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Comfort and Performance Properties of Raised and Laminated Denim Fabrics

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Abstract
In this study, denim fabrics manufactured using standard processes were selected as reference fabric and subjected to mechanical and chemical finishing treatment. The effects of the two finishing treatments on the comfort and performance properties of the fabric were investigated. The test samples were the reference fabric, raised fabric and laminated fabric. The comfort tests were for fabric thickness, air permeability and water vapor permeability. The performance tests were for tensile strength, fabric stiffness, tearing strength and fastness. Colour and microscopic image analyses of the samples were also made and evaluated. Raising and lamination improved the thermal resistance properties, whereas raising increased air permeability. Evaluating the performance, fastness and colour properties of the raised and laminated fabric samples did not reveal any significantly negative outcomes. Raising can be recommended for use on the condition that seasonal variations be considered, since it creates comfortable denim fabrics with improved thermal resistance and air permeability.

Key words: *denim, fabric, comfort, raising, lamination.*

Introduction

Denim is a product with high added value in the world. In Turkey, denim has an important share (around 25 - 30%) in woven apparel exports [1]. Studies of both its appearance and functionality demonstrate that denim, as a textile and then as apparel, is a remarkable commodity. Studies of denim mostly aim at cost reduction and product performance prediction. Today people demand not only elegant appearance but also comfort, and advances in communication technologies contribute to the proliferation of such expectations. As a result, comfort is also added to the expectations of the individual from apparel in relation with environmental conditions. Comfort, as a leading parameter of changing consumer expectations, has been the subject of many studies [2 - 6]. Apparel comfort is a complex notion, and can be defined as „a condition of contentment which indicates that an individual in apparel or in an environment is physiologically and psychologically stable" [7]. Also numerous other factors such as colour, fashion as well as physical and psychological conditions of the individual have an influence on the comfort. In determining apparel comfort, along with the environment, the level of movement, fibre, fabric, apparel, the physical and psychological condition of the wearer are important factors. Thermo-physiological comfort involves the perception of fabric comfort, temperature, coolness, wetness and sensibility. Thus thermo-physiological comfort depends on the heat and moisture transfer properties of apparel, on the feeling evoked by fabric on the skin as well as the mechanical interactions between the apparel and skin [8]. The measurable parameters for determining thermal comfort are water vapour permeability, thermal conductivity, thermal diffusion, thermal absorption, thermal resistance, fabric thickness and heat flow density. Apparel that feels comfortable, smooth and does not irritate the skin delivers physical comfort. The structural properties of fibres, threads and fabrics along with the fabric treatments such as finishing, coating, and lamination affect physical comfort [9].

Denim products are subjected to applications such as dying, printing, finishing, visual effects and lamination to meet the expectations of fashion. These processes affect the comfort properties of denim fabrics as well. These days, coated or laminated denim apparel is very popular. Laminated fabric is a material that is composed of two or more layers, of which at least one is a textile fabric [10, 11]. Lamination creates waterproof and breathable fabrics which can be used as apparel, automotive seat covers, footwear and more. Lamination usually involves a membrane of thin film forming a textile's surface. Membrane structures may be of a microporous or hydrophilic structure. Hydrophilic structures are chemically modified, very thin polyester or polyurethane films. This type of membrane structure has pores which allow water vapour molecules to pass, but inhibit water infiltration. In the literature, there are numerous studies investigating the different membrane types and their effects on comfort [12 - 16].

Raising is not one of the usual finishing treatments for denim fabric. This study subjected denim fabric samples to raising as a mechanical finishing operation. Raising renders fabric hairy by pulling individual fibres from the inner structure of the fabric to its surface. This operation creates a pile layer over the fabric surface. The product gains a more fluffy structure, and the amount of the air cushion trapped within its pores is increased, improving its ability to insulate. The raising operation is nearly always applied to winter clothes since they are intended to keep people warm. Shearing cuts the length of raised fibres on the fabric surface to a predetermined and equal value. Studies of raising in the literature were mostly

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about its effects [17]. There are few studies about the influence of raising on textile products [18, 19].

Generally the raising process is not applied on denim fabric. In raised denim fabric the denim is combined with knitted fleece fabric on the back surface of the denim fabric by lamination. This type of fabric is able to keep warm but its breathability and air permeability ability are weak. In this study; raising as a mechanical finishing process was applied directly to the back surface of denim fabric. So knitted fleece fabric and the lamination process were eliminated. Thus the keep warm function and air permeability properties were achieved only by performing the raising operation.

In this study, samples of standard denim fabric were subjected to lamination as a chemical finishing process and to raising as a mechanical finishing process. Standard denim fabric was the reference, and selected performance and comfort properties of the three types of fabrics were determined experimentally. The results of the study were then interpreted. This study aimed to evaluate the results of raising and laminating denim fabric in terms of physical comfort. Raising the denim fabric was an attempt to deliver thermal comfort. Since it is possible to use lamination to improve thermal comfort as well, it was included in the experimental study. While investigating the effect of these processes on thermal comfort, their effect on the fabric's performance was also evaluated.

Materials and methods

Materials

In this study, denim fabric woven in a 3/1 (S) twill weave was used as reference fabric. The warp thread of the reference fabric was 29,5/1 tex cotton thread, and the weft thread was 22.2 tex polyester+2% elastane. The fabric's warp density was 43 thread/cm, its weft density - 24 thread/cm, and its weight per unit area in g/m^2 was 220 g/m^2. The study evaluated three different types of fabrics: the reference and raised and laminated denim. Data for the sample fabrics is shown in ***Table 1***. The raising process chosen was velvet raising, applied to the back face of the reference fabric because the raising process is generally applied the back faces of fabrics. The sample fabrics were also subjected to shearing after the raising process.

Table 1. *Data belonging to the samples.*

Sample No.	Sample Name	Explanation	Production data
1	Reference fabric	Woven Fabric	As mentioned above.
2	Raised fabric	This fabric was obtained by applying two passages of raising over to the back face of the reference fabric.	Raising machine: Lafer Türk 2008 model Shearing machine used: Elektroteks 2005 model. Data for first and second passes of raising: Tension (%): 2 Fabric passing speed (m/min): 10 Lower and upper drum rotation speed (rpm) 100 Shear speed (rpm): 1150 Shear cutting amount (mm) 2.32
3	Laminated fabric	This fabric was obtained by applying polyurethane to the back face of the reference fabric.	Hot-melt lamination [6]

Table 2. *PU membrane properties [10].*

Membrane type	Membrane structure	Thickness, microns	Weight per unit area, g/m^2	Colour
PU	Hydrophilic	20	20	Matte white

Table 3. *Tests and processes in the experimental study.*

Test	No	Test Method	Test Standard
Comfort	1	Textiles - Physiological effects - Measurement of thermal and water-vapour resistance under steady-state conditions (sweating guarded-hotplate test) (ISO 11092:2014)	TSE EN ISO 11092 [20]
	2	Textiles-Determination of permeability of fabrics to air	TSE 391 EN ISO 9237 [21]
	3	Textiles-Determination of thickness of textiles and textile products	TSE 7128 EN ISO 5084 [22]
Performance	4	Tensile properties of fabrics- Part 1: Determination of maximum force and elongation at maximum force using the strip method.	TS EN ISO 13934-1:2013 [23]
	5	Textiles- Tear properties of fabrics- Part 1: Determination of tear force using ballistic pendulum method (Elmendorf) (ISO 13937-1:2000)	TS EN ISO 13937-1: 2002 [24]
	6	Determination of Mass Per Unit Length and Mass Per Unit Area of Woven Fabrics	TSE 251 [25]
	7	Stiffness Determination of Woven Textiles	ASTM D 4032-94 [26]
Colour Fastnes	8	Colour fastness to domestic and commercial laundering	TS EN ISO 105-C06 [27]
	9	Colour fastness to perspiration	TS EN ISO 105-E04 [28]
	10	Colour fastness to rubbing	TS EN ISO 105-X12 [29]
	11	Textiles - Tests for colour fastness - Part E01: Colour fastness to water	TS EN ISO 105-E01 [30]
Image analysis	12	Spectrophotometric analysis	
	13	SEM image analysis was performed for 3 fabrics. Because the samples were not conductive, gold palladium coating was initially made for the section, and then 100x enlarged images with 5kV voltage were investigated by means of a scanning electron microscope (SEM, Jeol JSM- 6390 LV model).	

In this study, polyurethane-based adhesive was utilised in order to glue the membrane and fabric for the hot-melt applied lamination process. The lamination process was applied to the back face of the reference fabric as well in order to compare the raised back face of the fabric. The general properties of the PU film are shown in ***Table 2***.

Methods

In this study, comfort, performance and fastness tests were applied to the sample fabrics in compliance with the relevant standards. The tests and standards are shown in ***Table 3***. The comfort tests were for fabric thickness, air permeability and thermal resistance, fabric performance tests - for tensile strength, fabric stiffness, and tearing strength, and. fastness tests were for washing, rubbing, water and perspiration fastness. Spectropho-

tometric analysis was used to observe the effects of the processes on colour properties, and SEM analysis was used to investigate differences on the surfaces of the fabrics.

Results and discussion

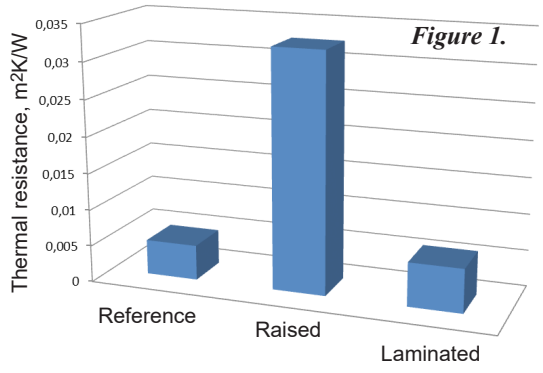
Comfort tests

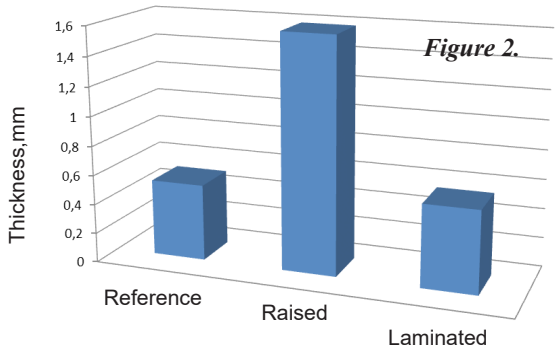
The results of the comfort tests are shown in ***Figures 1, 2,*** and ***3*** in graphic form. ***Figure 1*** shows that the raising process increased the thermal resistance considerably, while lamination yielded values similar to the normal thermal resistance values of denim fabrics. The air segments entrapped within the raising process induced hairs over the fabric surface become to function as a heat transfer reducing layer. ***Figure 2*** shows the fabric thickness results. It was raised from 0.52 to 1.59 mm. After two passes of the raising process, the increase is 206%. This result supports the evaluation of the air layer. The difference in thickness between the laminated fabric samples and reference fabric samples was very slight since the PU film is a very thin membrane. The air permeability results are shown in ***Figure 3***. It was observed that the raising-induced air layer enabled better air transfer than the reference fabric sample. It was detected that the air permeability value was zero for the laminated fabric samples because lamination seals the fabric. Consequently the raised fabric samples yielded the best physical comfort results in the tests.

Performance tests

The results of this study's performance tests are shown in ***Figures 4, 5*** and ***6***. The results of fabric stiffness tests and grammage tests are shown in ***Figures 7*** and ***8***, respectively. Fabric performance parameters such as the tensile strength, elongation%, tear strength and stiffness were analyzed statistically with One Way ANOVA, using SPSS 15®. The results of the analysis are given in the Appendix.

The combined evaluation of the tensile strength results of the reference, laminated, and raised fabric samples revealed, as expected, that the warpwise tensile strength values were superior to the weftwise strength values for all of the three fabric samples. Since raising involves the weft threads, the raised fabric samples yielded the lowest weftwise tensile strength values among all of the samples. The laminated fabric samples also yielded lower weftwise tensile strength values than the reference fabric samples, which may be attributed to the effect of the hot-melt lamination on the PET/elastane-based raw material of the weft threads and the membrane's structure. The raised fabric samples yielded the highest warpwise tensile strength values. The raised fabric samples' warpwise tensile strength values increased, whereas their weftwise strength values decreased. The reason for this may be the additional frictional forces that were created in the warpwise direction by the entangling, and the raising of intertwined fibres is created on the fabric surface, ultimately enhancing its resistance to the rupture load in the warp wise direction. The laminated fabric samples did not reveal any significant difference for warpwise tensile strength values in comparison to the reference fabric samples (see Appendix). The PU structure penetrates into the yarns with the lamination process, and then the fabric is subjected to shrinkage. Thus yarn-yarn friction between warp and weft yarns decreases and the direction of the warp and weft tensile strength is significantly lower. However, the decrease is less than for the raised fabric. Inspection of the percentages of elongation revealed that lamination and raising yielded similar behaviours both in the warpwise and weftwise directions in comparison to the reference fabric samples. Inspection of the tearing strength values revealed, as expected, that the warpwise tearing strength values were superior to the weftwise ones, for





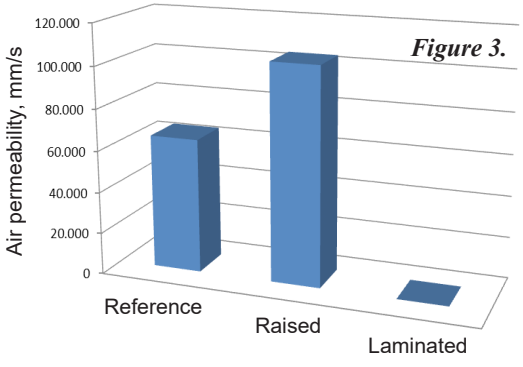
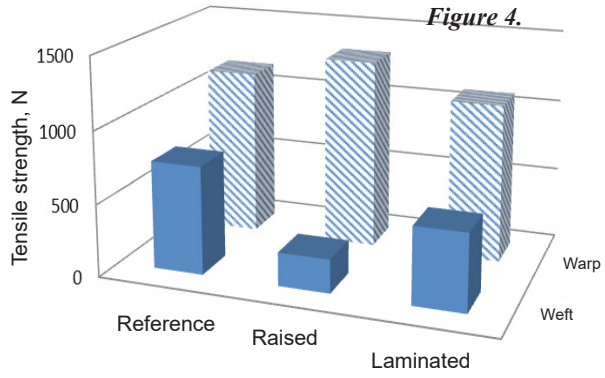
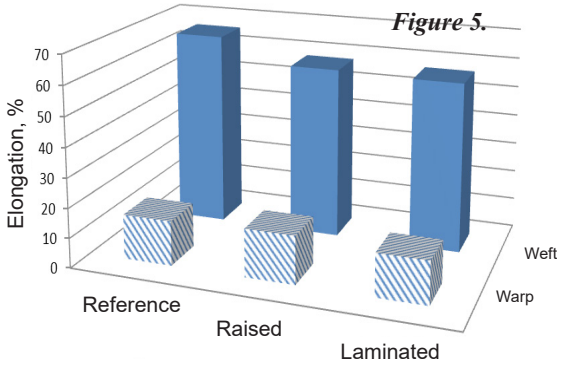


Figure 1. *Thermal resistance values of the samples.*

Figure 2. *Thickness values of the samples.*

Figure 3. *Air permeability values of the samples.*





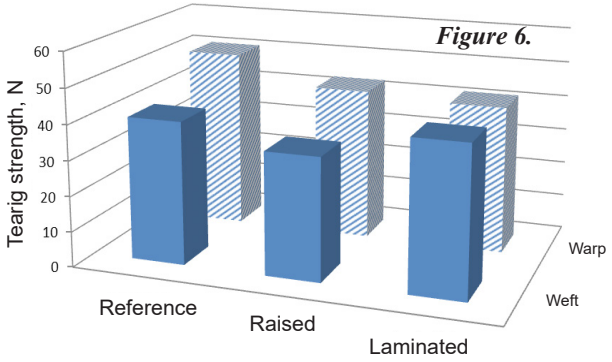


Figure 4. *Tensile strength values of the samples.*

Figure 5. *Percentages of elongation of the samples.*

Figure 6. *Tearing strength values of the samples.*

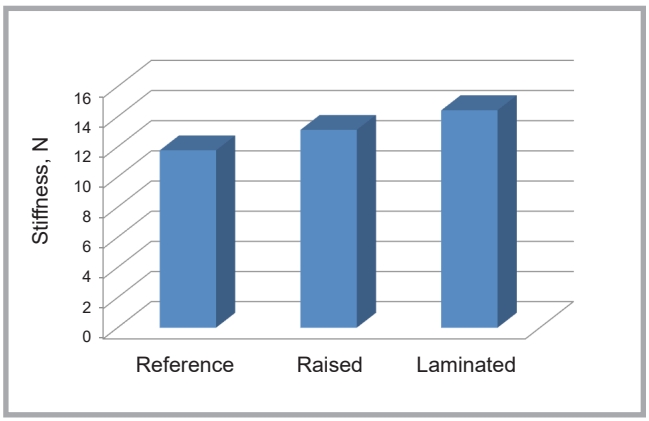


Figure 7. *Stiffness values of the samples.*

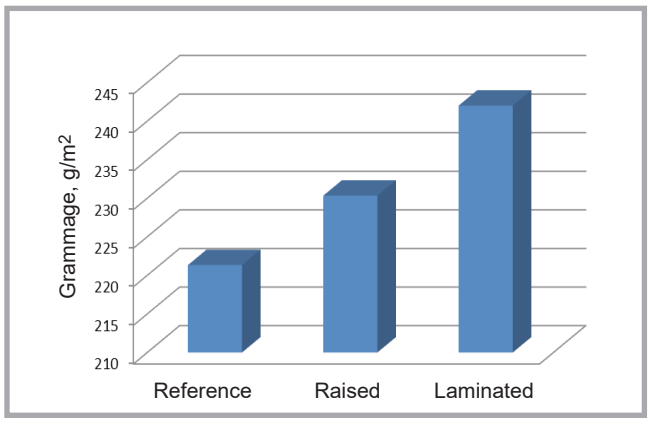


Figure 8. *Weight per unit area in g/m² values of the samples.*

all three types of fabrics. The fibre loss caused by raising reduced the weftwise tearing strength, whereas hot-melt lamination renders the fabric more compact and increases its tear strength.

The stiffness and weight per unit area in g/m² test results (***Figures 7*** and ***8***) indicated that the laminated fabric samples were the stiffest and heaviest. Laminating one face of the fabric increased both its stiffness and weight per unit area in g/m². The raised fabric samples yielded higher stiffness and weight per unit area in g/m² values than the reference fabric samples. The reason for this was the contraction of the fabric's width and the increased hairiness of the fabric surface due to raising. The raised fabric samples were lighter, softer and less stiff than the laminated fabric samples.

Fastness tests

Selected fastness tests: rubbing, perspiration, commercial and domestic washing and water were applied to the reference, raised, and laminated fabric samples, and the results were evaluated (***Tables 4, 5, 6 & 7***). Fairly good results were obtained from all the fastness tests for the three types of fabric samples. Only their wet and dry rubbing colour fastness properties were inferior to the other fastnesses, which is an expected outcome for denim fabrics.

Spectrophotometric colour analysis

The reference, raised and laminated fabric samples were subjected to spectrophotometric color analysis, the results of which are shown in ***Table 8***. The raised and laminated fabric samples were compared to the reference fabric samples separately, and the colour difference (ΔE < 1) was found to be acceptable.

Table 4. *Rubbing colour fastness results*

Sample	Dry	Wet
Referance	3/4	1/2
Raised	3/4	1/2
Laminated	4/5	4

Table 5. Colour fastness to perspiration test results.

Staining on						
Multi-Fibre Stripe	Acidic			Alkaline		
	Referance	Raised	Laminated	Referance	Raised	Laminated
Acetate	5	4	4/5	4/5	4/5	4/5
Cotton	4/5	4/5	4/5	4/5	4	4/5
Nylon	4/5	4	4/5	4	3/4	4/5
Polyester	4/5	4/5	4/5	4/5	4/5	4/5
Acrylic	4/5	4/5	4/5	4/5	4/5	4/5
Wool	4/5	4	4/5	4/5	4	4/5

Shade change					
Acidic			Alkaline		
Referance	Raised	Laminated	Referance	Raised	Laminated
4/5	4	4/5	4/5	4/5	4/5

Table 6. Colour fastness to domestic and commercial laundering test results.

Sample	Staining on						Shade change
	Wool	Acrylic	Polyester	Nylon	Cotton	Acetate	
Referance	4/5	4/5	4/5	4/5	4	4/5	4/5
Raised	4/5	4/5	4/5	4/5	4	4/5	4/5
Laminated	4/5	4/5	4/5	4	4	4	4/5

Table 7. Colour fastness to water test results.

Sample	Staining on						Shade change
	Wool	Acrylic	Polyester	Nylon	Cotton	Acetate	
Referance	4/5	4	4	4/5	4	4/5	4/5
Raised	4/5	4	4	4/5	4	4/5	4/5
Laminated	4/5	4/5	4/5	4	4	4	4/5

Table 8. CIElab values of the samples.

Samples	ΔL	Δa	Δb	Δc	ΔH	ΔE	Result
Reference+ Laminated	0.062	0.179	0.035	0.015	0.181	0.19	The laminated sample is lighter, more red, more yellow and more intense.
Reference+ Raised	-0.443	0.128	-0.191	0.217	0.074	0.5	The raised sample is darker, more red, more blue and more intense.

Microscopic Image Analysis: The samples were subjected to image analysis with a scanning electron microscope (SEM, Jeol JSM- 6390LV model), and front and back face image captures are shown in ***Figure 9***. Visual inspection of the front and back face images of the reference, raised and laminated fabric samples indicates the effects of the raising and lamination applications clearly. The conspicuous interlacing of weft and warp threads (b) on the reference fabric sample are barely visible on the raised fabric sample (d) due to its hairiness. The PU membrane covered the back face of the laminated fabric sample completely (f). Lamination and raising affected the front side of the fabric samples, although only slightly. Comparing the front face of the reference fabric (a) to the other fabric samples revealed that the front face of the raised fabric (c) was frayed, and that of the laminated fabric (e) displayed a structure in which the threads were drawn together.

Conclusion

Inspection of the test results of the denim fabric samples revealed that the raised fabric samples yielded the best physical comfort values for thermal resistance, air permeability and fabric thickness. Combined evaluation of the tensile strength results of the reference, laminated and raised fabric samples revealed, as expected, that the warpwise tensile strength values were higher than those of the weftwise. The raised fabric samples yielded the highest warpwise tensile strength values. The laminated fabric samples did not reveal any significant difference for warpwise tensile strength values in comparison to the reference fabric samples. Inspection of the percentages of elongation revealed that lamination and raising yielded similar behaviors in both the warpwise and weftwise directions in comparison to the reference fabric samples. Inspection of the tearing strength values revealed, as expected, that the warpwise tearing strength values were higher than the weftwise values for all three types of fabrics. It was established that the raised fabric samples yielded inferior weftwise tearing strength properties, whereas the laminated fabric samples yielded higher values. The laminated fabric samples had the highest fabric stiffness and grammage values. The raised fabric was lighter and softer than the laminated fabric. In general, fairly good results were obtained in all of the fastness tests for the three types of fabric samples. Their wet and dry rubbing fastness properties were inferior to the other fastnesses. The spectrophotometric color analysis of the all fabric samples indicated that the colour difference ($\Delta E<1$) was acceptable. Raising and lamination improved the thermal resistance properties, whereas the raising increased air permeability. Evaluation of the performance, fastness and colour properties did not reveal any significantly negative outcomes for the raised and laminated fabric samples. Raising can be recommended for use on the condition that seasonal variations be considered, since it creates comfortable denim fabrics with improved thermal resistance and air permeability.

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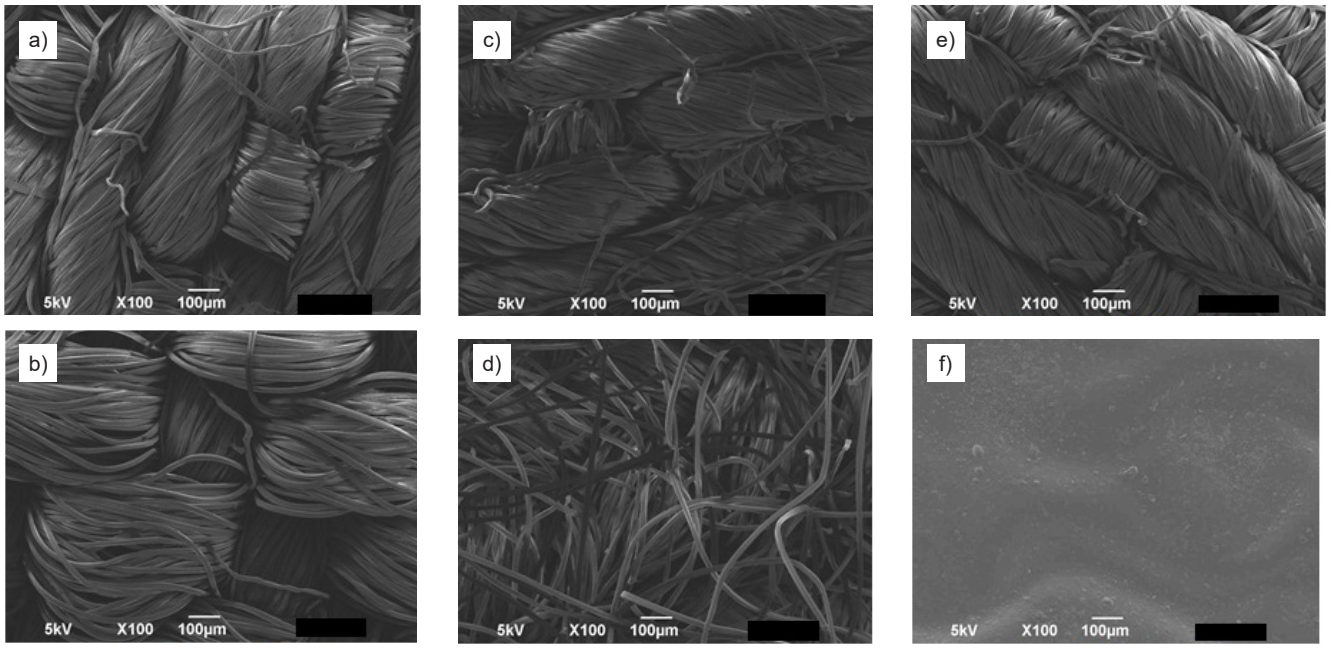


Figure 9. *SEM Images of samples. a) the reference front face, b) the reference back face, c) the raised front face, d) the raised back face, e) the laminated front face, f) the laminated back face.*

Appendix

*Results of statistical analysis (One Way ANOVA, Tukey HSD). *The mean difference is significant at the 0.05 level.*

Dependent Variable	(I) Sample	(J) Sample	Significant*
Tensile strength warp	Reference	Raised	0,002
		Laminated	0,199
	Raised	Reference	0,002
		Laminated	0,000
	Laminated	Reference	0,199
		Raised	0,000
Tensile strength weft	Reference	Raised	0,000
		Laminated	0,000
	Raised	Reference	0,000
		Laminated	0,000
	Laminated	Reference	0,000
		Raised	0,000
% Elongation warp	Reference	Raised	0,006
		Laminated	0,067
	Raised	Reference	0,006
		Laminated	0,000
	Laminated	Reference	0,067
		Raised	0,000
% Elongation weft	Reference	Raised	0,020
		Laminated	0,012
	Raised	Reference	0,020
		Laminated	0,958
	Laminated	Reference	0,012
		Raised	0,958
Tear strength warp	Reference	Raised	0,000
		Laminated	0,000
	Raised	Reference	0,000
		Laminated	0,163
	Laminated	Reference	0,000
		Raised	0,163
Tear strength weft	Reference	Raised	0,000
		Laminated	0,229
	Raised	Reference	0,000
		Laminated	0,000
	Laminated	Reference	0,229
		Raised	0,000
Stiffness	Reference	Raised	0,000
		Laminated	0,000
	Raised	Reference	0,000
		Laminated	0,000
	Laminated	Reference	0,000
		Raised	0,000

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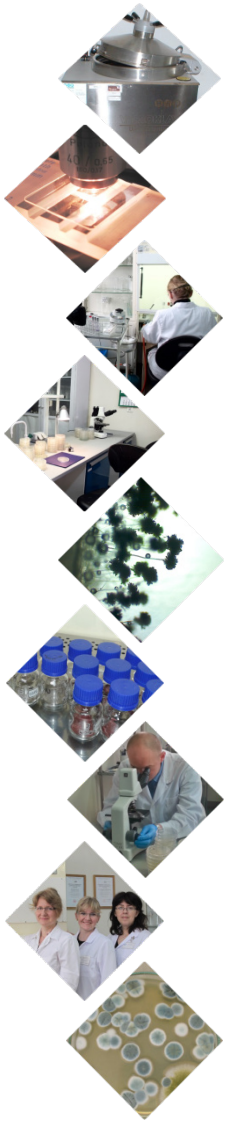
Tests within the range of textiles' bioactivity - accredited by the Polish Centre of Accreditation (PCA):

ilac-MRA PCA Polskie Centrum Akredytacji BADANIA AB 388

- antibacterial activity of textiles **PN-EN ISO 20743:20013**
- method of estimating the action of microfungi **PN-EN 14119:2005 B2**
- determination of antibacterial activity of fibers and textiles **PN-EN ISO 20645:2006**.
- method for estimating the action of microfungi on military equipment **NO-06-A107:2005** pkt. 4.14 i 5.17

Tests not included in the accreditation:

- measurement of antibacterial activity on plastics surfaces **ISO 22196:2011**
- determination of the action of microorganisms on plastics **PN-EN ISO 846:2002**



A highly skilled staff with specialized education and long experience operates the Laboratory. We are willing to undertake cooperation within the range of R&D programmes, consultancy and expert opinions, as well as to adjust the tests to the needs of our customers and the specific properties of the materials tested. We provide assessments of the activity of bioactive textile substances, ready-made goods and half products in various forms. If needed, we are willing to extend the range of our tests.

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