ACTA FACULTATIS XYLOLOGIAE ZVOLEN, 66(1): 115−123, 2024
Zvolen, Technická univerzita vo Zvolene
DOI: 10.17423/afx.2024.66.1.09

THE EFFECT OF SELECTED FACTORS ON THE MECHANICAL PROPERTIES OF THE SEAMS FOR UPHOLSTERY COVERS MADE OF SYNTHETIC LEATHER

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ABSTRACT

The quality and structure of the covering material of the upholstered furniture is an important factor affecting the properties of the stitched and, thus, the quality and durability of the upholstered furniture. The stitches of the cover layers are considered a critical place of the upholstery, in which deformations and possible damages are most visible. The paper is focused on synthetic leather, which is considered a composite, ecological and sustainable material. The bearer of the mechanical properties is the reverse side formed by the underlying textile. The focus is put on the influence of stitch length (4, 5, 6 mm) in the weft and warp direction of the underlying fabric of the synthetic leather. The stitched joint has higher strength and stiffness in the warp direction, but its efficiency is lower compared to the load in the weft direction. It means that the stitched material carries a greater load than the thread-connecting material. Joints with longer stitches hold the fabric together with less tension. The sewing thread carries higher loads with a longer stitch length. The results of joint strength and failure show that when creating cutting plans, it is advisable to orient the parts of the covering material so that the joint is stressed in the direction of the warp due to the user's load.

Keywords: furniture; upholstery seams; synthetic leather; sewing thread; seam length; seam quality.

INTRODUCTION

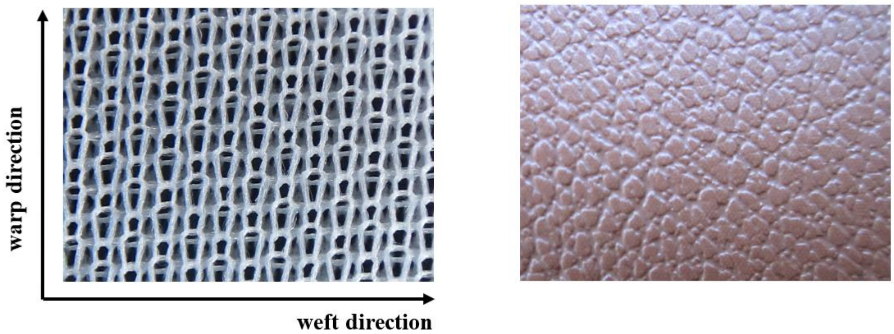
Fabric quality, as the most important element of upholstery or garment appearance, is determined by its mechanical properties. It is evident that these properties directly impact fabric processing properties. It can be seen through various forms of fabric behaviour under the loads that occur in sewing. Investigations of the correlations between stress and fabric behaviour are aimed at constructing a system to predict fabric behaviour in garment manufacturing processes, as well as to predict the appearance of the garment to be manufactured (Pavlinić *et al*., 2006; Geršak, 2003; Zavec and Geršak, 2000). The role of fabric properties in sewing performance and seam quality is essential. Therefore, it is crucial to understand the effect of different parameters on upholstery fabrics sewability properties. The quality of the eco-friendly fabric was investigated by the authors Esi and Baykal. (2020). In this study, recycled polyester yarns obtained by recycling waste polyethylene terephthalate bottles and standard polyester yarns were used in staple forms, 16 different chenille yarns were produced at different production parameters. As a result of the tensile strength tests and statistical analyses, it is concluded that the weft-breaking strength of all types of woven fabrics, which have 100% recycled polyester in the structures of chenille yarns as weft, is slightly decreased compared to other types, but this decrease is not statistically significant.

Upholstery seams, for example, serve two purposes, both form and function. They have a practical function that allows them to hold the fabric together better or ensure a more profound sense of security, but they can also add visual interest to a piece otherwise lacking.

The quality of seam is assessed by means of its efficiency, elongation, bending, stiffness, abrasion resistance, seam slippage strength, puckering, tightness, boldness and seam damage. A good seam has various functional and aesthetic requirements. The functional performance of the seam is evaluated by efficiency, elongation, density, slippage, bending stiffness and abrasion resistance of the seam. The basic material of garmenting is fabric and sewing thread (Bhaves *et al*., 2018), which also applies in the case of creating a high-quality upholstered cover (Lange *et al*., 2022). Sewing threads are used in garments, upholstery, air-supported fabric structures and geotextiles to join different components by forming a seam. The primary function of a seam is to provide uniform stress transfer from one piece of fabric to another, thus preserving the overall integrity of the fabric assembly. Industrial sewing techniques make specific and often very exacting demands on the threads involved in the sewing process. The sewability of sewing threads is of major importance, having a very profound effect on seam quality and production costs. The sewing and the seam performance of a sewing thread are largely influenced by the material to be sewn, the sewing technique and the end-use for which the sewn material is intended. According to Dobilaite and Juciene (2006), sewing thread has a significant influence on the mechanical properties and quality of the sewn joint. In the work, the influence of mechanical properties of sewing threads on the seam pucker is evaluated. Regarding seam pucker, the best results were established sewing with polyester threads, the reversible strain of which was the least. It was noticed that by increasing the number of layers in sewing, the influence of threads on seam pucker decreases. Polyester sewing thread is made of polyester filament or staple fiber, with high strength, good elasticity, wear resistance, low shrinkage, and good chemical stability. After different tests of extracted sewing thread from treated fabrics, it is clear that according to the properties wanted (softness, stiffness, non-wrinkling) the finishing products used affect the sewing thread's behavior differently. So stiffening, waterproofing and anti-wrinkling treatments increase the fabric resistance to needle penetration because of resins used when making film on the surface (Mansouri *et al*., 2014; Mansouri *et al*., 2022). Fireproofing of fabrics changes the seam strength, this may be due to fabric stiffening, resulting in less fabric flexibility. Under tension, the fabric will have a little stretch. To increase the seam strength, it is necessary to choose a thread with very high strength and low elongation at break. This solution will minimize the risk of broken threads in case of deviation of material features and technological parameters, which can be variable in the long duration of large-scale production (Skorupińska *et al*., 2021). Synthetic leather is a material that consists of two layers, a base fabric covered with a plastic material. Synthetic leatherettes are characterized by high durability, health safety, high abrasion resistance and their production and application are environmentally friendly. The surface layer may have an open-pored or compact construction consisting of PVC, although the modern types are made from PU and are embossed or textured to produce different leather looks. Nonwoven, woven and increasingly warp-knitted textiles, as well as combinations of these materials, are used as the textile materials. While faux leather has many of the same desirable attributes of genuine leather, it is not necessary to harm animals to create this substance. Also, the processing of genuine leather has rather inconvenient properties from an ecological point of view, with parameters such as consumption of energy, water and the intensive content of chemical processes in the production process (Birkocak, 2022). Woven and nonwoven fabrics, and occasionally weft-knitted fabrics, are usually used when producing synthetic leather, but warp-knitted fabrics are now being used more and more. Based on the results of the work by Rahimi and Ahmadi (2020), woven fabric-reinforced leathers show the highest tensile and bursting strength, followed by knitted and nonwoven fabrics-reinforced ones, respectively. The highest tear strength value is observed in the nonwoven reinforced samples. Meyer *et al*., (2021) compared leather, synthetic leather and other alternative materials. The technical performance of the materials was compared, which allows an estimation of possible application areas. Structure and composition were characterized by microscopy and FTIR spectroscopy, the surface properties, mechanical performance, water vapor permeability, and water absorption by standardized physical tests. None of the leather alternatives showed the universal performance of leather. Woven and nonwoven fabrics, and occasionally weft-knitted fabrics, are usually used when producing synthetic leather, but warp-knitted fabrics are now being used more and more. The aim of the work is to determine the influence of the stitch length and the structure of leatherette with warp knitted fabrics underlying layer on the mechanical properties of sewn joints.

MATERIALS AND METHODS

Test samples are made of two-layer synthetic leather (Fig. 1). The underlying layer is a polyester knit, the top layer is made of a combination of Polyvinyl Chloride (PVC) with a content of 56% and Polyurethane (PU) with a content of 11%. The thickness of the two-layer synthetic leather is 1.04 mm, the density is 650g/m^2. The yarns of the underlying layer are the same, the same in the warp and weft directions.



a) **b)**

Fig. 1 Reverse side (a) and facing side (b) of tested synthetic leather.

Two types of 100% polyester threads were used to create the stitches. The first thread is a multifilament thread SYNTON fineness 30, composed of a bundle of very thin, infinitely long polyester fibres. The second thread is staple sewing thread BELFIL fineness 30, made of short length polyester fibres. The parameters of sewn joints for three stitch lengths of 4 mm, 5 mm and 6 mm were tested. Stitch length is a distance between two consecutive needle punches in one step sewn by a sewing machine. A reverse twist point LR 100 sewing needle was used to create the stitches (Fig. 2). Using LR needles the stitches have a slight diagonal inclination. With this cutting point you achieve a lenticular incision. This is done at a 45° angle to the seam direction. The result is a decorative seam inclined slightly towards the left.

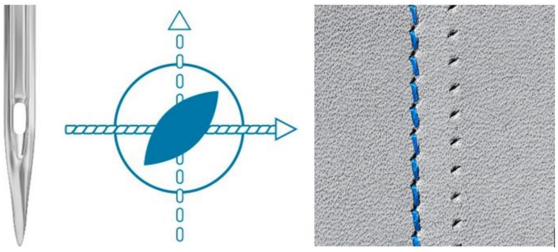


Fig. 2 LR sewing machine needle with cutting point.

The seams were loaded in the warp direction and also in the weft direction of the underlying layer of synthetic leather. In each direction, 8 test samples were tested. The stitches were made on a Juki 185 industrial sewing machine, with a tying stitch at a sewing speed of 4000 stitches/min. To determine the maximum force to rupture the seam, the Strip method, according to ISO 13935-1: 2014, was used. The tests were performed using the universal numerically controlled testing machine LabTEST 4.05. (Labor Tech). During the tensile test, the clamping length was set to 200 mm ± 1 mm, and the loading speed was 100 mm/min. The maximum force was recorded, and the type of damage of the sample was evaluated during the test. Two groups of samples were prepared to be stressed in the weft and in the warp direction of the synthetic leather underlying layer. The joints were loaded with a tensile force perpendicular to the seam line. The maximum force to rupture the seam was determined. The loading scheme of the sample and the performance of the test are shown in Figure 3.

Fig. 3 The loading scheme and sample dimension.

One of the parameters that characterizes the quality of a seam is its efficiency. Seam efficiency is defined as the capacity of the material itself to carry a seam. Seam efficiency is the ratio of seam strength to fabric strength. Equation (1) was used to calculate the seam efficiency:

$$P_s = \frac{F_{Smax}}{F_{FLmax}} \cdot 100[\%] \qquad (1)$$

Where: F_{Smax} - seamed fabric strength (N), F_{FLmax} - unseamed fabric strength (N).

The seams of the covering materials are characterized as joints with a mechanical fastener, therefore, the methodology according to EN 26891 was used to determine the size of the displacement in the joint. According to this methodology, the modulus of displacement

k_s (N/ mm) is determined in the interval from 10% to 40% of the maximum load. The slip magnitude is used as the basis for calculating the joint stiffness. The slip modulus a joint expresses force that is required to achieve a unit length deformation of the joint (Vilhanová, 2018). Joint stiffness is expressed in slip modulus k_s which is calculated by the eq. 2:

$$k_s = 0{,}4 \cdot F_{max}/\vartheta_{i,mod} \tag{2}$$

$$\vartheta_{i,mod} = \frac{4}{3} \cdot (v_{40} - v_{10}) \tag{3}$$

Where: F_{Smax} – maximum force to rupture the seam (N), v_{04} – slip at 40% F_{Smax} (mm), v_{01} – slip at 10% F_{Smax} (mm)

Statistical analyses were carried out by using STATISTICA 12 software. All test results were assessed at significant levels of 0.05. The Univariate and Independent-samples t-tests were applied to examine the interaction as well as individual effects of each parameter on the seam strength and seam efficiency. Post-hoc analysis were also performed by using Duncan test in order to determine which means of groups differ significantly.

RESULTS AND DISCUSSION

The average force achieved when breaking the reference, unstitched sample stressed in the direction of the warp is 432.00 N (coefficient of variation CV = 4.29%) with a corresponding deformation of 101.58 mm. When stressed in the weft direction, the average breaking force is 307.22 N (CV = 2.33%) with a deformation of 221.33 mm. In the direction of the warp, synthetic leather with a knitted underlying layer shows higher stiffness and less elasticity (Fig. 4). The tensile behavior of synthetic leather is non-linear mainly because of the nature of knitted fabrics of underlying layers. In the weft direction the non-linear behavior is more pronounced than in the warp direction, because these yarns are submitted to more interlacements, which is due to the higher number of warp yarns per unit length.

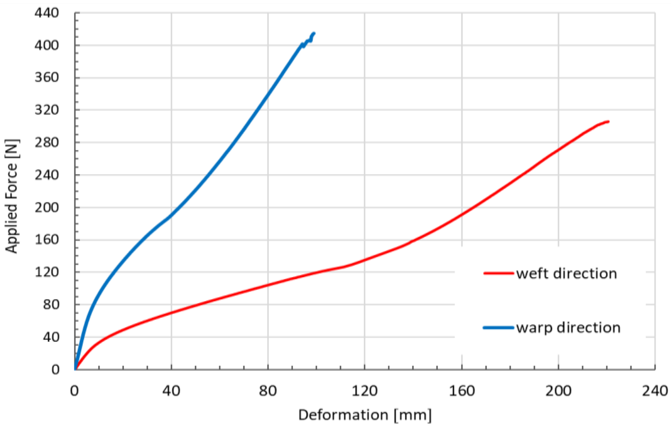


Fig. 4 Load – displacement curves unstitched sample of the in warp and weft directions.

When comparing the results with other scientific works (Ujevič *et al.*, 2009; Vilhanová *et al.*, 2022), the assumption that the samples of the synthetic leather with base layer from woven fabrics have a higher bursting strength and a smaller elongation at break than the samples of the artificial leather with base layer from knitted fabric was confirmed.

Table 1 shows the average tested mechanical properties of the seams synthetic leather in both direction, warp, and weft of the underlying layer.

Tab. 1 The average tested mechanical properties of the seams synthetic leather.

Type of sewing thread	Sewing direction	Stitch length (mm)	Seam strength $\overline{F_{max}}$ (N)	Coefficient of variation CV (%)	Seam efficiency (%)	Slip modulus (N/mm)
staple BELFIL	warp	4	357.98	3.27	82.86	4.68
		5	339.85	3.75	78.66	4.75
		6	328.46	4.21	76.03	4.63
	weft	4	276.57	5.09	90.02	0.97
		5	275.69	2.62	89.73	1.00
		6	260.40	3.12	84.76	1.03
multifil SYNTON	warp	4	350.97	4.31	81.24	4.80
		5	349.79	3.02	80.96	4.70
		6	321.82	5.18	74.49	4.32
	weft	4	281.27	3.66	91.55	1.06
		5	277.24	2.41	90.24	1.02
		6	270.30	5.08	87.98	1.00

Seams generally achieved higher rupture forces in the warp direction. The highest average values of the force at seam rupture were achieved with BELFIL staple thread, with a stitch length of 4mm (357.98N) and with SYNTON multifil thread and a stitch length of 4mm (350.97N). This difference represents only 2%. Higher seam strength in the direction of the warp of synthetic leather was also confirmed in the research of Lange *et al*., 2022 and Vilhanová *et al*., 2022.

Based on Duncan's test, the influence of the studied factors on the strength of the seam was determined. Table 2 shows that the influence of factors acting independently, namely load direction, stitch length and thread type, is statistically significant at the 5% significance level (p=0.000). However, the influence of all three factors acting simultaneously is statistically insignificant at the 5% significance level.

Tab. 2 Table of three-factor analysis of variance.

Effect	DOF	Univariate Results Significance for F_{Smax} and k_s Sigma-restricted parameterization Effective hypothesis decomposition			
		F_{Smax} Seamed fabric strength (N)		k_s Slip modulus (N/mm)	
		F	p	F	p
Intercept	1	54040.17	**0.0000**	17162.90	**0.0000**
Load Direction	1	658.58	**0.0000**	7123.27	**0.0000**
Stitch length (mm)	2	23.31	**0.0000**	2.18	0.1195
Sewing Thread	1	0.61	0.4351	0.00	0.9578
Load Direction*Stitch length (mm)*	2	2.97	0.0569	1.80	0.1723
Load Direction* Sewing Thread	1	1.56	0.2144	0.16	0.6875
Sewing Thread*Stitch length (mm)	2	0.57	0.5658	1.79	1.7338
Sewing Thread*Stitch length (mm)*Load Direction	2	2.08	0.1311	0.21	0.8092

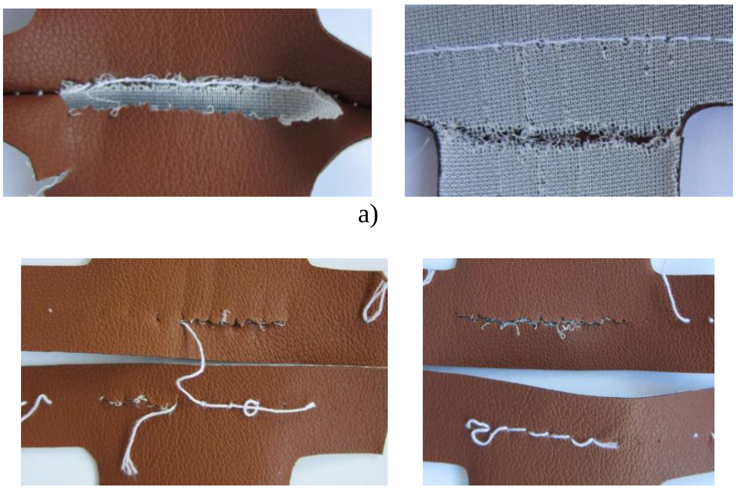
As shown in Figure 4, the unstitched reference sample has a higher stiffness in the warp direction, where the displacement modulus k_s = 4.80 N/mm, which is 80% more than in the weft direction (k_s = 1.01 N/mm). This is also visible in stitched samples, where the stiffness of the seam loaded in the direction of the warp of the underlying fabric of the synthetic leather is greater. In the case of BELFIL staple thread, the average value of the slip modulus in the warp direction is 4.68 N/mm, in the case of SYNTON multifil thread 4.606N/mm. The load direction factor is significant for the slip modulus ($p = 0.000$). Other factories as well as their concurrent effects are statistically insignificant.

According to (Gurarda, 2019), deam efficiencies of 60 – 80% are common but efficiencies between 80 and 90% are more difficult obtaining from seams. Low seam efficiency values indicate that the sewn fabric is damaged during sewing. Our measurements show a relatively high average seam efficiency (84%) for both types of threads, with a higher efficiency in the weft direction. Taking into consideration numerous parameters influencing the seam quality (type of material, type and thread count, seam type, stitch type, stitch denstiy), there are many possibilities for combining them with different final characteristics of seams. The main purpose of these combinations is defining the appropriate technical-technological parameters of sewing process to improve productivity and seam quality (Barbulov *et al*., 2012).

Evaluation of seam damage

Mechanical damages affect the aesthetics and performance of the upholstery cover. During stitching, a sewing needle may damage the fabric mechanically, breaking or fragmenting the yarns. Such damages may be apparent immediately after stitching but frequently will not appear until the product is used when seams are subjected to some form of tension, stress, strain, or deformation.

Damage at the joint in warp direction is characterized by tearing of the joined material and the sewing thread in the 4 mm stitch remains undamaged. Damage to the underlying knitted layer in the direction of the warp is visible on the reverse side of the fabric (Fig. 5 a). Damage at stitches of length 5 and 6 mm in the direction of the warp was expressed by damage to the covering material and to the connecting material, thread (Fig. 5 b).



a)

b)

Fig. 5 Failure modes of synthetic leather in warp direction
a) length stitches 4 mm, b) length stitches 5 mm and 6 mm.

At all stitch lengths 4; 5 and 6 mm in the weft direction, the material to be joined is broken, while the structure of the underlying layer around the joint is not damaged. Also, there was no breakage of the sewing thread. This is due to the lower strength of the joined material stressed in the weft direction, which is also reflected in the reference samples. It means that the failure will occur before the sewing thread itself starts to carry the load.

CONCLUSION

When sewing synthetic leather and covering materials in general, stitch factors such as thread type, stitch length, but also needle type, must be selected in such a way that the joint efficiency is not less than 70%. From this point of view, both staple sewing thread BELFIL and multifilament thread SYNTON staple threads are suitable for stitching synthetic leathers with stitch lengths of 4mm, 5mm and 6mm.

Based on the achieved strengths and the observed violation of the sewn joints, it is practical to orient the individual parts of the covering material in the creation of stitch plans. This ensures that the joint is stressed in the direction of the warp, aligning with the user's load. This practical approach is also supported by the slip modulus value, which is on average 4.5 times higher in the direction of the warp than in the direction of the weft.

When using a needle with an LR tip, both staple and endless filament sewing threads can be used. In future research, we recommend verifying the effect of thread fineness on the strength of upholstery stitched joints.

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ACKNOWLEDGMENT

This work was supported by the Scientific Grant Agency of the Ministry of Education, Science, Research, and Sport of the Slovak Republic Grant No. 1/0264/22.

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