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MATERIALS SCIENCE

Buckling of the woven fabric inside an embroidered element

Svetlana Radavičienė* and Milda Jucienė

Department of Clothing and Polymer Products Technology, Kaunas University of Technology, Studentu Str. 56, LT-51424 Kaunas, Lithuania

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Abstract. Today technologies of embroidery are applied for the production of composite materials, intelligent (smart) clothing or textiles as well as in medicine. In the modern production of garments, embroidery fulfils decorative, informative, and safety functions. The possible best quality of the embroidered element has to be ensured. The woven fabric covered with embroidery threads is compressed and buckled between the needle pricks. Such effects may result not only in relaxation processes in the embroidery threads after the embroidery process but may also affect the properties of the embroidered material. The behaviour of the material inside an embroidered element may result in the thickness of the material and influence its structure, bending rigidity, formability, shear stiffness, etc. Our aim was to investigate the buckling of materials with different physical properties inside embroidered elements. For investigations woven fabrics with different structure and mechanical properties and polyester embroidery threads were selected. The digital design (width 6 mm, length 60 mm) was generated applying Wilcom Embroidery Software 2006 Software Package. An automated embroidery machine Barudan BEVT-Z901CA was used to prepare the specimens. Embroidering process speed of 700 stitches per minute was applied. Six test specimens were embroidered in the warp and weft directions. The investigation showed that fabric structure indicators such as linear filling and linear porosity influence the formation of the height and shape of the buckling waves inside the embroidered element.

Key words: fabric, buckling, embroidery, embroidery threads, embroidered element.

INTRODUCTION

In modern production of garments, embroidery fulfils many more functions than just decorative, informative, or safety assurance functions. Embroidery technologies may be applied in medicine (for diagnostics and rehabilitation, production of implants), production of composite materials, manufacture of intelligent garments or textile items [1–8]. Therefore, the best possible quality of the embroidered elements shall be ensured. The woven fabric surrounded by the embroidery threads between adjacent needle pricks inside the embroidered element is compressed and buckled. Such effect may be caused both by the relaxation processes taking place in embroidery threads after the embroidery process and properties of the fabric [7,9]. Under the impact of certain forces, deformation of textiles varies subject to fibre composition and physical properties of the fabrics. The behaviour of stretch fabrics inside the embroidered elements may be influenced by the elastane filaments that these fabrics contain in the direction of warp and/or weft [10,11]. Analysis of the results of investigations with respect to buckling and compression of textiles has served as basis for drawing the conclusion that the fabric structure, direction, and mechanical properties as well as the stitching pattern direction, place, and density have a great influence on the deformation behaviour [12–16].

Assembling of textiles by an embroidery process was investigated by the Russian scientist Chernenko [17]; however, no detailed analysis of the influence made by fabric properties and technological factors on embroidery quality was carried out. The behaviour of embroidery articles in the process of wear was examined by researchers from Alexandria University in order to optimize the embroidery area, type of threads, and type of the needle according to fabric thickness. The behaviour of an embroidery garment in the process of

* Corresponding author, svetlana.radaviciene@stud.ktu.lt

wear is studied by measuring the embroidery design drapability, bending length, and crease recovery before washing as well as after 10 and 30 washing cycles [18].

Our aim was to investigate the buckling of fabrics with different physical properties inside an embroidered element.

MATERIALS AND METHODS

For investigations 15 fabrics differing in weave, thickness, surface density, density in the weft and warp directions, and other structures and mechanical properties were selected. Embroidery threads are grouped into upper embroidery threads and lower embroidery threads. We used industrial 100% polyester upper embroidery threads featuring the greatest reversible deformation [9] and 100% polyester lower embroidery threads.

The characteristics and performance of embroidery threads are listed in Table 1 and those of the fabrics selected for investigations in Table 2.

Thread density (P_m, P_a) and linear density (T_m, T_a), and surface density (W) of the threads of the fabric selected for investigation were established in compliance with LST EN 1049-2 and LST ISO 3801, respectively [19,20]. Diameters of warp and weft yarns (d_m, d_a) were calculated after evaluating the density and mass of volume of the fabric fibres. Peirce linear filling indicators e_m and e_a and surface filling indicator e_s were estimated using the least fabric thread density (P_m, P_a) and calculated yarn diameter (d_m, d_a).

The thickness (h) of the fabrics was measured with a thickness gauge SCHMIDT DPT 60 digital. Pressing plane area and pressing pressure of the thickness gauge are 20 cm^2 and 1.0 kPa, respectively. Ten measurements of test specimens of each selected fabric were carried out. Averages of the measured thickness values of the fabric were calculated; the relative error of measurement results did not to exceed 4%.

For tests an automated embroidery machine Barudan BEVT-Z901CA with one head and nine needles was used. Embroidery process speed of 700 stitches per minute was applied. For the experiment, test specimens (size 21.0 cm × 21.0 cm) of the selected fabrics were placed in a 13.0 cm diameter embroidery hoop. According to the manufacturer's recommendations, small-diameter hoops were used as far as possible. The fabric in the embroidery hoop was tight without wrinkles. The embroidery area was filled forming each stitch from one edge of the embroidery pattern to the other (Fig. 1).

Table 1. Characteristics and performance of the polyester (PES) embroidery threads

Legend	Raw material	Purpose	Composition	Linear density, tex
ETU	100% PES	Upper thread	Two-ply yarn, multifilament	27.0
ETL	100% PES	Lower thread	Two-ply yarn	24.7

Table 2. Characteristics and performance of the fabrics

Legend	Raw material	Weave	Thickness (h), mm	Surface density (W), g m^{-2}	Number of threads per unit length, cm^{-1}		Linear density, tex	
					P_m	P_a	T_m	T_a
A1	100% linen	Plain	0.34	150	19.9	18.4	26.3	26.3
A2	100% cotton	Plain	0.26	144	52.0	40.0	13.6	14.3
A3	67% cotton, 33% PES	Plain	0.30	137	42.0	28.0	19.0	19.0
A4	70% linen, 30% rayon	Plain	0.36	111	18.0	20.0	34.5/17.6	41.1/17.3
A5	45% wool, 55% PES	Plain	0.34	169	25.0	22.0	34.1	34.9
A6	100% PES	Plain	0.51	174	22.1	20.9	39.1	38.6
A7	50% rayon, 23% PES, 23% PA, 4% elastane*	Plain	0.54	245	45.9	23.2	10.2	72.2/70.6
A8	51% PES, 36% rayon, 12% virgin wool, 1% elastane**	Twill	0.53	241	36.1	25.9	35.0/30.3	35.2
A9	100% rayon	Plain	0.32	102	35.1	27.0	14.9	15.1
A10	85% linen, 15% PA	Twill	0.35	102	42.2	29.9	2.8	30.4
A11	98% PES, 2% elastane**	Satin	0.38	210	80.2	28.1	18.9	17.8
A12	100% PES	Satin	0.38	160	78.1	35.9	10.1	19.1
A13	100% linen	Plain	0.41	144	22.2	16.0	36.5	35.3
A14	100% PES	Satin	0.66	217	84.1	45.9	14.5	11.3
A15	65% wool, 35% PES	Rips	0.71	259	46.2	33.9	29.8	30.1

PES – polyester, PA – polyamide, * – with elastane yarn in the warp direction, ** – with elastane yarn in the weft direction.

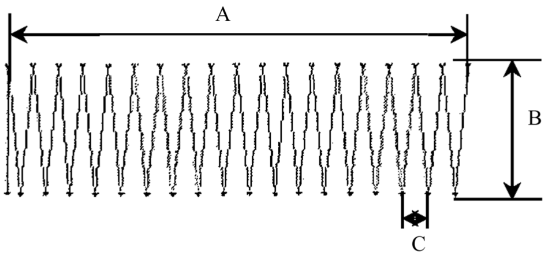

Fig. 1. Embroidery area formation diagram: A – length of the embroidered element = 60 mm, B – width of the embroidered element = 6.0 mm, C – stitch density = 0.42 mm.

Applying a correctly balanced embroidery stitch (on the back side the lower embroidery thread should occupy not less than 1/3 of the embroidery area), six test specimens of each selected fabric were embroidered in the warp and weft directions. The embroidery pattern width was 6 mm, length 60 mm, and stitch density 0.42 mm. The digital image was generated applying Wilcom Embroidery Software 2006 Software Package.

The behaviour of the fabric inside the embroidered element was analysed 24 h after the embroidery process when the test specimens were relaxed in standard conditions [21,22]. The test specimens of the 15 fabrics selected for analysis and embroidered with polyester embroidery threads were photo-captured in the middle of the embroidered element. Around the embroidered element, the test specimen was cut leaving ≈15 mm edges of the fabric. Before fastening into clamps, the embroidered element was cut in the middle. The prepared test specimen was fastened into clamps at a distance of ≈2 mm from the embroidered element to the clamps (Fig. 2).

Test specimens were shot with a digital camera OLYMPUS E620 1 with a resolution of 4032 × 3024 pixels. For photography, lens SIGMA AF-MF ZOOM LENS 105 mm F2.8 EX DG MACRO was used.

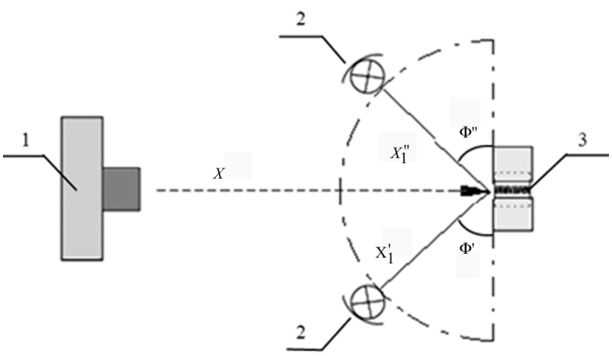

Fig. 2. Illustration of a photo-captured embroidered test specimen by a digital camera: 1 – digital camera; 2 – light source; 3 – test specimen. Distance between 3 and 1 is $X \approx$ 0.35 m; distance from light source 2 to test specimen 3 is $X_1' = X_1'' \approx 0.1$ m. The angle between the test specimen and light propagation direction $\Phi' = \Phi'' = 45°$.

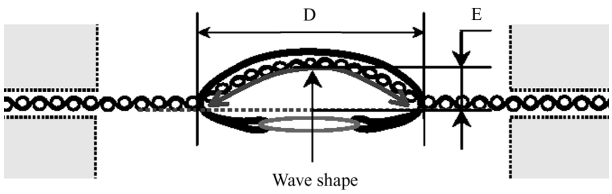

Fig. 3. Diagram for measuring an embroidered element: D – embroidery width, E – wave height.

For measuring the height of the compression (buckling) wave inside the embroidered element ImageJ Software Package was employed. It was presumed that the material inside the embroidered element (*D*) is in accordance with the coordinate system's *x*-axis. The buckling wave height (*E*, mm) was measured between the *x*-axis and the highest (maximum) point of the wave. The shape of the wave inside the embroidered element was obtained applying COREL DRAW X5 Software Package (Fig. 3).

The data obtained were processed statistically. Averages of values of investigation results as well as variation coefficients were calculated. The variation coefficient values did not exceed 9.6% in any case.

RESULTS AND DISCUSSIONS

The behaviour of the fabrics inside the embroidered element was influenced by the properties of the embroidery threads. Analysis of the results of the investigations indicated that the residual elongation ε_1 (amounting to 0.2%) of polyester embroidery threads ETU was significantly lower compared to their elastic elongation value ε_b (amounting to 2.67%). As elastic deformation is reversible, the threads may shrink after the embroidery process, possibly causing the puckering of the embroidered element.

Between the embroidery stitches the textile covered with embroidery threads is compressed and buckled inside the embroidered element, where waves of different shape and height will be formed. Referring to analysis of the results of the investigations, the following types of shape of the buckling wave inside the embroidered element may be discerned (Fig. 4):

1. even contour-shaped buckling waves (Fig. 4a),
2. flat S-shaped buckling waves (Fig. 4b),
3. uneven complex-shaped buckling waves (Fig. 4c).

Theoretically, the material inside the embroidered element should comply with the coordinate system's *x*-axis. However, due to relaxation processes occurring in embroidery threads after the embroidery process and properties of the fabric, a buckling wave is formed inside the embroidered element (Fig. 4).

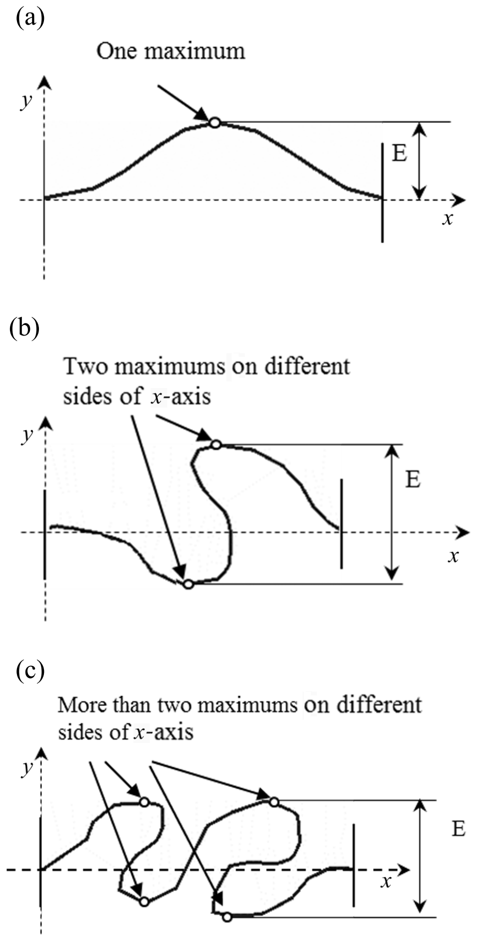

Fig. 4. Types of shapes of waves: a – Type 1, b – Type 2, c – Type 3. E – height of wave.

The buckling wave of Type 1 is formed inside the embroidered element on the positive side of the *y*-axis and it has one maximum point (Fig. 4a). The buckling wave of Type 2 is a more complex form of the wave: buckling waves are formed and the positive and the negative side of the *y*-axis has one highest and one lowest point (Fig. 4b) (i.e. has two maximums on different sides of the *x*-axis). Therefore the wave height is measured between these two points. The buckling wave of Type 3 is formed with two highest and two lowest points (Fig. 4c). In this case the wave height is defined by the maximum distance between the highest and the lowest points.

It was established that the shape of the wave depended on the structure of the fabric. Buckling waves of Type 1 were observed in the case of the embroidered elements of fabrics A1, A4, A10, and A13. Inside the embroidered elements the fabric threads were compacted after embroidery, thereby making the buckling wave slightly curved.

Buckling waves of Type 2 were formed inside the embroidered elements of fabrics A2, A3, A5, A6, A9, A14, and A15. These cases were influenced by the fact that the fabrics featured large values of fabric surface filling indicator (from 0.80 to 1.0).

Waves of Type 3 formed in the direction of warp in fabrics A8 and A11, and in the direction of weft in fabric A7. The values of surface filling indicators in fabrics A7 and A8 exceeded 1 in both these directions.

Comparison of the fabrics allows discerning a group of fabrics, i.e. A7, A8, A11, in which the shape of the buckling wave and its height inside the embroidered element in one direction of the fabric were significantly different from those in the other direction of the fabric. Fabrics A7, A8, and A11 contain elastane filaments: fabric A7 contains an elastane filament in the warp direction, whereas fabrics A8 and A11 contain an elastane filament in the weft direction. In these fabrics, the linear filling indicators in opposite directions were different. Formation of waves with different parameters in the weft and warp directions may be caused by different fibre composition of the fabrics (elastane filament) and different fabric density in the warp and weft directions.

Fabric A12 does not contain elastane filaments, but the buckling waves of Type 1 were observed inside the embroidered element in the weft direction. Flat S-shaped buckling waves of Type 2 were formed inside the embroidered elements in the warp direction. This could be influenced not only by the composition of the fibrous fabric, but also by the type of weave and the different structure of threads in the warp and weft directions.

A strong relation was established between porosity indicators of the fabric ε_m and ε_a and height values of buckling waves (Fig. 5a, b). Lower values of porosity indicators of the fabric were found to result in a lower height of the buckling wave. In this case, the correlation coefficients r in the warp and weft directions were –0.8538 and –0.7086, respectively. Thus, the lower the porosity of the fabric, i.e. the larger portion of the fabric was filled with threads, the higher was the wave formed by the fabric inside the embroidered element.

Analysis of the results revealed that linear filling indicators of fabrics and height values of the wave formed inside the embroidered element had a significant positive relationship (Fig. 6). A greater linear filling indicator of the fabric resulted in a higher wave inside the embroidered element. In this situation, fabric threads under compression have no space for compaction, and therefore the fabric buckles, forming a wave of certain height and shape.

Linear filling indicators of the fabric depend directly on the contour diameter of fabric threads and the raw material of the fabric. Hence, investigation of the quality of an embroidered element requires assessment of the fabric structure indicators in different directions of the fabric.

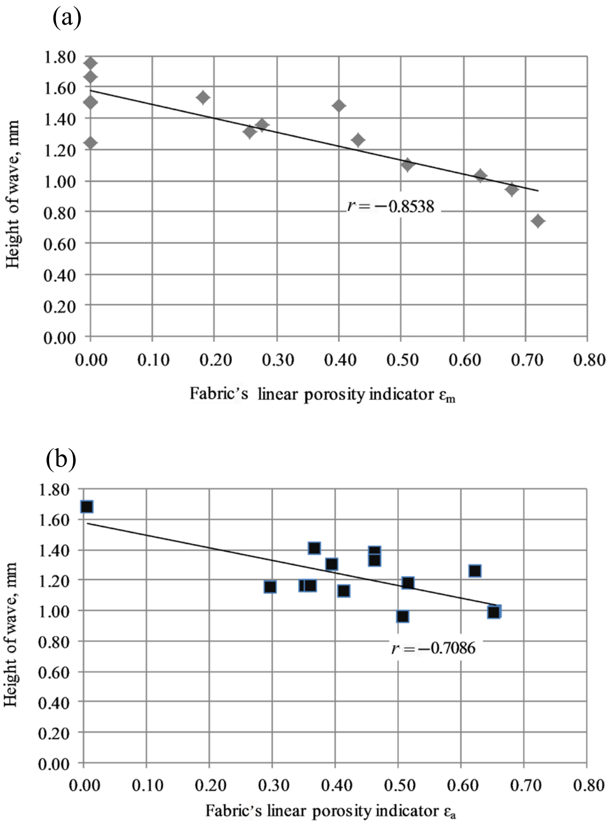

Fig. 5. Relationship between the height of the wave and the fabric's linear porosity indicators: (a) in the warp direction, (b) in the weft direction.

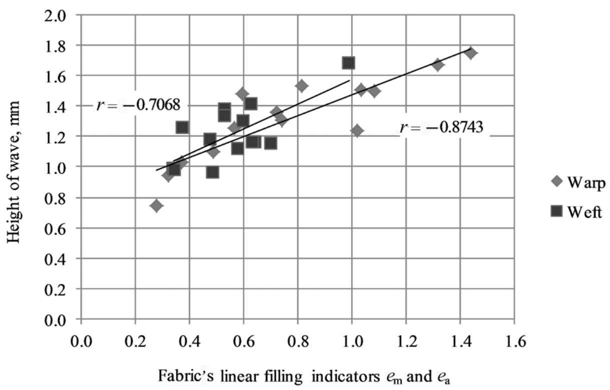

Fig. 6. Relationship between the height of the wave and linear filling indicators of the fabric e_m and e_a.

CONCLUSIONS

1. It was established that, due to compression of threads, the fabric buckled inside an embroidered element, thereby resulting in the formation of waves of different shape. Inside the embroidered element, the buckling wave of the fabric was slightly convex or buckled, resembling an S-shaped wave, and had an irregular profile.
2. The shape of the wave was found to depend on the filling indicators of the fabric. The lower were the values of linear filling indicators of the fabric, the more the shape resembled a straight line or was convex. Fabrics with large values of linear filling indicators buckled inside the embroidered element; they resembled an S-shaped wave or had an irregular profile.
3. A strong correlation was observed between porosity indicators of the fabric and height of the buckling wave. In this situation, correlation coefficients r in the warp and weft directions were – 0.8538 and – 0.7086, respectively.

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Kootud kanga kummumine tikitud elemendi sees

Svetlana Radavičienė ja Milda Jucienė

Tänapäeval ei ole tikanditel mitte ainult dekoratiivne, informatiivne või turvalisusfunktsioon rõivatööstuses, vaid neid võib kasutada ka meditsiinis, komposiitmaterjalide tootmisel ja samuti intelligentsetes tekstiilides või rõivastes. Seetõttu peab olema tagatud tikitud elemendi parim kvaliteet. Tekstiilse alusmaterjali käitumine tikitud elemendi sees võib mõjutada materjali paksust, struktuuri, paindumise jäikust, töödeldavust, lõikeomadusi jm. Antud töö eesmärgiks on uurida erinevate füüsikaliste omadustega alusmaterjali kummumist tikitud elemendi sees. Uurimisel kasutati erineva struktuuri ja mehaaniliste omadustega tekstiilseid alusmaterjale ning erinevaid polüestrist tikkimisniite. Töö tulemusel leiti, et tekstiilse alusmaterjali käitumist tikitud elemendi sees mõjutavad nii tikkimisniidi kui ka alusmaterjali omadused. Kanga lõime- ja koelõngade kokkusurumisel kummub alusmaterjal tikitud elemendi sees, mille tulemusena tekivad erineva kujuga lained. Lainekuju sõltub alusmaterjali täidetuse näitarvudest (e_m, e_a, e_s), mida on hinnatud kanga lõime- ja koelõngade tiheduse ning lõngade arvutusliku diameetri kaudu. Lainekõrgus aga on sõltuvuses alusmaterjali poorsuse näitarvudest (ε_m, ε_a). Mida väiksem on kanga poorsus, seda suurem osa sellest on täidetud koe- ja lõimelõngadega ning seda kõrgem on laine, mis moodustub riidest tikitud elemendi sees.