STUDY OF THE ABRASION RESISTANCE IN THE UPHOLSTERY OF AUTOMOBILE SEATS

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Abstract:

The automotive manufacturing industry is a key user of technical textiles. Cars consume a large amount of material, and the textiles are not an exception. The objective of this study is to compare four abrasion testers, which are used for the automobile sector. Previously the test parameters have been determined to make the most precise comparison, and four car seat upholstery structures have been compared. Martindale is the most complex abrasion tester: it generates a movement according to a curve of Lissajous and can test several samples simultaneously for a machine cycle; for this reason, it has been determined that part of the total results variations is attributable to the parameters of the used apparatus and tested structures as well.

Key words:

Abrasion tester, automotive textiles, upholstery, foam.

Introduction

Every middle-size vehicle uses between 12 and 14 Kg of textile products, without including tire cords for pneumatic and fibers which are used in composite materials. The 65% of this quantity is used, approximately, in the interior (40 to 45 m^2 of textile material per car) with a weight between 350 and 450 g/m^2 for the seats upholstery.

Car production development of components, parts, pieces and materials is orientated by the following criteria:

- Comfort
- Functionality
- Safety
- Economy
- Ecology

These criteria also are used for the interior coating textile and keeping in mind that the design of the interior is a differential element in the project of a car.

Car seat is perhaps, the most important part of the interior, it is the first element that the customer appreciates when he/she opens the door to look inside and it is the main interface between person and machine.

Therefore, the comfort is the first criterion that values the customer, specifically psychological comfort - makes reference to the aesthetic aspects - and physiological comfort captured by the view and touch. During the sitting the thermal comfort is evaluated by the “cold-hot” sensation.

Functionality and material safety criteria are captured during use of the vehicle, by means of wear, seat ventilation, the internal environment, ease of care, etc.

All these aspects relate to the technical characteristics of textiles, and the most important are the following:

- Mechanical behaviour: strength resistance, tear, bursting strength, stripes, pilling, abrasion, etc.
- Ageing behaviour: light resistance, colour fastness to light, sweat, rub, etc.
- Physiological behaviour: air permeability and water vapour permeability, thermal resistance.
- Security features: flame resistance, resistance to emission of volatile organic compounds, emission of condensable compounds, formaldehyde emission, amines emission, surface resistance, etc.
- Soiling behaviour: hidrorepellency and oilreppelency.

The most rigorous specifications for coating and upholstery refer to the abrasion, the high temperatures resistance and light resistance (UV).

The economic criteria affect the new manufacturing pieces technologies and adjust the productivity needs and material saving. This can influence tot he customer appropriate price and quality in the market.

Finally, the environmental considerations (reuse, recycled, pollution, etc.) influence to the customers as an integral part of the society, and its economic aspect as well.

Car Seats

Car seats are composed of the following elements:

1. Metal structure.
2. Filling: molded polyurethane foam.
3. Seat cover:
   - Exterior fabric,
   - Foam,
   - Support material (reinforcement material).

Fabric, which is mostly used for the car seats, is polyester with high abrasion resistance, UV light resistance and cleaning facility combined with a reasonable price, but disadvantage is that can not absorb nor transports humidity.

The inner layer of foam, varies from millimetres to 12 mm, and it has function of absorbing the seat surface irregularities, improves the comfort (compressibility, resilience) and indicates the stitches of the sewing lines with an adequate depth.

The reinforcement material has the task to give the dimensional stability to sandwich structure, facilitates the sewing and seam resistance. It can be a polyamide mesh or polyester and a non-woven as well.

These three layers, fabric-foam-reinforcement, are fixed by flame laminate. Machine setting controlling flame temperature, gap separation of the roller and speed can be optimized for each quality of the

The available technology for the weaving of the external fabric is a part of the the textile technology. These are:

- Woven fabric.
- Woven fabric with loom of double woven (velvets).
- Weft needle fabric done in circular knitting machine (generally with pile).
- Weft needle fabric for warp in Ketten (velvet) (Ketten knit fabric).
- Weft needle fabric for warp in Raschel of double knitting head (with pile) (Raschel knit fabric).

Each technolog has advantages and limitations, and car manufacturers use your criteria or priorities for different fabrics. These criteria are grouped by countries, geographical and continent areas.

The basic criteria for the selection are cost, design and benefits that corresponds to the attributes of textile products: price, fashion and quality.

The second upholstery element, the polyurethane foam, show an excellent elasticity and its technology is quite good develop but presents some disadvantages: low air steam permeability, toxic gases and odours generation in the rolling process, non-recyclability, etc.

Abrasion testing equipment

One of the criteria for the design and/or selection of the seat upholstery is the functionality. The abrasion resistance is one of the most important criteria (physical test).

Abrasion resistance is used to quantify, approximately, duration of the textile material in normal use. This resistance is determined by undergoing the textile to the mechanical action of devices wich are called abrasion tester, and which simulate, more or less, the wear by abrasive action. The concept "abrasion" develops a complex phenomenon where the abrasive or rubbing action make linear or radial tractions.
There are three main abrasion testers for the car sector: Martindale, Schopper y Taber. Martindale mechanical action against the abrasive element takes places according to a translatory movement of the specimen holder describing a Lissajous curve. The Figure 1 shows a head device. In the Schopper the abrasive action takes place according to a movement circular of the specimen holder a conical surface that generates a curvature of 5 mm to the abrasive surface, Figure 2; as a result, the abrasive effect appears tangentially.

In the Taber the abrasion is carried out by the action of two abrasive wheels disposed vertically on the specimen and situated in diametrical opposition that they turn in the opposite direction by the effect of the circular movement of the specimen holder, Figure 3.

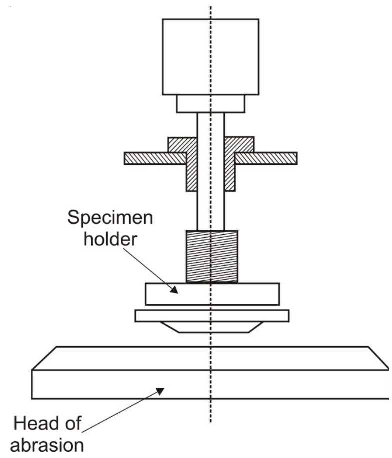
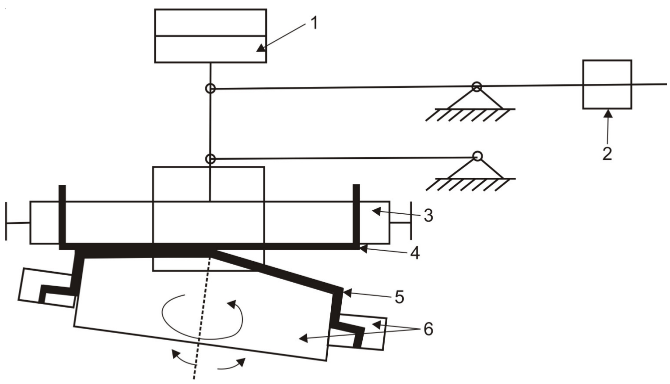


Figure 1. The Martindale head.



1. Weight additional
2. Balance load
3. Block abrasion
4. Abrasive material
5. Specimen
6. Subjection mechanism

Figure 2. The Schopper schema.

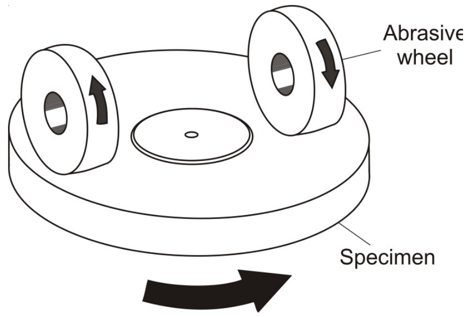


Figure 3. The Taber abrasive principle.

Besides these abrasion testers, a "linear" abrasion tester, made in Leitat Technical Center, has been used. Mechanical action in this device takes place by linear displacement of the specimen holder under an abrasive head (Figure 4); this alternative movement is carried out by a simple mechanism of crank arm-crank.

Besides the abrasive types, it is necessary to define the load

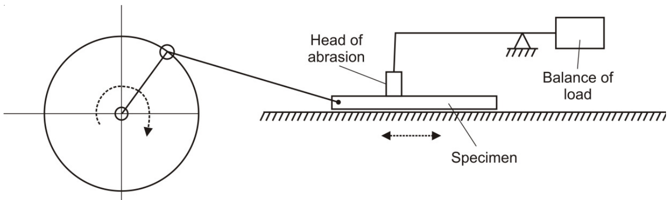


Figure 4. Mechanical principle of the "linear" abrasion tester".

or pressure between textile material and abrasive material, the speed work and the number of abrasive cycles.
The valuation of the test must be given, by four indicators o parameters:

- Number of cycles to specimen rupture or appearance of a hole.
- Weight loss of the specimen after a certain number of cycles.
- Degradation of the specimen surface after a certain number of cycles, for colour change in scale of gray (from 1 to 5).

In the automotive sector every manufacturer can use some specific testing methods, internal (home) standard developed according to general international standard, such as:

- BS 5690: 1991 (Martindale)
- DIN 53 863 3/4 (Martindale)
- DIN 53 863 2 (Schopper)
- DIN 53 754 (Taber)
- UNE-EN ISO 12947-1/2/3 (Martindale)

Work specifications for the abrasion tester

In accordance with international standards and automotive manufacture specifications test different materials have been used - with a foam and without a foam - with the purpose to find the test conditions similar between devices. The result appears in Table 1.

The abrasive materials for the Martindale, Schopper and the linear abrasion tester are abrasives whose specifications are summarized in the Table 2, according to the European standard for granulometry - system of classification of the FEPA (Federation of European Products of Abrasive) - that they are preceded of the letter "P" (in USA is used the system CAMI). And for the Taber two abrasive wheels are used whose specifications are in Table 3.

Table 2. The abrasive paper specifications.

FEPA-Standards 43-1:2006 ; 43-2:2006 y ISO 6344		
Grain designation	**Micrograin**	**Diameter particle micron** (inches)
P 320	Very fine	46,2±1,5 (0,00180)
P 400	Fine	35,0±1,5 (0,00137)
P 600	Extra fine	25,8±1 (0,00100)

Table 3. The Taber abrasive specifications.

TABER Abrading wheels			
TYPE	**Nº**	**COLOR**	**ABRASIVE ACTION**
CALIBRATED®	CS 10	Green	Light to medium
CALIBRATED®	H18	Grey	Ordinary

The valuation criterion adopted in this work is the weight loss calculated through the following percentage index:

$$P_I = \frac{p_0 - p_1}{p_a} \times 100$$

where:

p_0 - initial weight of the specimen in grams,
P_1 - specimen weight after abrasion in grams,
P_a - initial weight of the specimen part subjected to the abrasion in grams and is determined as follows:

$$p_a = p_0 \times \frac{\text{Abrasive area}}{\text{Specimen area}}$$

Area calculations and values resulted in the appropriate abrasion tester are detailed in the Table 4.

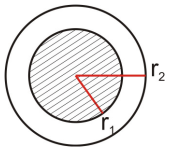
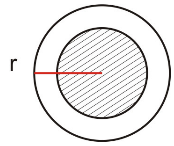
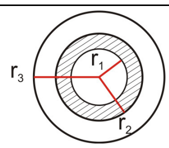
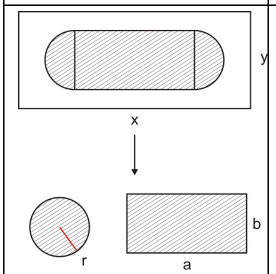
In the Martindale "r1" has been defined according to UNE-EN ISO 12947 and "r2" has been measured on the bottom of the specimen holder without sample. In the Schopper "r" it has been calculated from the abrasion area according to the GMW standard numbers GMW 3283, TL 522 26, TL 523 06/07. In the Taber "r1" and "r2" have been measured by tested plastic specimen. And finally, in to the linear abrasion tester, the measures "a" and "b" corresponding to the abrasion area has

Table 1. Specifications of the working conditions in the abrasion tester

Abrasion tester	**Dimensions specimen**	**Material abrasive**	**Force applied** (N)	**Contact area** (cm^2)	**Pressure** (N/m^2)	**Speed** (cycles/min)	**Cycles** (nº)	**Measu-rements** (nº)
MARTINDALE	Φ 38±5 mm	P320	10,20	11,34	9000	50	1000	4
		P400						
		P600						
SCHOPPER	100 cm^2	P320	9,81	50	1962	76	5000	5
		P400						
		P600						
TABER	Φ 130 mm	CS10	9,81	0,72	136100	60	2000	5
		H18						
LINEAL	21x6 cm^2	P400	5	4,5	1111,11	33	5000	5
		P600						

been measured on the fabric after the testing; the results are different for each fabric and direction of the sample (warp and weft), and the value that appears in the table is the average of all results.

Table 4. Geometry of the specimen and abrasive zone.

Geometry of the specimen and abrasive zone	Total area	Abrasive surface area	
		Calculation	Value (cm^2)
 Martindale	$P = r_2^2\pi$	$P = (r_2^2 - r_1^2)\pi$	6,605
 Schopper	$P = r^2\pi$	$\frac{r^2\pi}{2}$	50
 Taber	$P = r_3^2\pi$	$P=(r_2^2 - r_1^2)\pi$	$2.789,73 \times 10^{-6}$
 Lineal	$P = x \cdot y$	$P = r^2\pi + a \cdot b$	18,80

Automobile upholstery

The textile material used in this study has been provided by a supplier for the automobile upholstery. The external fabric is a velvet mesh obtained in a circular knitting machine of curl cut, and it presents the following characteristics:

- Gauge: E18
- Density: 13 mallas/cm
- Ground yarn: PES 167 dtex
- Loop yarn: Nm 40/2
- Weight: 305,78 g/m2

In the polyester polyurethane foams- foam - supplied, the following values have been obtained (Table 5). The non-woven upholstery is the polyester with height 0,81 mm and weight equal to 79,7 g/m2.

Experimental Designs

Structure influence

Graeco-Latin square design

The Martindale is, probably, the abrasion tester most used in the textile sector and the most complex (it generates a flat cyclic movement in the shape of curve of Lissajous). By these considerations we have decided to use it to study the influence of the foam in the upholstery abrasion resistance.

Table 5. Foam characteristics.

Height (mm)	3	4,2	5
Weight (g/m^2)	79	174	249
Density (kg/m^3)	26,34	41,43	49,80
Hardness (KPa)	7,11	7,11	7,11

We intend to compare four types of structures with regard to the lost of weight for effect of the abrasion as experimental answer: Only the fabric, the laminated fabric with foam of 3 mm more the reinforcement, the fabric with foam of 4,2 more reinforcement and the fabric with foam of 5 more the material of reinforcement. Each type of structure is a treatment or a level of the factor structures. The results have been obtained by the influence of test cycle, the specimen holder of the tester (there are four), and the position in the tester (there are four). Each of these disturbing factors is a block factor and as assumption there is no interaction between the treatments and the blocks. A Graeco-Latin design of 4 x 4 have been performed to increase the accuracy in the estimation of the experimental error (if there is no repetition, only three degrees of freedom is used in the comparisons). In the table 6 design is shown with the values of weight loss.

Table 6. weight loss (%) in the Graeco-Latin design.

	1	2	3	4
1	α,A 16,94	β,B 6,09	γ,C 4,29	δ,D 2,77
2	δ,C 5,20	γ,D 3,68	β,A 14,91	α,B 5,17
3	β,D 3,47	α,C 5,30	δ,B 5,08	γ,A 14,29
4	γ,B 5,02	δ,A 19,54	α,D 3,48	β,C 4,36

Replication I

Rows: cycles
Columns: positions
Greek letters: sopports
Latin letters: structures
A: fabric
B: upholstery 3 mm
C: upholstery 4,2 mm
D: upholstery 5 mm

	1	2	3	4
5	α,A 21,10	β,B 5,92	γ,C 4,76	δ,D 2,81
6	β,D 4,20	α,C 3,68	δ,B 14,91	γA 5,17
7	γ,B 3,47	δ,A 5,30	α,D 5,08	β,C 14,29
8	δ,C 5,02	γ,D 19,54	β,A 3,48	α,B 4,36

Replication II

Rows: cycles
Columns: positions
Greek letters: supports
Latin letters: structures
A: fabric
B: upholstery 3 mm
C: upholstery 4,2 mm
D: upholstery 5 mm

The analysis of variance of the results of the Graeco-Latin design is presented in Table 7. The statistical F structure is significant to 1 % (its value p gives significance level equal to 0,0000, indicating that the effect structure is great).

Tabla 7. The Graeco-Latin anova design

Source of variation	Sum of squares	Degrees of freedom	Mean Square	F
Cycle	25,3669	6	4,2278	1,2377
Position	16,3370	3	5,4446	1,5940
Structure	997,5420	3	332,514	97,348
Support	8,6883	3	2,8961	0,8478
Replicas	2,6000	1	2,6000	0,7612
Residual	51,2318	15	3,41572	
TOTAL	**1.101,77**	**31**		

There are differences between averages of the structure factor results. The graphic of averages considering the confidence intervals of 95% according to the LSD method (minimum significant difference) is presented in the Figure 5 and detects the differences A≠B, A≠C, A≠D. This way gives the practical conclusion that the worst structure is the fabric A ("without foam") and statistically their losses are bigger that the losses of the fabrics with foam (B, C and D).

However, the validity of the anova remains are related to the design hypotheses (in term of residual) and one of that, constant variance, is not verified, as it proves the Figure 6, where the residual is behaved as a fuel form.

This heteroscedasticity is because the structures with higher average have bigger variability and there is, therefore, a relation between the standard deviation and the average. To obtain homocedasticity we transformed data, based on the family Box-Cox transformation, have been transformed. The value λ which has been estimate forms the regression line between the logarithm of the deviation and the logarithm of the averages a of the structures, viewed in the Figure 7. As the result of this relation is a slope, approximately, of 1,5. The transformation, which has been utilized to obtain constant variance is root inverse data transformation.

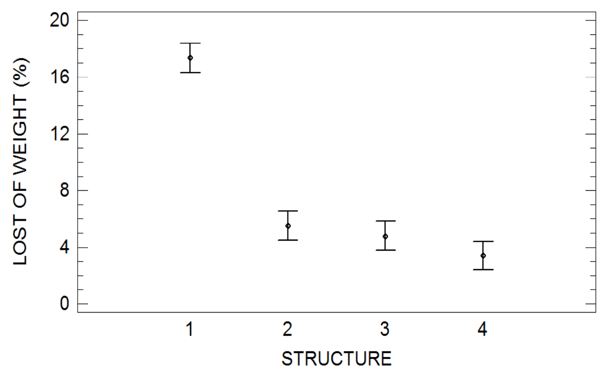


Figure 5. Means and 95,0 percent LSD intervals.

Applying the transformation to the data of the Graeco-Latin design, the Figure 8 shows the new graph of residues, where a bigger stability of the variance can be observed.

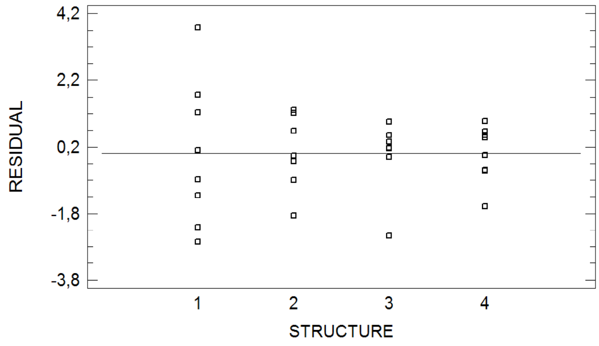


Figure 6. Residual plot for lost of weight.

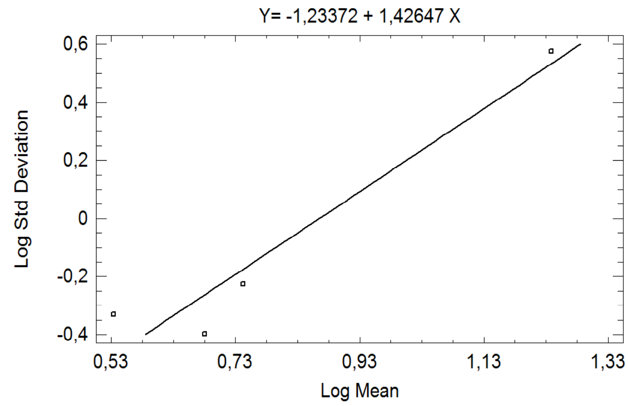


Figure 7. Linear relationship between the standard deviation and the means of the factor structures.

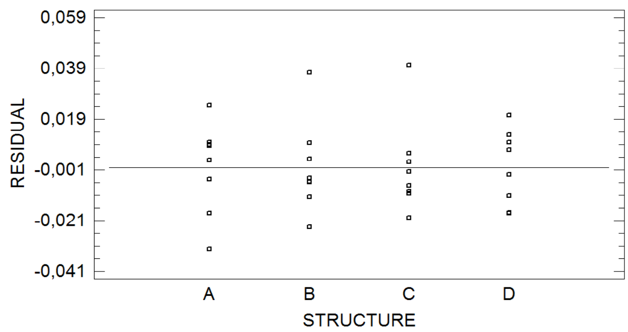


Figure 8. Residual plot for inverse SQR Lost of weight.

The analysis of variance of the Graeco-Latin design processed results shown in Table 8. The analysis also identifies the contribution to the total variance position (its value-p of F=5,10 is 0,0094, lower than 0,05).

Table 8. Transformed Anova Graeco-Latin design.

Source of variation	Sum of squares	Degrees of freedom	Mean Square	F
Cycle	0,003904	6	0,0006507	1,2335
Position	0,008085	3	0,0026951	5,1090
Structure	0,384153	3	0,128051	242,75
Sopport	0,0010406	3	0,00034687	0,6574
Replicas	0,0004063	1	0,00040634	0,7702
Residual	0,0079126	15	0,0005275	
TOTAL	**0,405502**	**31**		

The graphic of factor structures averages is shown in the Figure 9, and it can be observed that the confidence intervals of different structures are not equal, A≠B≠C≠D.

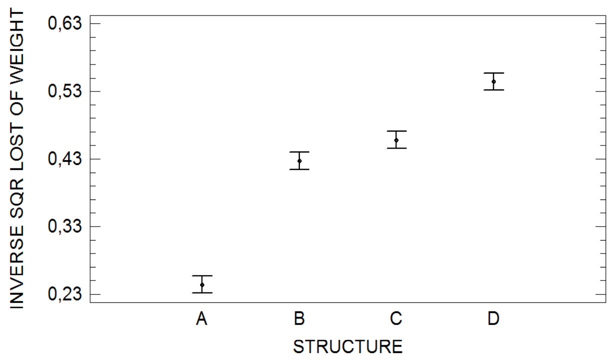


Figure 9. Means and 95,0 percent LSD intervals with the transformed answer (result).

Complete blocks random design

Whereas the structure factors and positions influence statistically to the results of weight loss, for the first fabric presents behaviour notably worse than the other ones, and plan design in blocks random completely (structures with foam as treatments and the positions as blocks) with the aim to study the influence of the foam as well. The analysis of the variance is shown in the Table 9. As it was already known the structure (p value 0,000) and position (p value 0,0107) are influential statistically.

Table 9. Anova design in complete blocks at random.

Source	Sum of squares	Degrees of freedom	Mean Square	F
Structure	9,11625	2	4,55813	100,51
Position	1,29316	3	0,431052	9,5
Residual	0,272115	6	0,0453521	
TOTAL	**10,6815**	**11**		

To obtain differences between the structures and positions the method of the minimum significant difference (LSD) of Fisher has been applied, which is presented graphically in Figures 10 and 11. The practical conclusion is that the upholstery with foam of 5 mm provides the best result, statistically its weight loss means is smaller that the means of the foam of 4,2 mm and 3 mm, and the foam of 4,2 is better than that of 3. However, as the weights and the densities vary linearly with the height the three structural parameters are confused.

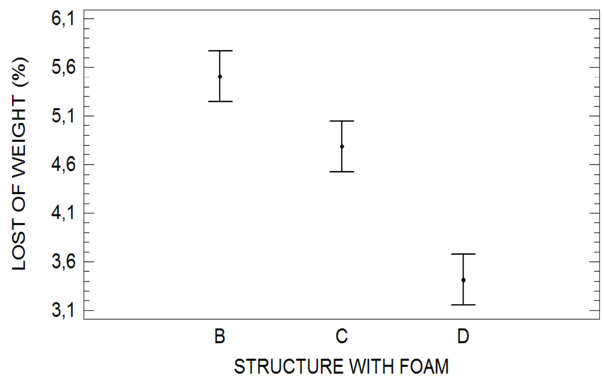


Figure 10. Means and 95,0 percent LSD intervals.

It is observed also that the graphic analysis notes that the positions 1 and 2 give higher result than the 3 and 4, and provides an indication of improvement which can deserve a posterior study.

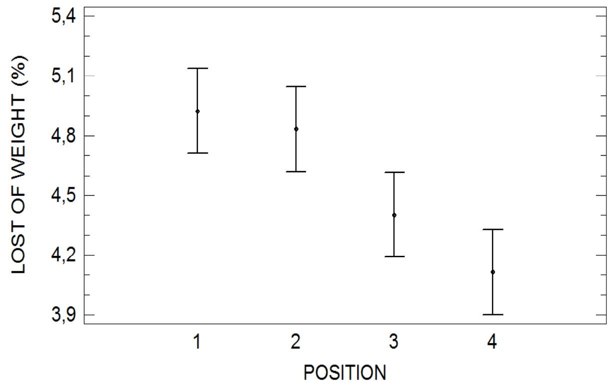


Figure 11. Means and 95,0 percent LSD intervals.

When the linear relationship between the losses and the height of the foam (or the weight) can be represented, a quadratic type linear model (x2) is obtained , obviously, negative as it shows the Figure 12, with a correlation coefficient 0,84 and a determination coefficient R2=74%.

The adequate parameters are presented in Table 10.

Table 10. Parameters of the model between the losses and the foam.

Parameter	Estimation	Error standar	Statistical T	Value p
β_0	6,79914	0,302266	22,49	0,0000
β_1	-0,129674	0,016415	-7,89	0,0000

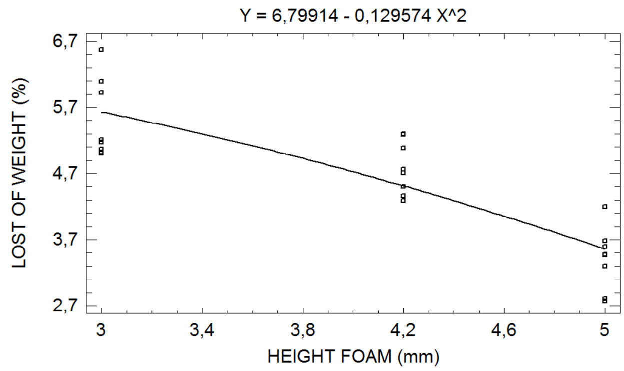


Figure 12. Plot of fitted model. Lost vs height.

Abrasion testers comparison

Completely randomized design

In order to compare the four abrasion testers the same abrasive paper P 320 has been used, except for the Taber where abrasive wheels, CS 10, has been used.

To calculate the experimental error five replicas have been carried out in each tester; in the Martindale, which provide four positions, the result of each replica is the average of these duplicate values. In the linear abrasion tester the result assessed in each of the five replicas is the average of ones obtained in two directions of the each sample (warp, weft).

The results of this design have been obtained with the upholstery of 5 mm and are given in the Table 11. The analysis of the variance is in the Table 12.

Table 11. Results of the completely randomized design.

ABRASIÓN TESTER	Weight loss (%)				
	Replications				
	I	II	III	IV	V
1. Martindale	4,99	4,93	4,70	4,84	5,18
2. Schopper	0,70	0,79	0,60	0,65	0,74
3. Taber	0,98	0,90	0,68	0,92	0,69
4. Lineal	2,97	2,94	2,85	2,90	2,67

Tabla 12. Anova of the completely randomized design.

Source of variation	Sum of squares	Degrees of freedom	Mean Square	F
Abrasión tester	59,7243	3	19,9081	1126,78
Residual	0,28284	16	0,0176775	
TOTAL	**60,0072**	**19**		

The value of the observed significance or p value of the statistical F=1126,78 is 0,0000 (very strong value). it can be concluded that there is difference or effect of the abrasion tester as for the weight loss.

The graph of averages by using LSD is presented in the Figure 13. It is observed that the confidence intervals of the abrasion tester Schopper and of the Taber (2 and 3) are similar, actually they are statistically equal as for their average results, and the losses that generate are smaller than the other two-abrasion tester.

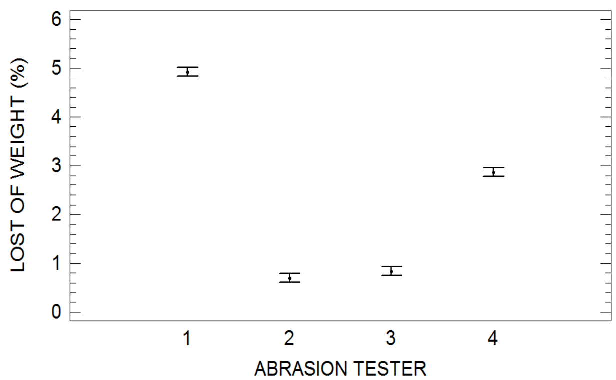


Figura 13. Means and 95,0 percent LSD intervals.

Conclusions

The abrasion tester are devices that accelerate the rubbing wear which the textile materials sustain in their life cycle, through mechanical movement abrasive action movement of the textile material against an abrasive material.

According to decreasing order to mechanical complexity there are the Martindale, Schopper, Taber and the "linear" abrasion tester.

According to the experimental results, the abrasion testers Schopper (with paper P 320) and Taber (with wheel CS 10) produce average weight losses, in upholstery of seats of automobile, which are statistically equal, although the Taber needs less time in obtaining this abrasion.
Moreover, the Martindale causes losses notably higher than other devices.

The polyurethane foam or foam influences to the abrasion resistance of car seats upholstery: increases the height and weight of the foam, from the studied range, losses are decreased in quadratic form.

Non-usage of a foam significantly reduces abrasion resistance.

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