Slit tear resistance of leather used in upholstery manufacturing

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ABSTRACT – REZUMAT

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The paper presents experimental research on the slit tear resistance of leather used for producing upholstery. A finite element analysis is done by simulating the product's behaviour, considering different factors and parameters, and materials are classified according to the normal stress results. The maximum force exerted during the tearing of the specimen has been observed at the SATRA tensile testing machine, with STM 466ST attachment and digital software control. The load at break, the extension at break, Young's Modulus, and the load-distance graphs were registered and the medium values were calculated. The Taguchi method based on orthogonal arrays was used to maximize the material characteristics significant for this type of analysis.

Keywords: *leather for upholstery, slit tear test, Taguchi method, finite element analysis*

Rezistența la sfâșiere a pieilor utilizate la fabricarea tapițeriilor

Lucrarea prezintă cercetări experimentale privind rezistența la sfâșiere a pieilor folosite pentru producerea tapițeriilor. O analiză cu elemente finite a fost făcută prin simularea comportamentului produsului luând în considerare mai mulți factori și parametri, materialele fiind clasificate în funcție de rezultatele tensiunii axiale. A fost observată forța maximă exercitată în timpul ruperii specimenului, folosind aparatul de testare la tracțiune SATRA, cu atașament STM 466ST și control digital prin software. A fost înregistrată forța la rupere, alungirea la rupere, modulul lui Young, precum și graficele încărcare-distanță și au fost calculate valorile medii. A fost utilizată metoda Taguchi bazată pe rețele ortogonale pentru a maximiza caracteristicile materialelor semnificative pentru acest tip de analiză.

Cuvinte-cheie: *piei pentru tapițerii, testul pentru sfâșiere, metoda Taguchi, analiza elementelor finite*

INTRODUCTION

Leather is still one of the most popular types of materials used to make upholstery products. It is a material with multiple uses in daily life due to its properties: vapour permeability, mechanical strength, air permeability, flexibility, and softness [1]. The processed leather must be of good quality, with as few surface defects as possible, and, after tanning, it has to be soft, supple, plastic, evenly painted, without stains, and must not discolour under the action of light [2]. The leather samples selected for the present research are hides types, finished on the exterior, with the natural outer, corrected, and respectively reinforced.

Leather hides contain water, protein, fatty materials and some minerals. The most important for leather making is protein, which consists of several types. The main ones are collagen and keratin. The approximate composition of a leather hide is 64% water, 33% protein (structural proteins: 0.3% elastin, 29% collagen, 2% keratin; 1.7% non-structural protein), 2% fats, 0.5% mineral salt, 0.5 other substances (pigments etc.) [3].

Because in everyday use, bags, backpacks, keys, various gadgets, accessories, and so on are placed on the upholstery pieces, which adds to the actual sitting on it, all this can tear the product. Testing slit tear resistance is very important in choosing materials and determining the final cost of products. The most important physical and chemical properties that material should have (table 1): excellent strength-on-weight ratio, very good tear resistance, and high resistance to environmental degradation [4, 5].

METHOD

Finite Element Analysis (FEA) is a complex numerical method used in various fields to simulate the behaviour of virtual products considering many factors and parameters.

Among the possible simulations can be reproduced the physical-mechanical tests, such as uniaxial and multiaxial tensile test [6, 7], last forming test [8, 9], crack of leather, stitch resistance [10], tear strength [11, 12] and others, necessary for evaluating the physical and mechanical parameters of the materials, including leather, synthetic leather, textiles, used in the upholstery industry.

A 3D design of the sample is done in Delcam PowerShape software. The application chosen to simulate the slit tear resistance on the leather specimen is ANSYS R17.2- Static Structural module. The following working procedure was adopted:

- Import and edit 3D geometry;

Table 1

PHYSICAL AND CHEMICAL PROPERTIES Of DIFFERENT MATERIALS

No.	Test description	Method	Specification		
			cow-hides	goat-hides	pig-hides
1	Water content/ volatile matter (%)	DIN EN ISO 4684	8–15	12–16	12–16
2	pH value	DIN EN ISO 4045	3.5	3.5–4	4
3	Chrome oxide concentration	DIN 5398-2	≤0.1	≤0.1	≤0.1
4	Fat content (%)	DIN EN ISO 4048	7–12	7–12	7–12
5	Tensile strength (N)	DIN EN ISO 3376	≥120	Min. 80	Min. 80
6	Percentage extension (%)	DIN EN ISO 3376	40–60	35–60	35–60
7	Stitch tear resistance (N)	DIN EN ISO 23910	≥80	≥60	≥60
8	Water vapour permeability (mg/cm^2)	DIN EN ISO 14268	≥1.0	2.5	2.5
9	Colour fastness to perspiration of the grain side	DIN EN ISO 105-E04	≥4–5	≥4–5	≥4–5
10	Resistance to water	Water dripped onto the back side rear side, dry at room temperature	Water dripped onto the back side may not result in a colour change or leave traces on the upper side after having dried (at ambient temperature)		
11	FOLDING TEST (72 hrs, at 80°C)	Folding 5 cm wide leather strip (grain side to grain side) and loading the fold with a weight of 2 kg.	No cracks shall be allowed to occur in the finish layer. check with a (6 times) magnifying glass		
12	Adhesive strength of finishing - dry	DIN EN ISO 11644	≥4	≥4	≥4
13	Adhesive strength of finishing - wet	DIN EN ISO 11644	≥1.2	≥1.2	≥1.5
14	Material and substances	PN-1004	Material according to pn-1004. the use of PCP is prohibited, the remaining quantity (e.g. contamination) must be less than 1 mg/kg		
15	Burning behaviour (flammability) (mm/min)	FMVSS 302 / PTL 8501	<100	<100	<100

- Establishing material properties;
- Setting analysis conditions (mesh, contacts, restrictions, loads);
- Setting the parameters to evaluate;
- Solving the model;
- Analysing the results.

Geometry and material properties play an important role in the virtual simulation of the mechanical test. As indicated by the “Standard Test Method for Slit Tear Resistance of Leather, ASTM D 2212”, the leather rectangular specimen has a length of 51 mm and a width of 25.4 mm with a slot in the middle with a side of 20 mm and another one of 5 mm. To the rectangular specimen, was assigned the properties of cow-hides, namely Young's modulus determined experimentally, as presented in table 1. The material is considered to be homogeneous and isotropic. 2 rectangular clamps were inserted on either side of the slot, as presented in figure 1.

A bonded contact with a 0.15 mm trim was established between the clamps and the leather specimen. Also, a standard mechanical dropped mesh with 49500 nodes and 35859 elements was created.

As shown in the standard, while the lower clamp is fixed, the upper clamp moves until the material breaks. Based on these specifications, the model has loaded the ANSYS Static Structural module.

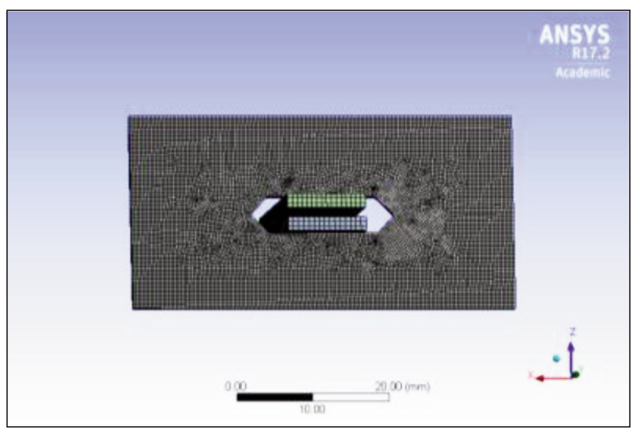


Fig. 1. 3D model for the slit tearing test

RESULTS AND DISCUSSIONS

The Taguchi method was used to determine the experimental plans (Design of Experiments – DOE). The method developed by Genichi Taguchi combines statistical methods with engineering techniques, to improve the quality of manufactured goods, manufacturing processes, or experimental testing.

The method of experimental plans allows rigorous organization of experiments, taking into account a well-defined objective. Through this method, a considerable decrease in the number of experimental attempts is obtained.
3 types of materials were used: cow-hides (1), goat-hides (2), pig-hides (3), with 3 types of thicknesses: 1.5 mm (X), 1.3 mm (Y), 1.1 mm (Z), and 3 different types of finishings: natural (A), corrected (B), reinforced (C).
Using the application Minitab v.16, a matrix of experiments consisting of 9 experimental plans was obtained, as seen in the table below (table 2).

Table 2

MATRIX OF EXPERIMENTS			
Material type	**Thickness**	**Cover**	**Experiment**
1	X	A	P1
1	Y	B	P2
1	Z	C	P3
2	X	B	P4
2	Y	C	P5
2	Z	A	P6
3	X	C	P7
3	Y	A	P8
3	Z	B	P9

Using Ansys, the normal stress (MPa) was evaluated for each experiment, being the stress produced by the perpendicular action of the force acting on the area of the specimen during the double-edged slit tearing test [13].
The formula to calculate average normal stress is force per unit area [14]:

$$\tau = \frac{F}{A} \quad (1)$$

where τ is the normal stress, and F – the force applied. In this case, it is used the maximum force for optimal material combination and A – the cross-sectional area of material with an area perpendicular to the applied force vector.
The simulation (figure 2) shows the distribution of normal stress along with the slot.
In table 3, the experiments are ordered according to the results, from the best to the lowest values

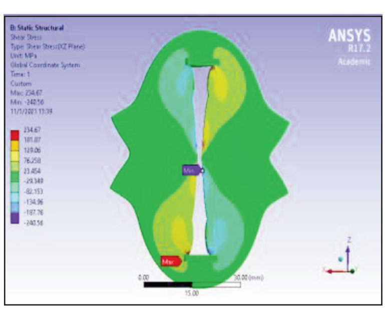


Fig. 2. Normal stress distribution analysis during slit tearing test

Table 3

TABLE OF EXPERIMENTS, ANSYS STATIC STRUCTURAL MODULE	
Experiment	**Normal stress (MPa)**
P1	120.040
P2	107.860
P3	78.124
P8	46.743
P9	45.878
P7	44.536
P4	43.402
P6	32.306
P5	33.260

obtained for the Normal Stress evaluated using FEA. The results of Normal Stress (MPa) show that the optimum material is **P1.**

MODEL VALIDATION

The reliability of Finite Element Analysis was validated by performing physical tests.
The tests were carried out according to the “Standard Test Method for Slit Tear Resistance of Leather, ASTM D 2212”. Other 3 standards were used as reference documents ASTM D 1610 Practice for Conditioning Leather and Leather; Products for Testing; D 1813 Test Method for Measuring Thickness of Leather Test Specimens, D 2209 Test Method for Tensile Strength of Leather.
According to ASTM D 2212, slit tear resistance is the load required to tear the cross-sectional thickness of the leather at a slit cut through the leather by a die or a sharp knife.
This test method is designed to measure the load required to tear leather at a slit cut perpendicular to its surface. It is of particular value in estimating the durability of leather to withstand tearing stresses encountered in the manufacture of upholstered products.
Equipment – SATRA STM 466ST Tensile testing machine attachment.
The specimen dimensions were 25.4 by 51 mm, cut with the long dimension either parallel or perpendicular to the backbone. The specimen cut with the slit tear had a slot of 11 mm long by 4.8 mm wide.
There were used 9 types of leather. All specimens were conditioned as prescribed in ASTM D 1610.
The testing has been done at a loading speed of 100 mm/min ± 20 mm/minute, in conformity with the norm SR EN ISO 3377-2:2016 [15].
After testing the slit tear resistance (figure 3) for the nine types of leather at break, the software of the tensile machine SATRA STM 466ST has registered for each experimental type the load-distance graphics as well as the maximum force at break in N, the load at break in N, the first peak in N, the averages of peaks and troughs in N, the break extension in %, Young's Modulus in N/mm^2. For each experimental plan,

Fig. 3. Slit tear test on SATRA STM 466ST

three slit tests were performed. For an adequate illustration of the characteristics registered at the tensile testing machine STM466, there have been used the medium values correspond to each experimental type (table 4).

Figure 4, *a, b*, and c shows the load-distance graphs for the tested materials tested with SATRA-STM 466 ST apparatus, for three experiments, P3, P5, P9.

The best result for the maximum force was registered for the **P1 experiment**, followed by P2 and P3. These results validate the results obtained previously with FEA.

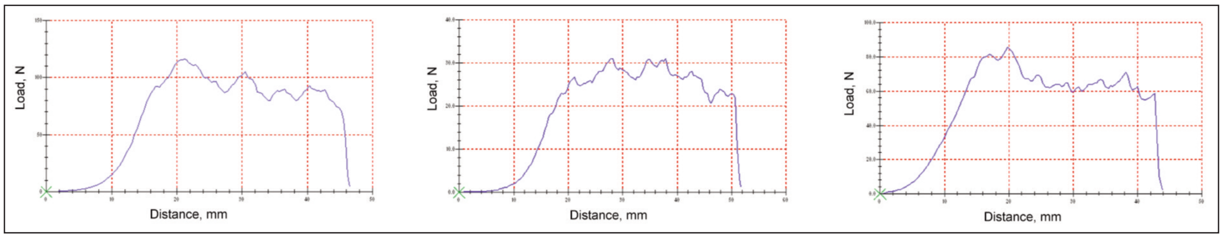
EVALUATION OF MATERIALS USING THE TAGUCHI METHOD

The experimental matrix contains three input variables, all at three levels, as presented in table 5. The choice of the signal factors was required so that the considered process can conclude the expected performance and have the smallest sensitivity to

Table 4

RESULTS OF SLIT TEAR TEST ON SATRA STM 466ST

Experiment	Cycle	Average of peaks and troughs (N)	Break extension (mm)	The first peak (N)	Load at break (N)	Maximum force (N)	Young's modulus, (N/mm^2)
P1	Mean	121.82	49.78	135.87	104.03	142.37	14.55
	Std Dev	2.53	5.19	17.13	13.15	11.59	1.34
	Max	123.47	55.2	154.7	116.5	154.7	14.92
	Min	118.91	44.85	121.2	90.3	131.7	14.24
P2	Mean	116.99	52.47	137.57	88.9	142.30	40.24
	Std Dev	13.47	3.71	5.56	18.47	8.06	5.45
	Max	132.47	56.67	143.8	109.7	149.5	46.53
	Min	107.92	49.67	133.1	74.4	133.6	36.87
P3	Mean	95.38	44.54	105.87	84.87	114.73	26.19
	Std Dev	9.43	1.64	14.94	21.76	10.97	3.12
	Max	105.47	45.5	122	107	124.9	29.12
	Min	86.79	42.65	92.5	63.5	103.1	22.91
P4	Mean	50.19	44.21	49.67	48.57	55.2	14.93
	Std Dev	0.56	0.63	3	1.63	0.53	0.72
	Max	50.56	44.9	52.7	50.4	55.6	15.7
	Min	49.54	43.67	46.7	47.3	54.6	14.28
P5	Mean	25.5	51.92	26.67	22.07	30.63	10.83
	Std Dev	2.46	1.35	0.15	1.1	3.96	1.37
	Max	27.07	52.85	26.8	22.8	34.4	12.32
	Min	22.66	50.38	26.5	20.8	26.5	9.62
P6	Mean	47.03	53.92	51.57	38.67	53	11.15
	Std Dev	2.32	5.75	3.52	2.84	2.71	0.86
	Max	49.67	58.03	55.6	41.9	55.6	12.1
	Min	45.31	47.35	49.1	36.6	50.2	10.43
P7	Mean	50.51	47.22	55.97	47.6	60.43	15.38
	Std Dev	2.42	1.49	7.6	6.7	3.07	1.47
	Max	53.27	48.3	63.7	54.7	63.7	16.45
	Min	48.75	45.53	48.5	41.4	57.6	13.71
P8	Mean	90.86	48.08	91.83	80.83	103.5	36.16
	Std Dev	5.55	5.56	9.19	5.53	3.47	2.61
	Max	94.83	52.67	102	86	105.7	38.55
	Min	84.52	41.9	84.1	75	99.5	33.37
P9	Mean	60.61	44.67	65.67	56.83	72.6	15.67
	Std Dev	7.03	1.92	14.09	7.25	14.17	3.45
	Max	65.88	46.5	81.4	62.9	85.9	19.21
	Min	52.64	42.67	54.2	48.8	57.7	12.32



a *b* *c*

Fig. 4. Load-distance graph: *a* – P3 experiment; *b* – P5 experiment; *c* – P9 experiment

Table 5

SIGNAL FACTORS			
Levels	**Material type**	**Thickness (mm)**	**Finishing type**
1	Cow-hides	1.5	Natural
2	Goat-hides	1.3	Corrected
3	Pig-hides	1.1	Reinforced

noises. The current study targeted the influence of signal parameters on the slit tear resistance of leather for upholstery.

The first three columns of table 6, noted A, B, and C represent the signal factors (material, thickness, and finishing), while the following two, noted N1 and N2 are the noise factors (maximum force and first peak force).

The S/N ratio (signal-to-noise) is a technique used in engineering and science that correlates the signal parameters to the noise parameters (table 7). The aim of applying this technique is to obtain the most advantageous solution of signal parameters that influence the structure so that the S/N ratio is maximized [16, 17]. Also, the standard variation, the mean values, and the coefficients of variation are calculated. The results obtained after the statistical analysis for the S/N ratio are graphically represented in figure 5. To determine the accuracy of the Taguchi model that was given, a normal probability plot was drawn (figure 6). It can be noted that the distribution of the

Table 6

RESULTS OF DOE-TAGUCHI, *L*9 ARRAY									
Experiment	**A**	**B**	**C**	**N1-Maximum force**	**N2-First peak**	**SNRA1**	**STDE1**	**MEAN1**	**CV1**
P1	1	1	1	142.37	135.87	42.8607	4.59619	139.120	0.0330376
P2	1	2	2	142.30	137.57	42.9148	3.34462	139.935	0.0239012
P3	1	3	3	114.73	105.87	40.8305	6.26497	110.300	0.0567993
P4	2	1	2	55.20	49.67	34.3562	3.91030	52.435	0.0745742
P5	2	2	3	30.63	26.67	29.0802	2.80014	28.650	0.0977362
P6	2	3	1	53.00	51.57	34.3651	1.01116	52.285	0.0193394
P7	3	1	3	60.43	55.97	35.2793	3.15370	58.200	0.0541872
P8	3	2	1	103.50	91.83	39.7482	8.25194	97.665	0.0844923
P9	3	3	2	72.60	65.67	36.7612	4.90025	69.135	0.0708794

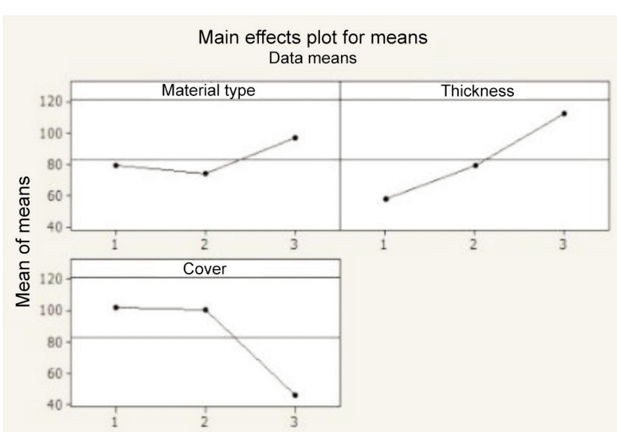


Fig. 5. Main effects plot for means

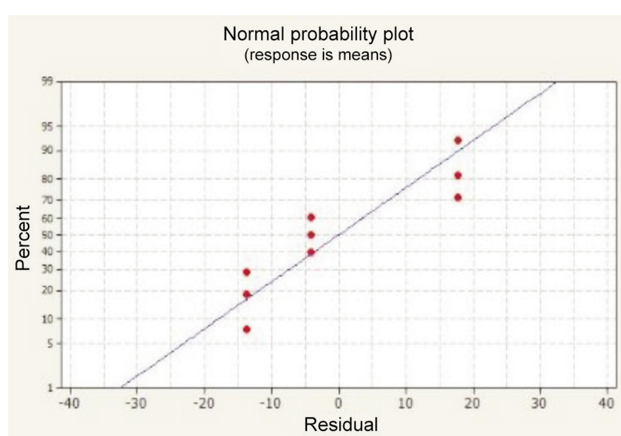


Fig. 6. Normal probability plot for means

residual values reported to the median is close to normal.

The classification of influence level, presented in table 6, is maximum influence – the A factor *A* (material type), followed by finishing, and minimum influence – the B factor (thickness).

The S/N ratio is calculated for every factor level association. The formula for the larger-is-better S/N ratio is:

$$\frac{S}{N} = -10\log\left[\sqrt{y^2}\left(1 + 3s^2 \times \sqrt{y^2}\right)\right] \quad (2)$$

where *S* is the standard deviation, *y* – nominal value, *s* – an average of determined values and *N* – number of runs.

Table 7

RESPONSE TABLE FOR SIGNAL-TO-NOISE RATIOS LARGER IS BETTER			
Level	**A**	**B**	**C**
1	42.20	37.50	38.99
2	32.60	37.25	38.01
3	37.26	37.32	35.06
Delta	9.60	0.25	3.93
Rank	1	3	2

The best association of signal parameters to obtain the higher value for the S/N ratio is A1B1C1*,* representing cow-hides, 1.5 mm thickness, and natural cover (table 7) representing the **P1 experiment.**

CONCLUSIONS

The following conclusions were formed:

- A finite element analysis resulted in normal stress values that offered the possibility of ranking the experiments. FEA is a technique used successfully in many fields, and as this article demonstrates, it can also be used successfully in the field of upholstery production to simulate the behaviour of materials considering many factors and parameters.
- To determine the experimental plans for the rigorous organization of experiments, taking into account a well-defined objective the Taguchi method was used. Through this method, a considerable decrease in the number of experimental attempts is obtained.
- The accuracy of the results obtained by Finite Element Analysis was validated by performing physical tests. Slit tear resistance of leather was performed using SATRA STM 466ST equipment to evaluate the durability of leather encountered in the manufacture of upholstered products, for the nine types of leather at break. There were registered load-distance graphics, as well as the maximum force at break, the load at break, the first peak, the averages of peaks and troughs, the break extension, and Young's Modulus.
- Signal-to-noise ratio from the Taguchi technique was used to obtain the most advantageous solution of parameters that influence the material. By classification of influence level, the best results have been obtained for cow-hides, 1.5 mm thickness, and natural cover.

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