COMPARATIVE STUDY ON THE QUALITY OF UPHOLSTERY WOVEN FABRICS I: TENSILE AND SHEAR RESISTANCE

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REZUMAT. Stofele de mobila reprezintă o categorie a textilelor de interior importanta in asigurarea confortului si durabilității amenajărilor spațiilor rezidențiale sau nerezidențiale. Alături de proprietățile estetice, stofele de mobilă trebuie sa prezinte o serie de proprietăți funcționale, cu utilitate atât în procesul de confecționare a tapițeriei, cât și în cel de exploatare. Studiul de față își propune sa analizeze proprietățile funcționale pentru trei variante de stofe de mobilă, cu scopul de a le ierarhiza din punct de vedere calitativ și al valorii de utilizare. Studiul cuprinde două părți: in prima parte sunt determinate rezistența la întindere axială și rezistența la forfecare, iar in partea a doua, rezistența la abraziune și rezistența la foc. Ierarhizarea finala a celor trei articole s-a realizat pe baza unor coeficienți de importanță acordați fiecăreia dintre aceste proprietățile analizate.

Cuvinte cheie: Textile de interior, Stofe de mobilă, Rezistența la întindere axială, Rezistența la forfecare.

ABSTRACT. Woven upholstery fabrics are an important category of interior textiles, which provide comfort and durability to the furnishings of both residential and commercial spaces. Besides their aesthetic qualities, woven upholsteries need to have properties, which are beneficial to both the upholstery manufacturing process and their practical usage. This study aims to analyze the functional properties for three variants of woven upholstery fabric, with the intent of ranking them according to their quality and value of use. The study consists of two parts: the first part describes the testing method for tensile and shear resistance and the second describe the testing of abrasive resistance and resistance to fire and associated fire-retardant properties. The final ranking relies on setting some importance coefficients to the aforementioned properties and computing a global evaluation index.

Keywords: Interior textiles, Woven upholstery, Tensile resistance, Shear resistance.

1. INTRODUCTION

Woven upholstery fabrics are interior textiles and can be classified in two broad categories: domestic and contract use. The areas of which the contract upholstery market is composed include the following categories: automotive (aircraft, cars, buses, trains etc.), commercial (offices, hotels, restaurants, cinemas, theatres etc.), educational (classrooms, sports and leisure complexes etc.), institutional (hospitals, nursing homes, clubs etc.).

Regardless of their purpose, upholstery fabrics have to be designed with certain properties in mind such as tensile resistance, abrasion resistance and flame resistance - which ensure their functionality and appearance retention, as well as resistance to seam slippage, colour - fastness to light and rubbing, stain repellence, easy clean etc. - for easy maintenance and long operational life. For contract upholstery fabrics, the functional and aesthetic properties have to be ensured for at least 5 years [7].

This study aims to analyze the functional properties for three variants of woven upholstery fabric, with the intent of ranking them according to their value of use. Five properties have been analyzed - four were aesthetic and functional, (tensile/abrasion/flame resistance and appearance retention) and the last one pertains to processability (formability, defined by shear resistance).

The study was structure in two parts. This paper represents the first part of the study, which presents the structural characteristics of the three woven fabrics (their structure, the type of yarn used, the nature of the fibers, the yarn fineness and density, the type of weave structure used) and the results of the ranking based on the results of evaluation of tensile resistance and shear resistance. The second part of the study ranks the three fabrics because of importance coefficients assigned to each of the analyzed properties [8].

2. STRUCTURAL CHARACTERISTICS OF THE ANALYSED UPHOLSTERY FABRICS

All of the three articles are made of polyester yarns with different fineness, structure and colour. Figure 1 illustrates the three woven upholstery variants.

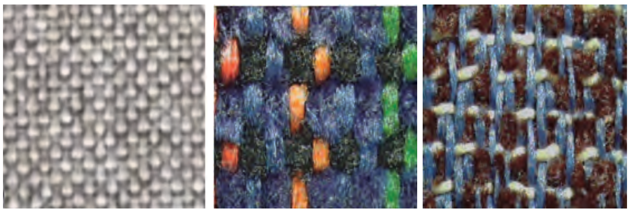

a) b) c)

Fig. 1. Photographs of the three analyzed woven upholstery fabrics.
a) 1st Article; b) 2nd Article; c) 3rd Article.

Table 1 presents the structural characteristics of the analyzed woven upholstery fabrics – the structure and fineness of the yarns, the yarn densities and the weave structure. The first two articles are simple woven fabrics (with one weft and one warp system) and are creating using a plain weave structure. Both articles present a thermal bonded nonwoven fabric on their reverse side, which is mean to strengthen the mechanical properties of the material: tensile resistance, tear strength, slippage resistance, and abrasion resistance. The third article does not have a thermal bonded backing as the enhancing of functional properties is ensure by its structure - a compound woven fabric with double-warp structure, which contains three systems of yarns: two warps and one weft. The first article is unicolor, articles 2 and 3 have colour and weave design (Fig. 1).

Table 1. **Structural characteristics of the 3 woven upholstery articles**

	1st Article		2nd Article		3rd Article	
	Warp	**Weft**	**Warp**	**Weft**	**Warp**	**Weft**
Yarns' structure	Intermingled yarns	Intermingled yarns	Multifilament yarns	Contains two types of yarn: Chenille yarns and Intermingled yarns (ratio of 1:1)	Multifilament yarns	Contains two types of yarn: Chenille yarns and Slub yarns (ratio of 1:1)
Yarns' linear density [tex]	167	250	50x2	Chenille weft: 400 Intermingled weft: 250	Face warp: 16.7 Back warp: 16.7	Chenille weft: 170 Slub weft: 100
Yarns' density [yarns/10 cm]	72	56	96	64	Face warp: 200 Back warp: 400	160
Weave structure	Plain weave		Plain weave		Double-warp weave (3/1 twill weave on face, warp systems ratio of 1:1)	

Table 2 presents the mass and thickness of the three articles. Despite their different fineness and yarn densities, they were designe in a way that allowed their specific parameters to be comparable.

Table 2. **Mass and thickness for the 3 articles**

	1st Article	2nd Article	3rd Article
Mass [g/m^2]	300	296	336
Thickness [mm]	1.05	0.87	0.94

3. TENSILE RESISTANCE

The tensile resistance of a textile material depends on multiple factors such as the type and the characteristics of the raw material, the fineness and the structural characteristics of the yarns, the weave type, and the density of the yarns. The behavior of woven fabrics under stretching is a good indicator for how it is going to perform under its intended use. Even if it is unlikely for the woven fabric to reach its breaking point under normal usage, the highest force it can resist without breaking serves as a good absolute value for benchmarking and comparison, and is a good indicator of its overall resistance.

Under standard conditions, the determining of tensile behavior is performed on samples cut along the direction of the warp and weft [2]. The testing of woven fabrics for tensile resistance is done according to the SR EN ISO 13934-1 standard [11]. This standard (known as the "strip test") outlines the method of determining the maximum tolerated force without breakage and of elongation under the determined maximum force.

The sampling was made such that each sample contains unique warp and weft yarns so that it can be as representative of the whole material. For each of the 3 variants, 5 samples in the warp direction and 5 in the weft direction were prepared.

The samples were cut to an initial rough dimension of 350 x 60 mm and then trimmed down by removing the outside yarns until the desired 50 mm width was obtained. A fringed edge of about 5 mm was formed on each side.

The testing of the woven fabrics for tensile strength was realised on a constant rate of extension testing machine (H5KT – SDL Atlas, Fig. 2), under the following conditions:

- Initial gauge length: 200 mm
- Rate of extension: 100 mm/min
- Sample dimensions: 350 x 50 mm
- Direction of load: Warp and Weft

Fig. 2. SDL Tensile testing machine.

Before the trials, the samples were conditioned for 24 hours under standard atmosphere for textile testing. Tests were done for each of the 3 types of upholstery woven fabrics on both warp and weft directions. The maximum force and the elongation at the maximum force (alongside the full force-extension curves) were collected from each trial.

Figures 3 and 4 present the representative force-extension curves for the tensile testing of the three variants on the warp and weft direction respectively.

Table 3 summarizes the mean values for the maximum force (F_{max}) and corresponding elongation for the 3 variants of tested woven fabrics.

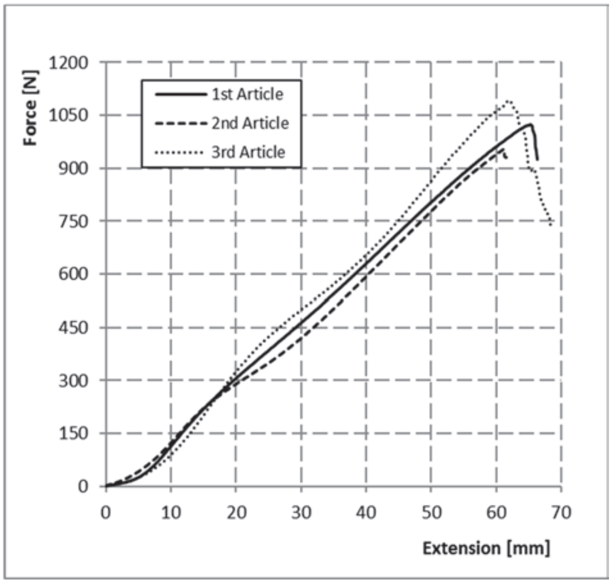


Fig. 3. Tensile test – warp direction: Force versus Extension curves for the three woven upholstery articles.

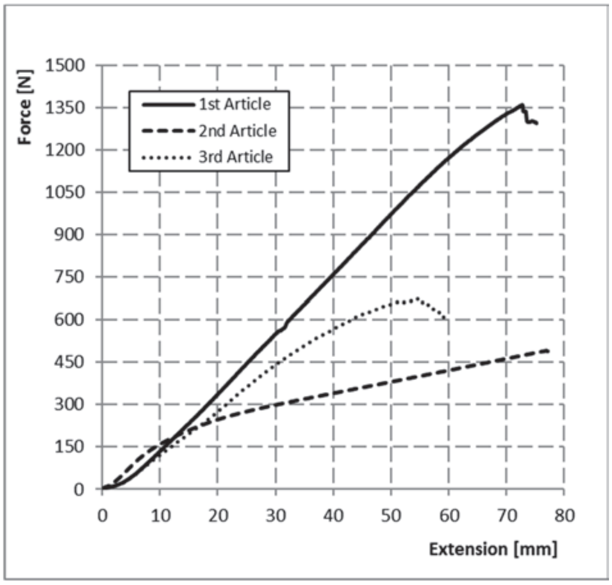


Fig. 4. Tensile test – weft direction: Force versus Extension curves for the three woven upholstery articles.

Table 3. **Maximum force and corresponding elongation for the three woven upholstery fabric types**

Art.	Direction	Fmax (N)	CV_{Fmax} (%)	Elong. (%)	$CV_{Elong.}$ (%)
1st	warp	970	7,78	33,10	2,13
	weft	1363	0,389	37,02	2,8
2nd	warp	929	3,88	31,68	4,1
	weft	493	0,86	32,35	2,34
3rd	warp	1089	0,48	30,06	2,21
	weft	693	3,75	27,73	1,68

Figures 5 and 6 represent the mean values for the maximum force and corresponding elongation in the warp and weft directions respectively.

According to the chart in figure 3, the three variants have similar force-extension curves in the warp direction. In figure 5 a difference in the maximum force can be observed between the variants in the warp direction.

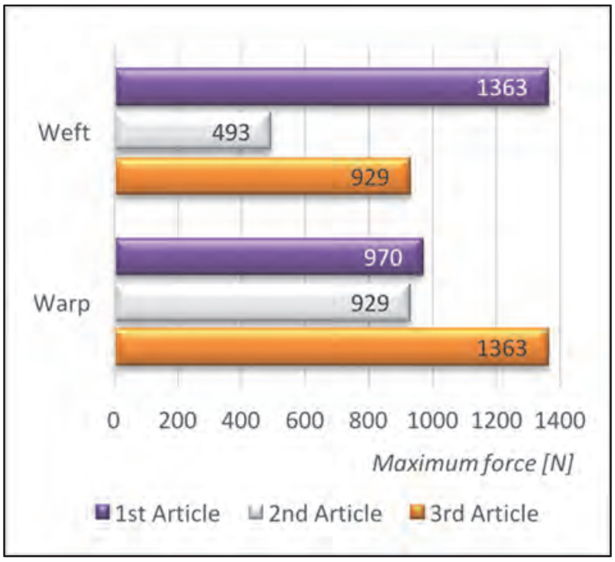


Fig. 5. Tensile test: Maximum force values for the three woven upholstery articles.

The largest maximum force was recorded for the third type of woven upholstery, the one with a density of 600 yarns/10 cm. The other two variants, which have a lower yarn density (72 yarns/10 cm and 94 yarns/10 cm for the first and second type respectively), obtained similar maximum force values, both significantly lower than the third.

The ranking for the maximum force in the tensile test in the direction of the warp is as follows:

I – 3rd Article;
II –1st Article;
III – 2nd Article.

In the direction of the weft, the three types differ more, both regarding to the force-extension curves and the maximum force. The ranking for the same test in the direction of the weft is as follows:

I – 1st Article;
II – 3rd Article;
III – 2nd Article.

The significantly lower resistance of the second type of woven upholstery fabric can be explained by the presence of chenille yarns in the weft, which have a lower specific resistance when compared to normal yarns.

The chart from figure 6 shows that both on the warp and the weft directions, the least amount of elongation was recorded for the third type of fabric, the one with the compound weave structure, with evolution of the warp yarns 1 up and 3 down. The first two showed comparable maximum elongation, both significantly higher than the third type. This can be explained by the different degree of undulation of the warp yarns in the different variants of weaves. The yarns, which form a plain weave structure cause a greater amount of elongation than yarns with the path 1 up, and 3 down.

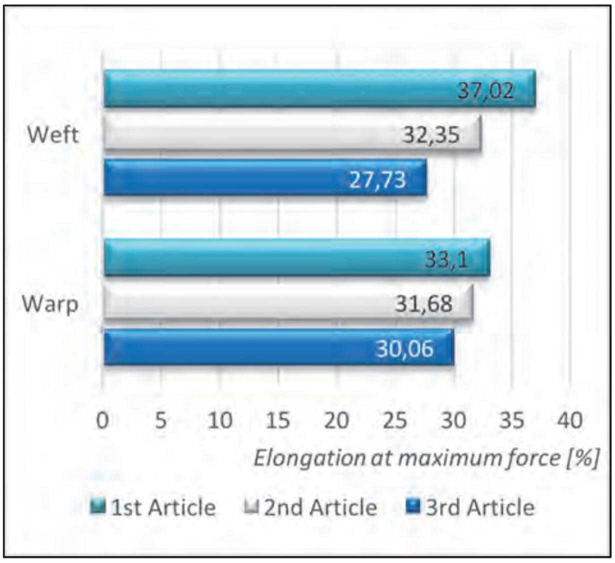


Fig. 6. Tensile test: Elongation at maximum force for the three woven upholstery articles.

The overall ranking of tensile behavior of the three tested types, aggregating both warp and weft ways is as follows:

I – 1st Article;
II – 3rd Article;
III – 2nd Article

4. SHEAR RESISTANCE

In the process of creating upholstery for furnishings, the woven fabrics have to follow the shape of double-curvature surfaces without creasing. This property is known as formability. The in-plane shearing behavior of textile upholstery is an important aspect of fabric formability. When the weave is subjected to a shearing force, the warp and weft yarns shift from their initial position relative to each other (perpendicular). In figure 7, θ represents the angle of the change away from the normal right-angle positioning of the warp and weft system (called shear angle) under the shear forces (T), in "pure shear" deformation (the load is applied in the direction of one of the yarn systems). The degree of in-plane shear of the woven fabric is indicated by the shear angle value registered when the warp and weft yarns become locked and wrinkles may occur [4, 5, 9]. The higher the shear angle that can be obtained without locking the yarns, the higher the formability of the woven fabric.

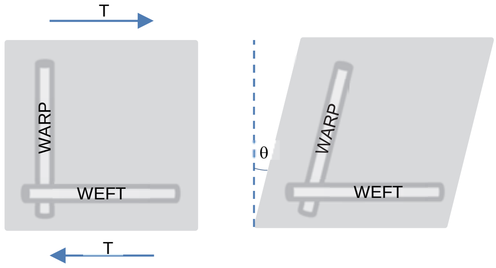


Fig. 7. Pure in-plane share deformation of a woven fabric
T = the shear force; θ = the shear angle.

The shear resistance of woven fabrics is influenced by the raw materials, the yarn density, the warp/weft density ratio, yarn fineness and the weave structure used. The shear resistance of a woven fabric is proved to have the ability of being accurately determined from the tensile properties tested at a 45° rotation ("bias extension") [3]. Bias extension tests are simple to perform on a tensile testing machine and provide repeatable results [6]. The standard analysis of the test is based on two assumptions: inextensibility of the fibers and rotations at the yarn crossovers without slippage [1].

The bias extension test was done on a H5KT – SDL Atlas (Fig. 8-a) tensile testing machine under the following conditions:

- Initial gauge length: 200 mm;
- Rate of extension: 100 mm/min;
- Sample dimensions: 300 x 50 mm;
- Direction of load: 45° rotation from the weft/warp way.

Before the tests, the samples were conditioned for 24 hours under standard atmosphere for textile testing. For each type of woven upholstery fabric, five samples were prepared. The initial length of the sample (in the testing direction) was twice its width (L = 2xW, in Fig. 8-b).

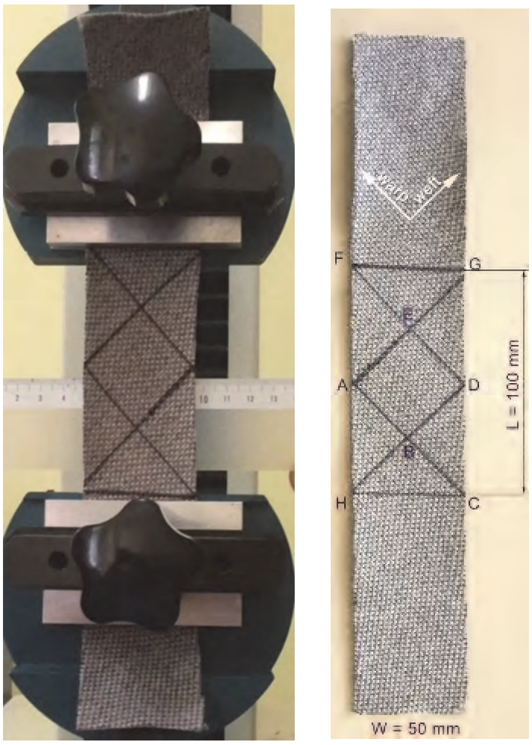
When the distance between the grippers is at least twice the width of the sample, "pure shear" deformation can be achieved since there are warp and weft yarns which can freely rotate during testing – this happens within the ABDE square (Fig. 8-b).

For each of the three variants force-displacement curves were collected during testing. These curves are recorded up to an elongation of 30 mm, not until the sample breaks. This is because the results of the bias extension test can be used to accurately determine in-plan shear properties up to a material shear angle of ~55^0 [10].

The material shear angle is defined as (see Fig. 9):

$$\theta = \frac{\pi}{2} - 2 \cdot \Phi \qquad (1)$$

where ϕ is the angle in the central region (ABDE square in Fig. 8-b), known as "pure shear angle".



a) b)

Fig. 8. Bias extension test on SDL Atlas tensile testing machine for the 1st Article:
a) Bias extension set-up. b) Bias extension sample.

The shearing behaviour is influenced by the number of weft and warp yarns within the central zone which are not held by the grippers. Table 4 presents the number of yarns in the central zone for each direction (warp/weft) for the three variants of woven upholstery types tested.

Table 4 - **Numbers of yarns in the center shear zone for the 3 articles**

Article	**Direction**	**Numbers of yarns in the center shear zone**
1st	Warp	25
	Weft	20
2nd	Warp	34
	Weft	22
3rd	Warp	210
	Weft	56

Figure 9 presents the manner of the deformation for the 1st Article, and shows the pure shear angle (ϕ) and the material shear angle (θ).

Pure shear angle can be calculated from the gripper displacement by using the following formula:

$$\Phi = \arccos \frac{D + d}{\sqrt{2} \cdot l} \qquad (2)$$

where d is the gripper displacement and D and *l* are the dimensions mentioned in Fig. 8.

By taking into account the fact that the sample was chosen with the initial length to be equal to twice its width (L = 2W), we have D = W = *l*, therefore the equation (2) becomes:

$$\Phi = \arccos\frac{W+d}{\sqrt{2}\cdot W} \tag{3}$$

where d is the gripper displacement and W is the width of the sample.

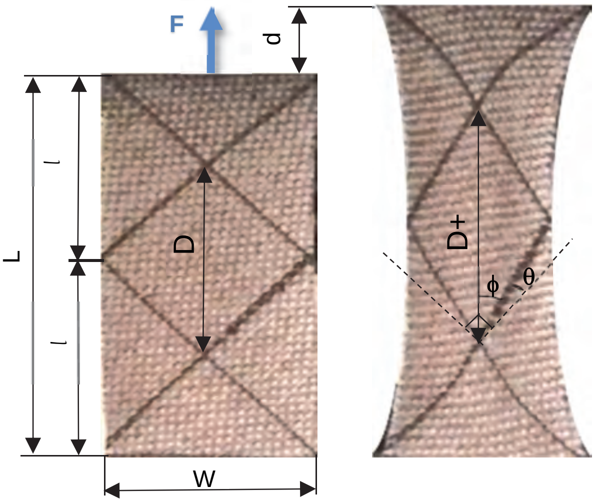


Fig. 9. Deformation of a bias sample (1st Article)
F = the tensile force; d = the gripper displacement; ϕ = the pure shear angle; θ = the material shear angle; L = the initial gauge lenght; W = the width of the sample.

By replacing the value for the pure shear angle from the equation (3) in the formula (1), we can express the material shear angle as a function of the grip displacement:

$$\theta = \frac{\pi}{2} - 2\cdot \arccos\frac{W+d}{\sqrt{2}\cdot W} \tag{4}$$

Fig. 10 represents the force/displacement curves for the three tested variants.

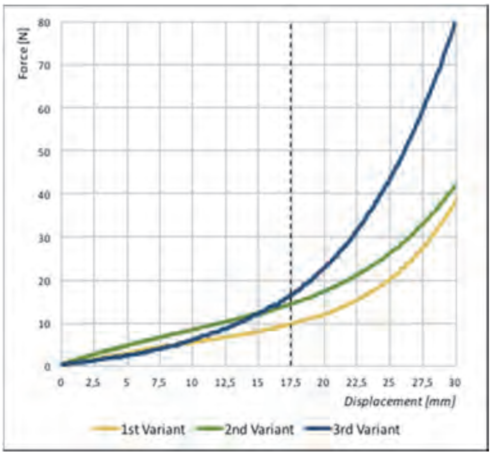


Fig. 10. Bias extension test: Force versus displacement curves for the 3 variants of woven upholstery.

It can be observed that the necessary force for a displacement of 10 mm is approximately the same for the three articles. The minimum force needed for creating a 17.5 mm displacement (corresponding to a shear angle of 55^0) was recorded for the first article (9.75 N). For the second article, creating a 17.5 mm displacement requires a force greater by 47% than the first one (14.4 N). The third article managed to sustain a force 72% greater than the first one and 16% greater than the second one before reaching the same displacement.

Figure 11 represents the force versus shear angle for the three woven upholstery variants. Because of the dependency between material shear angle and displacement (formula 3), the hierarchy of the three for a 55^0 angle is the same as can be seen in Fig. 10.

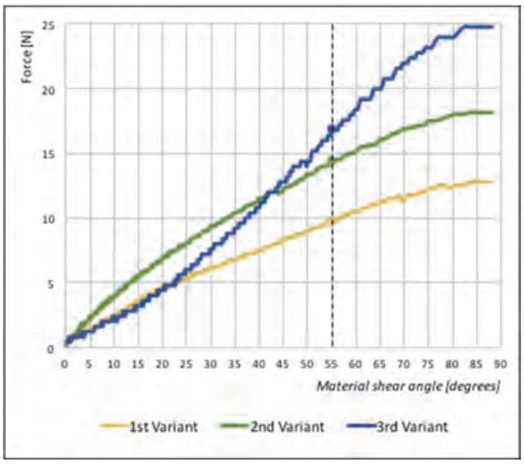


Fig. 11. Force versus shear angle for the three woven upholstery.

This hierarchy is backed by the analysis of the video capture of the testing runs, which aimed to determine the time when the first folds formed. Table 5 presents the transversal shrinkage of the sample during the tensile test as a function of time and displacement. The same table marks the time of the first folds forming in each individual type tested:

- For the 3rd Article, first folds appear at +5 sec (at a displacement of 8.35 mm and 21.2^0 shear angle).
- For the 2nd Article, first folds appear at +9 sec (at a displacement of 15 mm and $43.6^{\,0}$ shear angle).
- For the 1st Article, first folds appear at +12 sec (at a displacement of 20 mm and 73.7^0 shear angle).

The explanation for the good formability of the first two variants comparative to the third could be the type of the structure and the warp/weft density ratio. Both are simple structures with a single warp and weft system, and the density ratio is low (72/56 for the 1st Article and 96/64 for the 2nd article), which allows for the rotation and repositioning of the yarns during bias extension testing. The third article has two superposed warp systems, with a total density much greater than the weft (600/160) which can explain the quick onset of yarn locking during the bias extension testing.

Table 5 – **Transversal shrinkage of samples as a function of time and displacement**

Time [s]	**Displacement [mm]**	**Transversal shrinkage [mm]**		
		1st Article	**2nd Article**	**3rd Article**
0	0	0	0	0
1	1.70	0	0	0
2	3.35	2	1	1
3	5.00	2	2	2
4	6.70	3	3	3
5	8.35	3	3	3
6	10.00	5	5	4
7	11.70	6	6	6
8	13.35	7	8	8
9	15.00	9	8	9
10	16.70	11	9	10
11	18.35	11,5	11	11
12	20.00	12	12	12
13	21.70	14	13	14
14	23.35	16	15	15
15	25.00	17	16	17
16	26.70	18	20	18
17	28.35	19	22	20
18	30.00	22	24	21
19	31.70	23	25	23
20	33.35	24	25	24

It can be concluded that the final hierarchy of formability properties of the three woven upholstery fabrics is as follows:

I – The 1st Variant
II – The 2nd Variant
III – The 3rd Variant.

5. CONCLUSIONS

This paper is the first part of a study that aims to find a method of ranking the quality of woven upholstery fabrics by analyzing five properties – four aesthetic and functional, (tensile/abrasion/flame resistance and appearance retention) and one pertaining to processability (formability, defined by shear resistance). It presents the structural characteristics of the three woven fabrics (their structure, the type of yarn used, the nature of the fibers, the yarn thickness and density, the type of weave used) and the results of the ranking based on tensile resistance and shear resistance tests.

The testing results can be summed up in the following aspects:

- In the warp way, the 3rd variant has the best resistance (with 600 yarns/10 cm density). The other two variants with lower densities (72 and 92 yarns/10 cm for the 1st and 2nd article respectively) have similar values, both lower than the 3rd article.
- In the weft way, the hierarchy is as follows: I - the 1st article, II - the 3rd article and III - the 2nd article. The significantly lower results for the 2nd article can be explained by the presence of chenille yarns in the weft.
- The overall resistance tally (when assessing the resistance of both warp and weft way) favours the 1st article, followed by the 3rd and the 2nd.
- Concerning the formability of the material, the hierarchy of the three variants is as follows: I - the 1st article, II - the 2nd article and III - the 3rd article.

The study will be continued with part two – this is going to rank the woven upholstery fabric types with regard to their abrasion and fire resistance properties. Also in the second part, a final hierarchizing of the types is going to be done by defining importance coefficients for each of the analyzed properties.

REFERENCES

[1] Boisse, P., Hamila, N., Guzman-Maldonado, E., Madeo, A., Hivet, G. et al. *The bias-extension test for the analysis of in-plane shear properties of textile composite reinforcements and prepregs: a review.* International Journal of Materials Forming, **10** (4), p. 473-492, 2017.

[2] Cioara, L., Cristian, I.,Onofrei, E., *Caracteristici de structură şi proprietăţi ale ţesăturilor.* Ed. Performantica, 2004, Iaşi, Romania.

[3] Du ZQ, Yu WD. *Analysis of shearing properties of woven fabrics based on bias extension.* J. Text. Inst. **99**, 385–392, 2008.

[4] Harrison, P., Clifford, M.J., Long, A.C., *Shear characterisation of viscous woven textile composites: a comparison between picture frame and bias extension experiments*, Compos. Sci. Technol. **64**, 1453–1465, 2004.

[5] Hassan Alshahrani et al., *Experimental Investigation of In-Plane Shear Deformation of Out-of-Autoclave Prepreg, International Journal of Composite Materials*, **5**(4): 81-87, 2015.

[6] Launay J, Hivet G, Duong A.V, Boisse P. *Experimental Analysis of the Influence of Tensions on in Plane Shear Behaviour of Woven Composite Reinforcements*. Composites Science and Technology, **68**, p. 506–515, 2010.

[7] Nielson, K. J., *Interior Textiles: Fabrics, Application, and Historic Style*, John Wiley and Sons Inc., New Jersey, USA, 2007.

[8] Piroi, C., Cristian, I., Harpa, R., *Comparative study on the quality of upholstery woven fabrics II: Abrasion resistance and flammability*, Proceedings of the 4th Technical Textiles Present and Future Symposium, 10-11nov. 2017, Iasi, Romania.

[9] Wang, J., Page, J.R., Patod, R., *Experimental investigation of the draping properties of reinforcement fabrics*, Compos. Sci. Technol. **58**. 58, 229–237, 1998.

[10] Xiongqqi Peng, Jian Cao, *Biais extention test standard*. www.wovencomposites.org/load03/Bias_extension_Northwestern.pdf, accessed on Aug. 2017-08-23

[11] SR EN ISO 13934-1: *Materiale textile. Proprietăţi de tracţiune ale ţesăturilor*. Partea 1: Determinarea forţei maxime şi a alungirii la forţa maximă prin metoda pe bandă, elaborat de Comitetul Tehnic ISO/TC 38, Textile.

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