. Apparent density of full grain leather samples (L1 - L4) calculated for bends (Bd), shoulders (Sh) and bellies (Bl) of each leather cut (Da1 - Da3) as an arithmetic mean of three measurements, alongside with average values calculated for each sampled area of all leather cuts from one batch (Da) with corresponding coefficient of variation (CV)

Leather sample	Sampling location	Apparent density				
		D_{a1} (kg/m³)	D_{a2} (kg/m³)	D_{a3} (kg/m³)	D_a (kg/m³)	CV (%)
L1	Bd	727.173	722.176	697.321	715.557	1.82
	Sh	750.836	749.405	737.611	745.951	0.79
	Bl	692.543	737.173	669.122	699.613	4.03
L2	Bd	736.246	757.221	-	746.733	1.40
	Sh	768.133	760.501	-	764.317	0.50
	Bl	724.527	711.744	-	718.135	0.89
L3	Bd	765.519	775.158	764.590	768.423	0.62
	Sh	740.625	777.064	778.740	765.476	2.30
	Bl	777.641	771.253	754.806	767.900	1.25
L4	Bd	730.082	745.663	700.487	725.411	2.58
	Sh	756.852	784.498	731.318	757.556	2.87
	Bl	761.551	667.884	693.389	707.608	5.59

With the purpose of easier analysis of obtained results tracebility, average results of thickness, mass per unit area and apparent density of leather samples L1 – L4 calculated for each sampled area of all side leather cuts from one batch alongside with coefficient of variation were presented separately in Figures 4 - 6.

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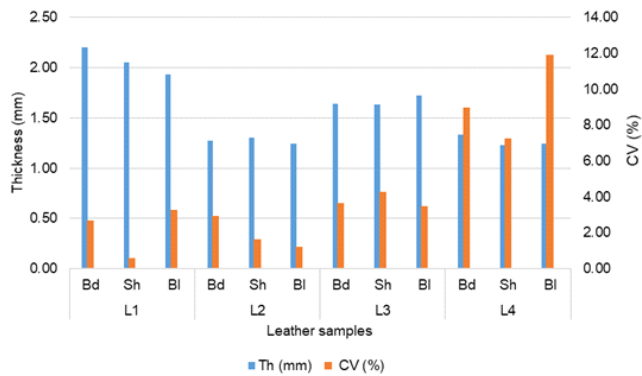
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Figure 4. Average thickness of full grain leather samples (L1 - L4) calculated for each sampled area of all side leather cuts from one batch - bends (Bd), shoulders (Sh) and bellies (Bl) with corresponding coefficient of variation (CV)
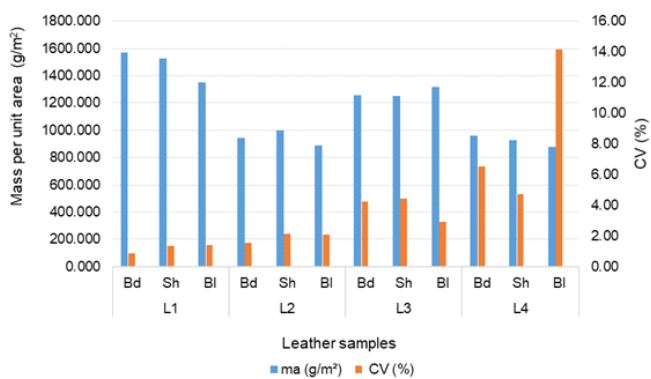

Figure 5. Average mass per unit area of full grain leather samples (L1 - L4) calculated for each sampled area of all side leather cuts from one batch - bends (Bd), shoulders (Sh) and bellies (Bl) with corresponding coefficient of variation (CV)
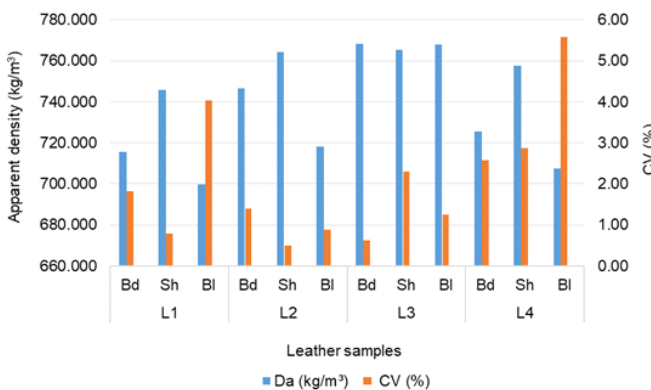

Figure 6. Average apparent density of full grain leather samples (L1 - L4) calculated for each sampled area of all side leather cuts from one batch - bends (Bd), shoulders (Sh) and bellies (Bl) with corresponding coefficient of variation (CV)

By evaluating the obtained results of tested leather samples (L1 – L4) thickness and mass per unit area shown in Tables 1 and 2, sorted by certain leather side cuts and with a given average results calculated of all leather side cuts from one batch, the following was determined:

• Thicker leathers, L1 (synthetic tanned, chrome free basically dyed in cyan and waterproofed full grain leather) and L3 (chromium tanned, basically dyed in black and waterproofed full grain leather), intended for making of the outer parts of the footwear uppers, are also heavier and therefore of larger mass per unit area.

• Lining leathers, L2 (synthetic tanned, chrome free full grain leather, surface treated with slightly beige pigmented casein and polyurethane polymerization binders) and L4 (chromium tanned and waterproofed wet blue full grain leather), intended for making of the inner parts of the footwear uppers, are thinner, lighter, and at the same time of lower mass per unit area.

• Tracebility of average results determined for the same kind of leathers

samples (L1 – L4) is clearly visible in Figures 4 and 5.

Bends (Bd), the central part of leather back, are characterized by their even thickness, tightness, evenly and densely intertwined leather tissue (there is the densest tangle of collagen fibres that are laid almost vertically). Shoulders, are often thicker than bends, but not necessarily stronger. The uniformity of its structure is partially disrupted by the presence of pores in which fat was retained during the life of the cattle. It has natural wrinkles and the orientation of collagen fibres that is not vertical but slightly oblique. Bellies (Bl) are, in general, thinner and softer, with sparser intertwined tissue fibres and in overall lower quality (orientation of collagen fibres is nearly horizontal) [20]. In this study, no significant differences in the obtained results of leather thickness, sampled from the bends and shoulders were found, which indicates the high quality of the leathers tested. In general, tested samples from the belly of the leather cuts were thinner, lighter and more uneven in structure. This is confirmed by the results shown in Tables 1 and 2, and Figures 4 and 5. Higher coefficient of variation was observed in L4 leather samples, that was caused by a significant deviation of the mass per unit area and thickness values within the same batch, and were especially noticeable in the leather sampled from the belly location.

Belly leather samples are, in general, also of less apparent density. A relatively large coefficient of variation is found for apparent density within the leather side cuts, even for the same leather type. That is especially noticeable in L1 and L4 leather samples and indicates high variability of tested property. Method used is designed to determine the apparent density from their area and thickness measured with constant degree of loading. Therefore, apparent (bulk) density, weight of a definite volume of leather, indicates the overall fullness, density and compactness of the structure of tested leather samples. Regardless of the leather type, in samples sampled from the shoulder of leather cuts, higher values of apparent density were determined (Table 3 and Figure 6). This can be explained by the fact that during the processing, the space and pores originally occupied by water and fat is slowly squeezed and decreased driven by an internal pressure release causing the materials to shrink.

By evaluation of the apparent density of thicker chromium tanned full grain leather L3 with the thicker chrome free synthetic tanned full grain leather L1, significantly higher values of apparent density were observed at chromium tanned full grain leather L3 (Fig. 6), indicating a significantly higher compactness and better crosslinking of the fibrillar leather structure. This is possible to explain by a different chemistry of tanning materials used and different reaction mechanism of the chrome and synthetic tanning agents. Tanning agents used have different chemical structure and composition. Their mutual effect is to bond collagen fibres, and to ensure leather resistance to external influences with the purpose of achieving the final product of high quality [11, 21]. The reaction between the chrome tanning material and the collagen molecule occurs at ionised carboxy groups. It has been generally assumed in leather science that the reaction which determines the powerful tanning effect and high hydrothermal stability conferred by chromium ions, is through crosslinking at the carboxylate side chains of collagen. As, many molecules of collagen pack together to form the fibril, the stability of the fibre bundles depends on crosslinks formed between adjacent molecules and fibrils, i.e. inter-molecule and inter-fibril bonding. When used synthetic tanning agent, where tanning compounds can interact strongly with the amino side chains of collagen, reaction occurs primarily at amino groups of collagen molecule. In this way, reaction promoting penetration through the leather cross-section. However, the crosslinking is relatively inefficient [10].

When compared the apparent density values of synthetic tanned leathers L1 and L2 (Figure 6), significantly higher apparent density values were found in L2 leather samples, which is associated with the structure of the processed leather grain surface. Namely, although synthetic tanned full grain leather L2 is not waterproofed, their surface was finished with casein and polyurethane polymerization binders.

3.2. Leather mechanical properties

Breaking force, percentage elongation at break and tensile strength of leather samples L1 – L4 determined for all sampled areas of each tested leather side cut separately, were presented in Tables 4 – 7. For this purpose, arithmetic mean of - three measurements for the test pieces with the longer side parallel to the backbone, three measurements for the test pieces with the longer side perpendicular to the backbone, and six measurements for both directions were calculated.

The average values of breaking force, percentage elongation at break and

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tensile strength of leather samples L1 – L4 for each sampled area of all tested side leather cuts from one batch alongside with coefficient of variation calculated for the direction parallel to the backbone and perpendicular to the backbone, were presented in Figures 7 – 9. The influence of sampling location, type of tanning agent used and the leather processing level on the results obtained were analised.

Table 4. Breaking force, breaking elongation and tensile strength of full grain leather sample L1 calculated for bends (Bd), shoulders (Sh) and bellies (Bl) for each leather cut (L1-1 to L1-3) as an arithmetic mean for the direction parallel to the backbone (↑), perpendicular to the backbone (→) and the mean of these two tests

Leather sample	Sampling location	Breaking force			Breaking elongation			Tensile strength		
		F_1 (N)	F_2 (N)	F_3 (N)	E_{b1} (%)	E_{b2} (%)	E_{b3} (%)	T_{n1} (MPa)	T_{n2} (MPa)	T_{n3} (MPa)
L₁	Bd ↑	421.1	568.1	493.2	80.07	83.20	91.06	19.41	25.82	22.12
	Bd→	304.3	403.4	319.7	107.53	108.40	109.40	14.15	18.50	14.34
	Bd mean	362.7	485.8	406.5	93.80	95.80	100.23	16.78	22.16	18.23
	Sh↑	457.3	367.7	449.2	73.06	70.26	69.26	23.82	19.05	23.27
	Sh→	404.6	340.6	345.4	84.53	71.06	89.33	21.29	17.65	17.62
	Sh mean	431.0	354.2	397.3	78.80	70.66	79.30	22.56	18.35	20.45
	Bl↑	200.8	439.8	481.3	80.40	84.87	70.13	10.24	23.65	26.59
	Bl→	378.9	404.1	315.0	84.60	95.60	115.33	19.33	21.84	17.50
	Bl mean	289.9	422.0	398.2	82.50	90.24	92.73	14.79	22.74	22.05

Table 5. Breaking force, breaking elongation and tensile strength of full grain leather sample L2 calculated for bends (Bd), shoulders (Sh) and bellies (Bl) for each leather cut (L2-1 to L2-2) as an arithmetic mean for the direction parallel to the backbone (↑), perpendicular to the backbone (→) and the mean of these two tests

Leather sample	Sampling location	Breaking force		Breaking elongation		Tensile strength	
		F_1 (N)	F_2 (N)	E_{b1} (%)	E_{b2} (%)	T_{n1} (MPa)	T_{n2} (MPa)
L₂	Bd ↑	212.7	316.8	80.13	62.47	17.73	25.14
	Bd→	143.1	200.8	82.47	104.47	12.03	16.06
	Bd mean	177.9	258.8	81.30	83.47	14.88	20.60
	Sh↑	199.3	327.0	72.40	66.60	14.55	25.15
	Sh→	281.7	263.7	92.73	97.53	20.87	20.60
	Sh mean	240.5	295.4	82.57	82.07	17.71	22.88
	Bl↑	242.8	189.9	75.93	59.60	21.68	15.96
	Bl→	205.2	177.3	94.80	100.80	18.32	14.90
	Bl mean	224.0	183.6	85.37	80.20	20.00	15.43

Table 6. Breaking force, breaking elongation and tensile strength of full grain leather sample L3 calculated for bends (Bd), shoulders (Sh) and bellies (Bl) for each leather cut (L3-1 to L3-3) as an arithmetic mean for the direction parallel to the backbone (↑), perpendicular to the backbone (→) and the mean of these two tests

Leather sample	Sampling location	Breaking force			Breaking elongation			Tensile strength		
		F_1 (N)	F_2 (N)	F_3 (N)	E_{b1} (%)	E_{b2} (%)	E_{b3} (%)	T_{n1} (MPa)	T_{n2} (MPa)	T_{n3} (MPa)
L₃	Bd ↑	324.2	303.0	452.60	56.66	55.80	54.00	21.05	20.07	29.20
	Bd→	167.8	202.1	221.60	60.33	60.93	57.46	10.83	13.04	14.21
	Bd mean	246.0	252.6	337.1	58.50	58.37	55.73	15.94	16.55	21.70
	Sh↑	299.3	274.6	485.00	45.66	48.33	43.20	19.06	18.68	32.77
	Sh→	282.9	321.5	214.40	58.93	57.47	61.93	18.02	21.58	14.79
	Sh mean	291.1	298.1	349.7	52.30	52.90	52.57	18.54	20.13	23.78
	Bl↑	378.4	422.7	344.2	50.66	59.73	37.00	22.00	23.75	22.06
	Bl→	191.5	140.1	193.0	71.13	71.26	55.80	11.47	8.19	12.22
	Bl mean	285.0	281.4	268.6	60.90	65.50	46.40	16.73	15.97	17.14

Table 7. Breaking force, breaking elongation and tensile strength of full grain leather sample L4 calculated for bends (Bd), shoulders (Sh) and bellies (Bl) for each leather cut (L4-1 to L4-3) as an arithmetic mean for the direction parallel to the backbone (↑), perpendicular to the backbone (→) and the mean of these two tests

Leather sample	Sampling location	Breaking force			Breaking elongation			Tensile strength		
		F_1 (N)	F_2 (N)	F_3 (N)	E_{b1} (%)	E_{b2} (%)	E_{b3} (%)	T_{n1} (MPa)	T_{n2} (MPa)	T_{n3} (MPa)
L₄	Bd ↑	291.5	233.0	223.9	66.60	50.53	82.20	22.60	19.75	17.09
	Bd→	140.5	268.0	165.1	72.00	43.86	82.86	10.81	22.52	12.70
	Bd mean	216.0	250.5	194.5	69.30	47.20	82.53	16.70	21.13	14.90
	Sh↑	233.0	236.2	197.9	47.93	54.13	67.86	19.10	20.19	14.34
	Sh→	172.5	168.7	240.9	83.33	66.85	62.66	14.14	14.18	17.33
	Sh mean	202.8	202.5	219.4	65.63	60.49	65.26	16.62	17.18	15.84
	Bl↑	200.9	160.9	250.2	74.73	51.20	52.00	16.88	16.59	19.86
	Bl→	150.5	175.0	202.5	61.80	42.33	134.00	12.65	17.50	15.82
	Bl mean	175.7	168.0	226.4	68.27	46.77	93.00	14.76	17.04	17.84

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By evaluating the obtained results of tested leather samples (L1 – L4) breaking force, breaking elongation and tensile strength shown in Tables 4 - 7, sorted by certain leather side cuts and with a given average results calculated for the direction parallel to the backbone, perpendicular to the backbone and the mean of these two tests of every sampling location, the following was determined:

- When measuring the mechanical properties of the leather via breaking force, breaking elongation and tensile strength, it is standard practice to take the mean of two tests, one made in the direction parallel to the backbone, the other at right angles. As the directional run of collagen fibres profoundly affects the mechanical properties of the final leather, the directional run also governs the way in which leather is cut in use when the footwear uppers are cut, toe to heel, in the line with the backbone. Therefore, by expressing the mean of values determined for both directions, which are generally different, deviation in quality of specific parts of the leather sampled from different areas are difficult to notice, and applicability for certain purpose is more difficult to assess.

For this reason, in this study, the analysis of the average values of breaking force, breaking elongation and tensile strength, calculated for each sampled area of the leather samples (L1 – L4) from one batch, in the direction parallel to the backbone and perpendicular to the backbone was caried out and presented in Figures 7 – 9.

From the results shown in Figure 7, it can be seen that values of breaking force determined are in average higher in the direction parallel to the backbone for all leather samples. Thicker and heavier leathers L1 and L3, intended for making of the outer parts of the footwear uppers, at the same time show higher values of breaking force. Tracebility is clearly visible by comparing the results shown in the Figures 4, 5 and 7. In general, average values of breaking force determined for bends and shoulders are higher, and the bellies are weaker. The difference are present, but not markedly large.

The results presented in Figure 8 indicate that values of breaking elongation determined in all tested leather samples are higher in the direction perpendicular to the backbone. In general, when compared to the other parts of the leather, average values of breaking elongation determined for bellies in the direction perpendicular to the backbone are higher. However, it is interesting that in thicker leader samples L1 and L3 (Figs. 8a and 8c) the highest values of breaking elongation were found in bends (108.44% and 93.47% respectively). Comparison of leather samples tanned with the same tanning agent shows higher average values of breaking elongation in synthetic tanned leathers L1 and L2 in relation to the cromium tanned leathers L3 and L4 (Figs. 8a and 8b vs 8c and 8d). At the same time, in average, thinner chromium tanned leather L4 has higher extensibility when compared with thicker leather L3 (Figs. 8d and 8c). In thinner synthetic tanned, but surface polyurethane impregnated, finished leather samples L2 (Figure 8b) were found lower values of breaking elongation when compared with thicker leather L1 (Figure 8a). Therefore, from the obtained results is evident that the percentage elongation at break of all leather samples is also affected by their apparent density (presented in Figure 6) and compactness of the cross-linked structure. Higher coefficient of variation was observed in L4 leather samples, that was caused by a significant variation within the same batch, and were especially noticeable in the leather sampled from the belly location.

From the results shown in Figure 9, it can be seen that values of breaking strength calculated (based on values of breaking force, mean width of the test piece (ca 10 mm) and mean thickness of the test piece) are in average higher in the direction parallel to the backbone for all leather samples. In this study, no significant differences in the obtained results of leather breaking strength, sampled from the bends, shoulders and belies were found in the direction parallel to the backbone within the same leather sample (L1 – L4). That indicates the high quality of the leathers tested. Thicker leathers L1 (of thickness in range from 1.93mm to 2.20mm) and L3 (of thickness in range from 1.64mm to 1.72mm), at the same time show higher values of breaking strength. But, at the same time in average, in thinner chromium tanned leather L3 (Figure 9c) was found higher breaking strength when compared with thicker synthetic tanned leather L1 (Figure 9a) in the direction parallel to the backbone. For thinner differently tanned lining leather samples L2 (of thickness in range from 1.24mm to 1.27mm) and L4 (of thickness in range from 1.24mm to 1.33mm) that is not a case (Figs. 9b vs 9d), which indicates the fact that the thickness of the cattle full grain leather (i.e. the proportion of corium tissue in full thickness) and type of tanning agent used affects the obtained values of breaking strength.
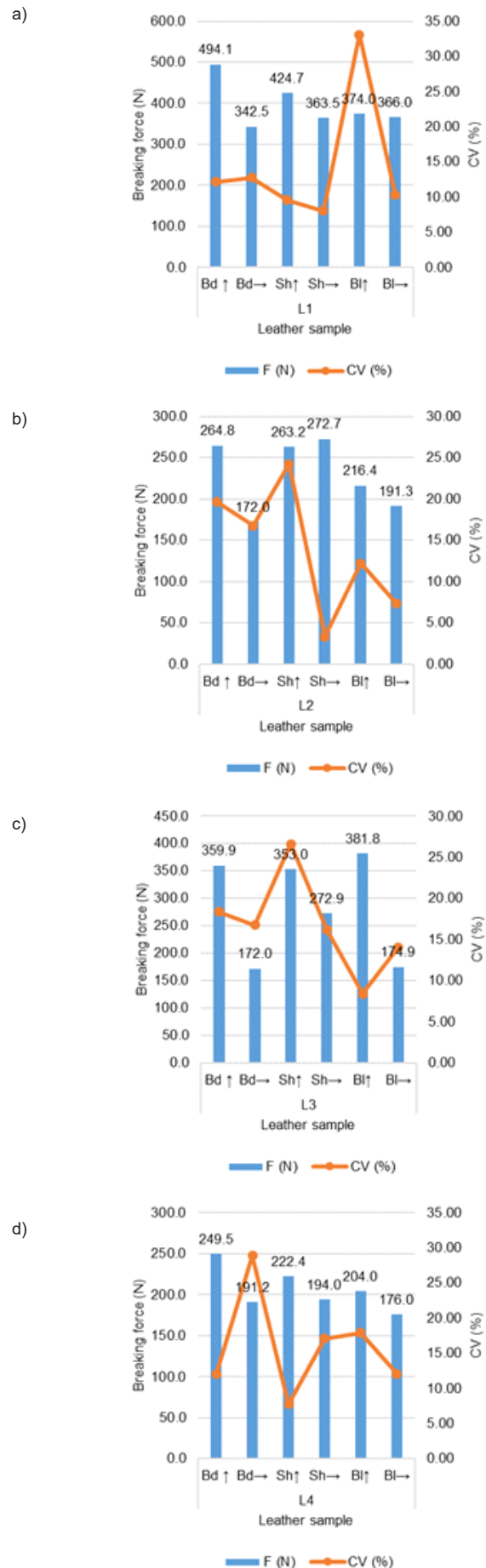
Figure 7. Average values of breaking force of full grain leather samples: a) L1, b) L2, c) L3 and d) L4 determined for each sampled area of all tested side leather cuts from one batch - bends (Bd), shoulders (Sh) and bellies (Bl) with corresponding coefficient of variation (CV) calculated for the direction parallel to the backbone (↑) and perpendicular to the backbone (→)

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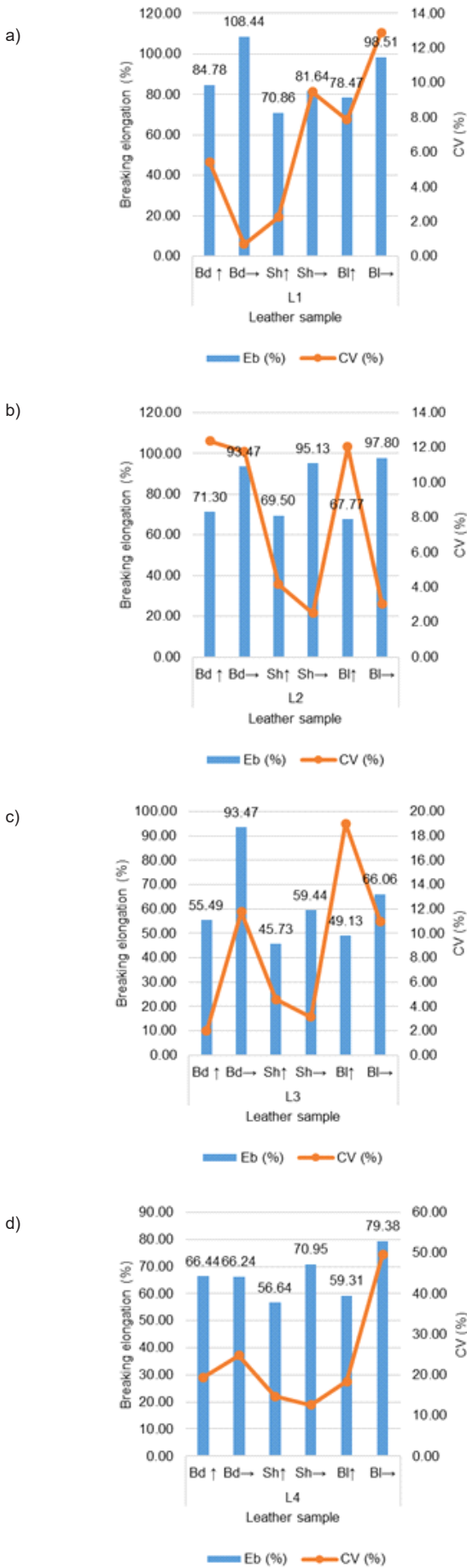
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Figure 8. Average values of breaking elongation of full grain leather samples: a) L1, b) L2, c) L3 and d) L4 determined for each sampled area of all tested side leather cuts from one batch - bends (Bd), shoulders (Sh) and bellies (Bl) with corresponding coefficient of variation (CV) calculated for the direction parallel to the backbone (↑) and perpendicular to the backbone (→)
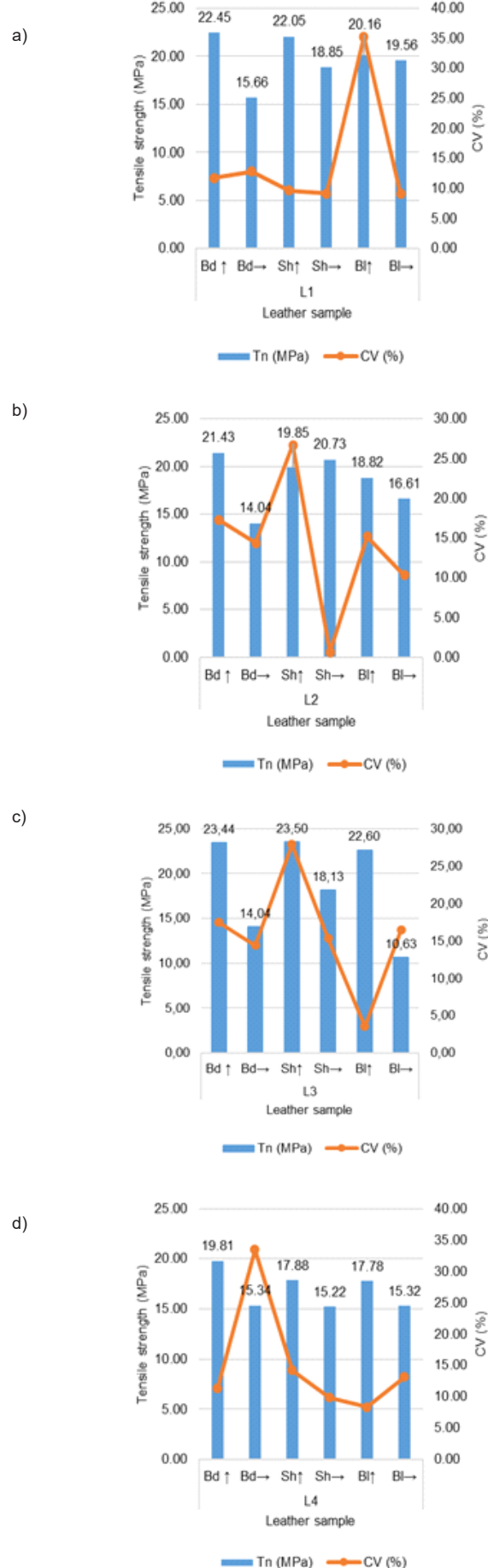
Figure 9. Average values of breaking strength of full grain leather samples: a) L1, b) L2, c) L3 and d) L4 determined for each sampled area of all tested side leather cuts from one batch - bends (Bd), shoulders (Sh) and bellies (Bl) with corresponding coefficient of variation (CV) calculated for the direction parallel to the backbone (↑) and perpendicular to the backbone (→)

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4. Conclusion

In the past, leather was used for every part of the footwear, but today it is largely confined to the upper. Actually, consumers expectation and needs demand development of footwear that integrates fashion and personal desires, as well as real leather quality, that includes appropriate physical, mechanical properties and functional performance barrier effect to water, thermal comfort, and antimicrobial resistance. Full grain leather refers to the strongest and most durable part of the cattle hide, but leather quality changes with sampling location, depending on variation present in the leather fibrous structure. Leather properties are also affected by tanning and finishing processes utilized during production.

According to the analysis of physical and mechanical properties, performed on synthetic and chromium tanned finished and non-finished cattle full grain leathers, intended for making of the outer an inner parts of footwear uppers, sampled from the bend, shoulder and belly it was found that:

- Thicker leathers, intended for making of the outer parts of the footwear uppers, are also heavier and therefore of larger mass per unit area. Lining leathers, intended for making of the inner parts of the footwear uppers, are thinner, lighter, and at the same time of lower mass per unit area. No significant differences in the obtained results of leather thickness, sampled from the bends and shoulders were found, which indicates the high quality of the leathers tested. In general, tested samples from the belly of the leather cuts were thinner, lighter and more uneven in structure.

- Belly leather samples are, in general, also of less apparent density. Regardless of the leather type, in samples sampled from the shoulder of leather cuts, higher values of apparent density were determined. By evaluation of the apparent density of thicker full grain leathers, higher values of apparent density were observed at chromium tanned full grain leather. When compared the apparent density values of synthetic tanned leathers, higher apparent density values were found in L2 leather samples, which is associated with the structure of the processed leather grain surface.

- Values of breaking force determined are in average higher in the direction parallel to the backbone for all leather samples. Thicker and heavier leathers, at the same time show higher values of breaking force. In general, average values of breaking force determined for bends and shoulders are higher, and bellies are weaker.

- Breaking elongation determined in all tested leather samples are higher in the direction perpendicular to the backbone - generally in bellies, but the highest values were found in bends of samples L1 and L3. Higher average values of breaking elongation were found in synthetic tanned leathers when compared with the cromium tanned leathers. The percentage elongation at break of all leather samples is also affected by their thickness and apparent density.

- Values of breaking strength are in average higher in the direction parallel to the backbone for all leather samples. No significant differences in obtained results within the same leather type, sampled from the bends, shoulders and belies were found in the direction parallel to the backbone. That also indicates the high quality of the leathers tested. Thicker leathers show higher values of breaking strength. But, at the same time in average, in thinner chromium tanned leather L3 was found higher breaking strength when compared with thicker synthetic tanned leather L1 in the direction parallel to the backbone. For thinner differently tanned leather samples that is not a case, which indicates the fact that the proportion of corium tissue in full thickness and type of tanning agent used affects the obtained values of breaking strength.

It was concluded that the full grain leather possess different physical and mechanical properties depending on the manufacturing process, sampling location and their macro- and microstructural characteristics. Differences observed in the tested properties of full grain leathers also define their applicability for footwear uppers. They should be especially taken into account when the specific parts of footwear uppers are cut – facing, tongue, collar, upper, quarter or vamp lining. Furthermore, three full grain leathers, used in this study, instead of finishing, is passed only through an ironing process which significantly reduces their production costs.

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