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INVESTIGATION OF THE INFLUENCE OF TECHNOLOGY PARAMETERS AND THREAD TYPE ON EMBROIDERED TEXTILE ELEMENT QUALITY

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Abstract:

Embroidery can be applied to improve esthetic or functional properties of products. However, the expected appearance of the original design may be discarded by unsuitable selected technological parameters of embroidery machine. Thus, the influence of the technological parameters and embroidery thread types on the embroidery geometric parameters and on tension characteristics of embroidery has been investigated in this research.

The research results revealed that the changes in geometry parameters of the designed digital image compared with the ones of actual embroidery samples are dependent on embroidery filling type, stitch density, and thread type. Mechanical testing of the embroidery elements has proved that embroidering influences the decrease in material breaking force and elongation at break compared with their initial tension characteristics.

Keywords:

Embroidery technology, PU-coated fabric, SEM, geometric parameters, thread, fluorescent, metallic, tension characteristics

Introduction

Embroidery can be applied to improve garment esthetic or functional properties. Embroidery is found in various new functional applications in fashion engineering, medicine, or smart textiles due to the unique opportunity of creating three-dimensional light-weight structures and laying threads on the base material in all directions. It is remaining one of the advantageous technologies due to the opportunity to vary in sensor geometry design and material choice [1]. The wearable electronics may be integrated directly into smart textile products applying embroidery [2]. The embroidery technique is also considered as the advantageous manufacture technology for wearable textile antennas due to several reasons: bespoke or mass-produced designs can be manufactured using digitized embroidery machines; glue is not required; and the designs are more esthetic and integrated into clothing rather than being attached to it [3].

Standard embroidery technology represents an additional processing tool for fibrous biomaterials, which can be applied in medicine [4]. However, the use of industrial embroidery machines limited the values of stitch density and the spatial resolution of stitches [4]. Therefore, for designing more complex textile architectures, the use of thinner yarns, higher stitch densities, and machine modifications was considered as being of high importance for the development of industrial embroidery machines [4]. The manufacturing process of smart textile and clothing uses the multilayered embroidery method that requires especially high accuracy [2, 5, 6]. However, a very common governing problem in embroidery manufacture is that the shape and dimensions of the actual embroidery do not usually conform to the shape and dimensions of the designed digital image [5]. There are several objective evaluation methods for the examination of the conformity of shape and dimensions of embroidered elements to the designed digital ones. These methods are based on the measurements of the geometrical parameters of circle [7, 8] or rectangle [9]. In both cases, the designed element is fully filled by embroidery threads. Former investigations have also demonstrated that the greatest nonconformities were observed in the stitch formation direction of the embroidered element, and they are influenced by structural distinctions and properties of fabrics and threads, embroidery filling, technological parameters, technical characteristics of embroidery machines as well as type of material fixation in it, working method, and worker's experience [5, 9]. It was proven also that the embroidery direction makes the influence on the elongation of the embroidered element [2]. Moreover, the waves with different height and different shape may be formed inside the embroidery element dependently on the type of embroidery threads [10-12]. Notwithstanding several attempts toward objective evaluation of embroidery accuracy, it can be seen that the objective evaluation of embroidery quality has not been studied widely. Also, there was not considered that during embroidering, the sewing needle makes very frequent penetrations into material structure during the stitching, and the needle may damage material structure, especially the one of the coated materials. This situation may influence the change in material strength and deformation. Furthermore, the damaged polyurethane (PU) coating of knitted fabric influences the worse functionality and appearance of product.

Thus, the aim of this research is to evaluate the influence of the embroidery technological parameters of the industrial computerized embroidery machines and embroidery thread types on the geometric parameters as well as on the tension characteristics of original design elements embroidered on PU-coated polyester (PES)-knitted fabric.

2. Experimental

2.1. Materials

The object of investigation was commercially available PES-knitted fabric coated with porous PU layer fabric (CF; Figure 1) suitable for jackets, dresses, trousers, and other product manufactures (fabric course density—21 loops/cm; fabric wale density—15 loops/cm).

Two layers of polyester nonwoven fabrics (NF) were applied for the stabilization of embroidery area. The edges of NF pieces were removed after embroidery process. The multilayer textile system CF+2NF was embroidered applying the different embroidery threads (Table 1) and technological parameters (Table 2 and Figure 2).

The thickness of coated fabric (CF), h_{CF}, and embroidery sample were measured with I-40-L SCHMIDT gauge with 0.01 mm accuracy at 49 kPa pressure. The thickness of CF was equal to 0.48 mm. Area density (mass per area) of the CF was determined according to the standard LST EN 12127 [13], and it was found being 404.57 g/m^2. The area density of NF was obtained 53 g/m^2 in compliance with LST EN 29073-1 [14]. The thickness of NF, h_{NF}, was equal to 0.46 mm.

Five specimens were tested for each set of samples. Structure parameter measurement error varied from 0.75% to 3.49%.

Designed digital image (Figure 2a) was embroidered applying commercially available embroidery threads, the characteristics of which are presented in Table 1.

The influence of technological parameters (Table 2) on the geometric parameters and tension characteristics of embroidery was determined using SL1 embroidery threads (Table 1). They were used for the threading of machine needles and shuttle. The appearance and quality of the embroidery applying different types of embroidery threads also may vary due to the differences among their thickness, construction, fiber composition, and application area [7, 10, 11]. On the basis of the determined optimal technological parameters, the influence of thread type on the embroidery quality was investigated using SL2, SL3, and SL4 threads for the needle threading (Table 1) and SL1 threads—for the shuttle threading in all cases.

2.2. Embroidery technological parameters

Embroidery digital images (Figure 2a) were designed applying *Wilcom Embroidery Studio* software (e3.0 version).

The designed digital images were embroidered on CF (Figure 2b) using an industrial machine *Barudan* with one embroidery head. The head was equipped with 15 *Schmetz* needles (size no. 11). The long axis of embroidery was oriented lengthwise course direction of CF. *Zigzag* underlay was embroidered according to the designed digital image shown in Figure 2c. 0.2 mm pull compensation was adjusted. An automatic thread cutting was turned on in that case if the next embroidered element was at a larger distance than 6 mm, and the bar-tack of the last stitch was programed if the location of the next element was expected at a larger distance than 2 mm. The bar-tacks were also programed in start and end points. 2 mm travel run was adjusted. 35% shortening of the stitches was chosen. Maximum number of shortened stitches was 5. Designed digital image was saved in *.*dst* format and stored on the computer memory.

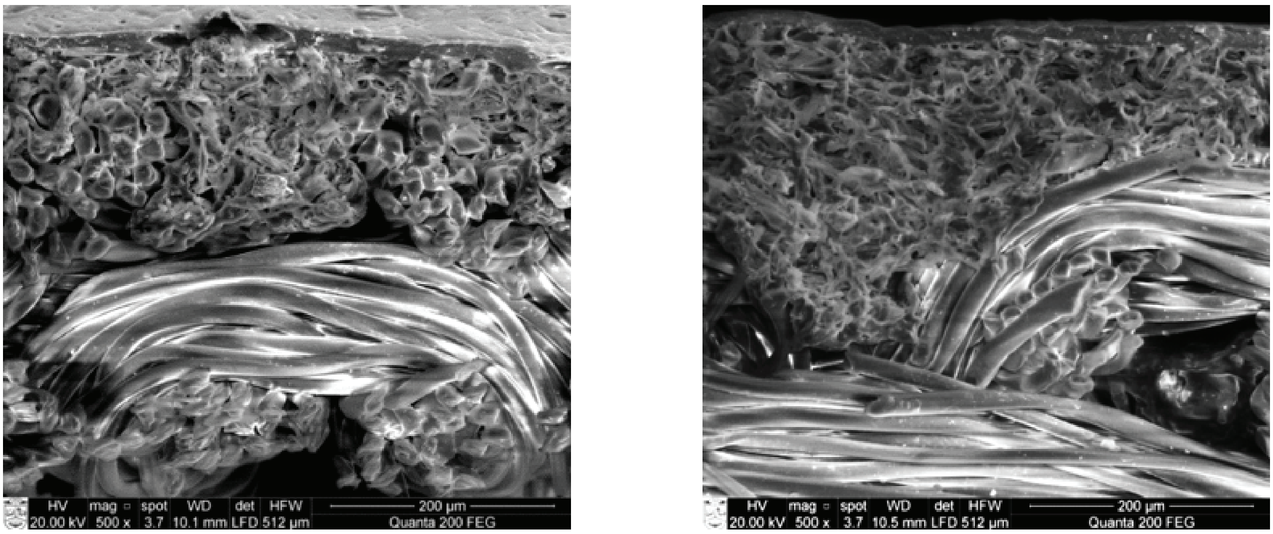

Figure 1. SEM images of the PU-coated PES knitted fabric's cross-sections: course (a) and wale (b).

Table 1. Characteristics of embroidery threads

Sample code	Manufacturer, Name/ code	Ticket no.	Fiber composition	Color	Application
SL1	Amann, Isacord 0145	40	100% PES	Gray	Standard
SL2	Madeira	60	100% PES	Gray	Small thickness
SL3	Gunold, Glowy Weiss	40	50% PES, 50% PP	White	Fluorescent
SL4	Isamet, 0511	40	36% PES, 42% PA, 22% others	Gray	Metallic

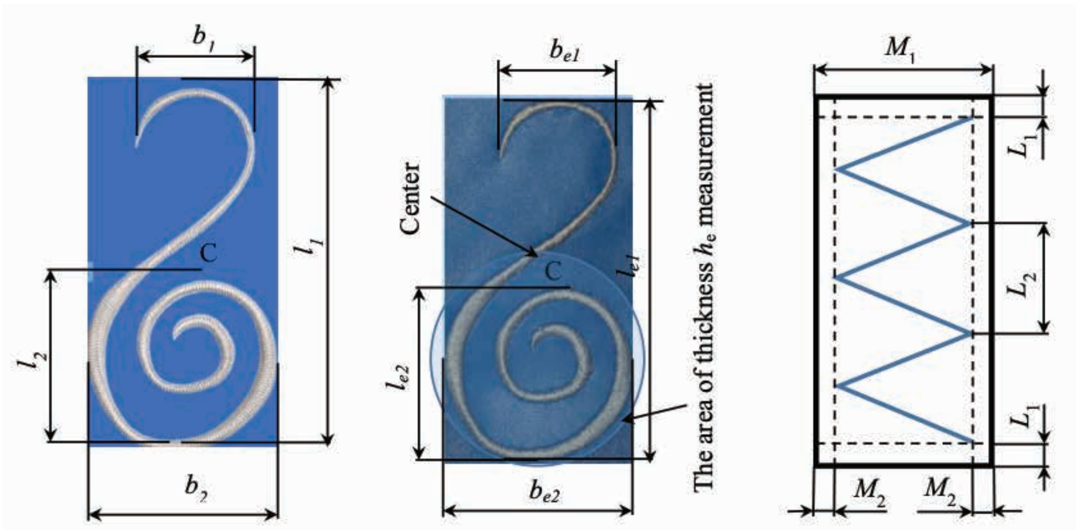

Figure 2. Designed digital image with the dimensions: b_1 and b_2 widths as well as l_1 and l_2 lengths (a), embroidery sample with the measurement scheme of geometry parameters: b_{e1} and b_{e2} widths as well as l_{e1} and l_{e2} lengths and h_e embroidery thickness (b); underlay parameters (2 mm spacing [L_2], 5 mm stitch length [L_3], 0.3 mm distance from contour line [M_2], 2 mm distance between under layer contour [L_1], and embroidery start point/end point, M_1 - total embroidery height) (c).

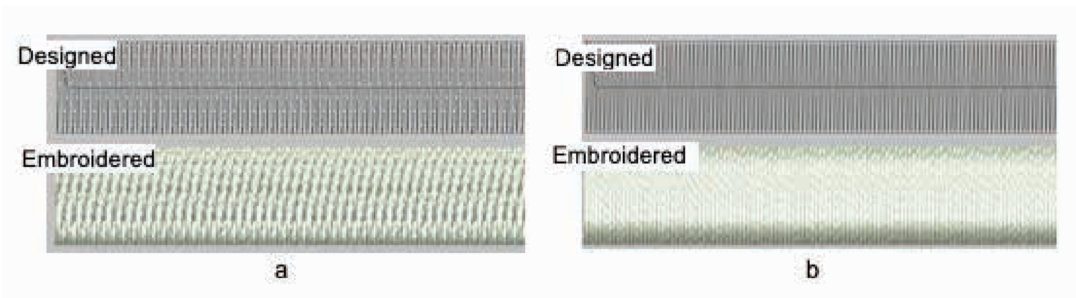

Figure 3. Filling types: *Tatami* (a) and *Satin* (b).

Two filling types *Tatami* (Figure 3a) and *Satin* (Figure 3b) were applied for the embroidery of designed images.

Stitch density was changed for both cases. *Tatami* filling is more suitable for the embroidery of larger material areas. These areas can be covered by overspread short stitches, which could be oriented toward different sample directions. This filling type influences the lower fabric shrinkage due to embroidery, and it could be used as the under layer of embroidery.

Satin filling is the most usually applied for the embroidery of the narrow-designed images, which could be covered by one continuous zigzag stitch. The maximum available length of this type of stitch is recommended to be 10 mm because of the limit when the high embroidery quality may be ensured. Embroidery covered with this stitch mode is more raised and smoother. In this case, sample shrinkage increases because of longer embroidery stitches. Three groups of samples were embroidered with *Satin* mode selecting the autosplit of the stitch near 9 mm length value and changing the stitch density parameters (Table 2).

Five specimens were tested for each set of samples, and they were conditioned according to the standard LST EN ISO 139 [15] before embroidery quality evaluation tests to ensure the full relaxation of embroidery threads.

Table 2. Embroidery technological parameters

Filling type					
***Tatami* (Stitch length—4.2 mm)**			***Satin* (Stitch *autosplit*—every 9 mm)**		
Sample code	Quantity	Stitch density parameter (mm)	Sample code	Quantity	Stitch density parameter (%)
T1	5	0.30	S1	5	70
T2	5	0.40	S2	5	80
T3	5	0.45	S3	5	90

2.3. Determination of the changes in the embroidery geometry parameters

Embroidery samples were captured using a digital Nikon D3100 image camera, which was fixed stationary at a distance h_1 of 30 cm from the sample surface placing a ruler beside to evaluate the capturing scale. The center of camera lens was matched with the center of embroidered element C (Figure 2a and b). Captured images (Figure 2b) were edited, and the measurements of geometry parameters were processed applying *Corel DrawX6* software package.

Widths (b_{e1} and b_{e2}) and lengths (l_{e1} and l_{e2}) of the embroidery sample were measured using the scheme shown in Figure 2b. Dimension conformity between embroidered element (Figure 2b) and designed digital image (Figure 2a) was determined. Percentage changes in the geometrical parameters of embroidery were calculated according to the following equations (1)–(4):

Change in length $$\Delta l_1 = \frac{l_{e1} - l_1}{l_{e1}} \times 100 \quad (1)$$

Change in width $$\Delta b_1 = \frac{b_{e1} - b_1}{b_{e1}} \times 100 \quad (2)$$

Change in length $$\Delta l_2 = \frac{l_{e2} - l_2}{l_{e2}} \times 100 \quad (3)$$

Change in width $$\Delta b_2 = \frac{b_{e2} - b_2}{b_{e2}} \times 100 \quad (4)$$

where Δl_1 and Δl_2 - the changes in length parameters; Δb_1 and Δb_2 - the changes in width parameters; l_1 and l_2 - designed length parameters (mm) (Figure 2a); b_1 and b_2 - designed width parameters (mm) (Figure 2a); l_{e1} and l_{e2} - the length parameters of embroidery (mm) (Figure 2b); and b_{e1} and b_{e2} - the width parameters of embroidery (mm) (Figure 2b).

Changes in the embroidery sample thickness compared with the sum thickness of CF and two layers of NFs h_{CF}+2h_{NF} were determined according to the following equation (5):

Change in thickness Δh,%:

$$\Delta h = \frac{h_e - (h_{CF} + 2h_{NF})}{h_e} \times 100 \quad (5)$$

where h_e – thickness of embroidery sample, mm; h_{CF} – thickness of CF, mm; and h_{NF} – thickness of NF, mm.

2.4. Uniaxial tension testing

Uniaxial tension test was carried out at ambient temperature using computerized CRE-type tension machine H10 KT (Tinius Olsen, UK) with a load cell of 10 kN. A tension velocity (crosshead speed) was 100 mm/min. The dimensions of working area of the lengthwise oriented fabric sample were 100 mm x 50 mm. Five specimens were tested for each set of samples in uniaxial tension test. The measurement errors in uniaxial tension test varied from 6.74% to 25.59%.

3. Results and discussion

Depending on the manufacturer's requirements as well as on the expected quality embroidery, parameters for the same embroidery design and fabric may differ. Analyzing the influence of filling type and technological parameters on the geometry of embroidered element, it has been determined that $h_{(CF+2NF)}$ thickness (Figure 4), designed as b_1 and b_2 width parameters as well as l_1 and l_2 length dimensions of digital image (Figure 5) in all cases, did not correspond with the ones of the embroidery samples. For all the cases that were tested, the thickness of the embroidery samples increased from 20.59% to 66.18% depending on the technological embroidery parameters and from 25.74% to 61.03% depending on the thread type.

From Figure 4a and b, it can be seen that the changes in thickness increase after increasing stitch density for *Tatami* and *Satin* fillings. The changes in thickness of the embroidery samples are higher for *Satin* filling than for *Tatami* due to the different stitch filling constructions (Figure 3).

Evaluating the influence of different thread types on the change in CF's thickness due to embroidery, the highest increase in the

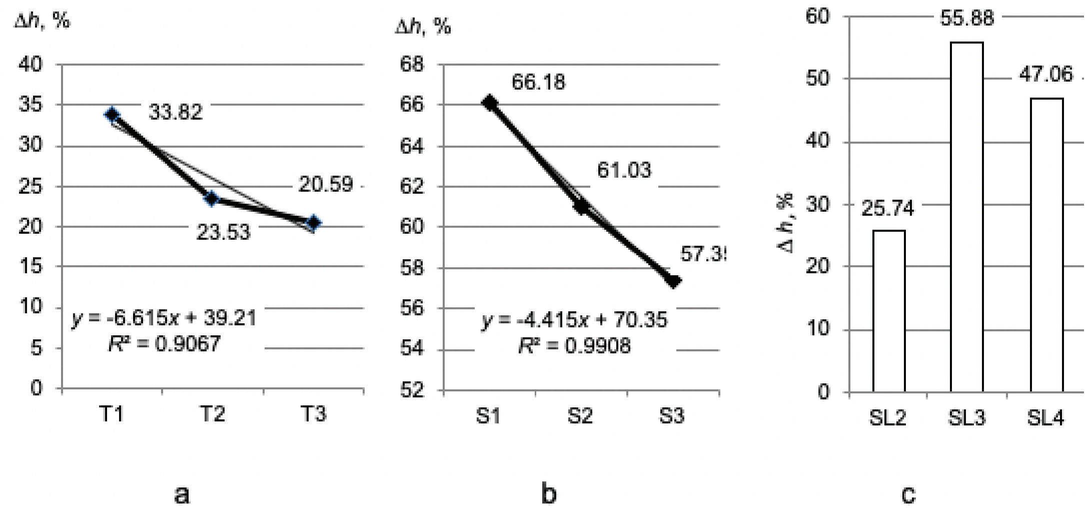

Figure 4. Percentage changes in the embroidery sample thickness Δ*h* applying SL1 embroidery threads for both *Tatami* filing (T1, T2, and T3) (a) and *Satin* filing (S1, S2, and S3) (b) and for different embroidery threads SL2, SL3, and SL4 with S2 technological parameter set (c) (*Note*: Measurement error varied from 0.75% to 3.42%).

sample thickness was determined for SL3 fluorescent thread because of their specific finishing and higher stiffness.

The ticket number did not make influence on the changes in embroidery thickness as the SL2 and SL3 threads having the same numbers have shown the different values of the changes in embroidery sample thickness (Figure 4c). Also, these changes for SL2 thread were considerably lower than the ones for SL3 embroidery thread.

The analysis of the obtained results presented in Figure 5 has shown the nonconformities of geometry parameters Δb_1, Δb_2, Δl_1, and Δl_2 between the designed digital images and the ones of the actual embroidered images (Figure 2a and b).

These nonconformities were dependent on the filling type (*Tatami* or *Satin*) as well as on the stitch density, which has been applied for embroidery (Table 2) and on the type of embroidery threads (Table 1).

These nonconformities were not very high, but they demonstrate some tendencies. The higher nonconformities of widths (Δb_1 and Δb_2) and Δl_1 length are obtained when the *Satin* filling (S1, S2, and S3) is applied. This appears using one long stitch, which may be up to 10 mm. In this case, there is more space for the formation of the wave inside of embroidery when the CF has been locked between the two adjacent needle penetration points. These fixed waves due to fabric buckling have been locked inside embroidery influence the changes in the geometry parameters of embroidered element [7, 8]. *Tatami* filling decreased the material shrinkage due to embroidery up to minimum expected values compared with the one of *Satin* filling. Meanwhile, the application of *Tatami* (T1, T2, and T3) filling influences the lower changes in the geometric parameters of embroidery compared with the *Satin* filling instead of the change in Δb_2 parameter that was higher. The reason for this could be the tight filling of the CF surface with overspread short stitches, which were oriented toward different directions. b_2 parameter was very important for whole appearance of embroidery. Thus, based on the obtained results as well as on additional visual evaluation, the S2 set of

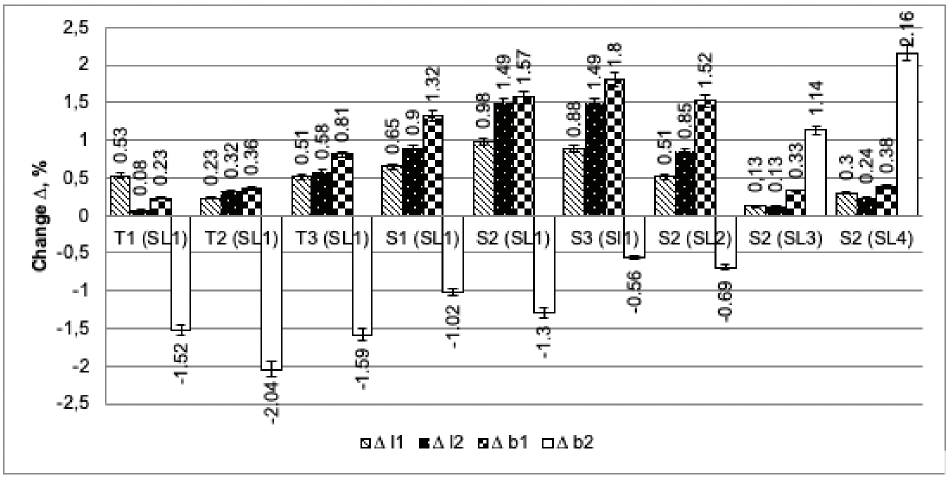

Figure 5. The changes in embroidery dimensions: widths (Δb_1 and Δb_2) and lengths (Δl_1 and Δl_2) in the case of applying SL1 embroidery threads for both *Satin* (S1, S2, and S3) (a) and *Tatami* filing (T1, T2, and T3) (b) and for different embroidery threads SL2, SL3, and SL4 with S2 set of technological parameters (c).

technological parameters was chosen as the optimal one to investigate the influence of thread type on embroidery quality.

The analysis of the obtained results in the context of other authors [7, 8, 11] has revealed that the assessment of embroidered element properties and embroidery thread deformation plays a crucial role. Between embroidery stitches, the fabric is compressed [7, 10, 11], and the waves inside the embroidered element have been formed. The size of waves has been dependent on the thread properties [7, 10]. Analysis of the investigation results (Figure 5) has demonstrated that the smallest nonconformities between designed and actual embroidery b_2 dimension were observed by SL2 embroidery threads and between l_1 dimension – by SL3 fluorescent embroidery threads.

During product wear, materials are affected by various external mechanical forces that influence garment comfort, durability, and esthetic appearance. Thus, the influence of the embroidery on the tension characteristics of the CF was investigated (Figure 6). Initial tension characteristics of the CF were 588.8 N force and 76.26% elongation and of the NF were 15.2 N and 34.04%, respectively. The uniaxial tension characteristics of the initial fabric system CF+2NF were as follows: 650.0 N breaking force *F* and 80.60% elongation at break *ε.*

The changes in the mechanical properties such as strength and extension of CF in the embroidery zone should be considered due to the importance of different parameters. During embroidery process, the CF is damaged by puncturing it by the sewing needle near the embroidery contours and its strength and elongation decrease (Figure 6). And, the amount of material damage is directly dependent on the needle parameters as well as on the density of stitches [16]. The material is also puckered around all embroidered contour due to some reasons: embroidery thread extension and followed relaxation, the changes in material structure as well as its transportation in the embroidery process [11, 17].

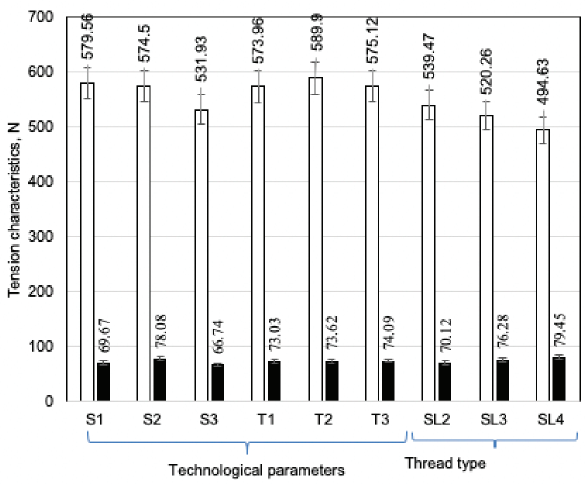

Figure 6. Force at break (white columns) and elongation at break (black columns) of embroidery applying SL1 embroidery threads for both *Satin* filing (S1, S2, and S3) and *Tatami* filing (T1, T2, and T3) as well as for different embroidery threads SL2, SL3, and SL4 with S2 technological parameters.

During analysis of the influence of technological parameters for both *Tatami* and *Satin* fillings, it is evident that the breaking force *F* of the embroidery samples decreased from 1.6% to 9.7% (instead of T2 case when it was increased in 1.2%) compared with the CF and from 9.2% to 18.2% compared with the one of the fabric systems CF+2NF, which was used in the embroidery process. The elongation at break *ε* of the embroidery samples decreased from 2.8% to 12.5% (instead of S2 case when it was increased in 2.4%) compared with the CF and from 3.1% to 17.2% compared with the one of the fabric systems, which was used in the embroidery process.

The comparison of the embroidery breaking force with the one of the fabric systems is more important than the one of the CF as the NF layers stay inside embroidery, and it strengthens the sample.

During the investigation of the influence of the embroidery thread type on tension characteristics, it was shown that the use of SL4 metallic thread decreases mostly (in 23.9%) the breaking force of the embroidery compared with the one of the CF+2NF systems and with the one of the CF, that is, in 16%. The elongation at break remains almost unchanged in that case.

4. CONCLUSIONS

- There were shown that the changes in the thickness, widths, and lengths of the designed digital images compared with the ones of actual embroidery samples are dependent on the filling type, stitch density, and thread type. The changes in the thickness of embroidery manufactured applying *Satin* filling were higher compared with those of *Tatami* filling. The thickness of embroidery increases after the increase in stitch density for both *Satin* and *Tatami* filling types.
- The breaking force and elongation at break of the embroidery samples were decreased compared with these characteristics of the CF as well as with the ones of the investigated fabric system (CF+2NF) in almost all cases.
- The results investigating the influence of the embroidery thread type on the accuracy of embroidery have shown that the changes in embroidery thickness are the lowest compared them with the ones of other investigated embroidery threads applied with the S2 set of technological parameters.
- Aiming to avoid the poor quality of the embroidered samples, the design of digital image could be discarded previously. Therefore, these corrections could be made with respect to the structural distinctions of applied fabrics, to fabric deformation properties as well as to the thread type. Ensuring the achievement of this purpose, the most suitable embroidery technological parameters (filling, stitch type, density, etc.), one or two underlays, and other implements should be chosen.

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