Textile structures for the treatment of burn wounds – characterization of elastic and antibacterial properties

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ABSTRACT – REZUMAT

Textile structures for the treatment of burn wounds – characterization of elastic and antibacterial properties

The paper shows the elastic and antibacterial features of the textile structures (Layer I and III) which make up a three-layer composite material with well-defined features, aimed at the treatment of human burns. The textile structures obtained through weaving (5 variants) and interweaving (3 variants) were further treated with active substances: collagen, colloidal silver, CMC, clay, hyaluronic acid, polyurethane, etc. By using specialized software, fundamental statistical indicators were calculated for the modulus of elasticity and anisotropy variables: mean, dispersion and standard deviation, median and quartiles, skewness, and kurtosis for asymmetry and highlighting the cases in which interventions should be carried out. The histograms and box-plot graphs of the modulus of elasticity and anisotropy variables were obtained. For the functionalized textile structures, with different levels of anisotropy, the antibacterial activity was evaluated on Gram-positive microorganisms (Staphylococcus aureus ATCC 6538) and Gram-negative (Escherichia coli ATCC 8739) and Candida albicans, variety ATCC 10231 by determining the logarithmic and percentage reduction of microorganism populations. The hemocompatibility was determined by evaluating the hemolytic index (ASTM F756-13). The results obtained led to the definition of the combinations of structures of the multilayer matrix.

Keywords: *elasticity, anisotropy, statistics, antimicrobial, microorganism, haemolytic*

Structuri textile pentru tratarea plăgilor cauzate de arsuri – caracterizarea proprietăților elastice și antibacteriene

Lucrarea prezintă caracteristicile elastice și antibacteriene ale structurilor textile (Stratul I și III) care alcătuiesc un material compozit cu trei straturi cu proprietăți bine definite, care vizează tratarea arsurilor umane. Structurile textile obținute prin țesere (5 variante) și interțesere (3 variante) au fost tratate cu substanțe active: colagen, argint coloidal, CMC, argilă, acid hialuronic, poliuretan etc. Prin utilizarea unui software specializat s-au calculat indicatori statistici fundamentali pentru modulul de elasticitate și variabilele de anizotropie: medie, dispersie și abatere standard, mediană și quartile, asimetrie și coeficientul Kurt pentru asimetrie și evidențierea cazurilor în care ar trebui efectuate intervenții. Au fost obținute histogramele și graficele box-plot ale variabilelor modulului de elasticitate și anizotropiei. Pentru structurile textile funcționalizate, cu diferite niveluri de anizotropie, activitatea antibacteriană a fost evaluată pe micro-organisme Gram-pozitive (Staphylococcus aureus ATCC 6538) și Gram-negative (Escherichia coli ATCC 8739) și Candida albicans, tulpina ATCC 10231 prin determinarea logaritmică și reducerea procentuală a populațiilor de microorganisme. Hemocompatibilitatea a fost determinată prin evaluarea indicelui hemolitic (ASTM F756-13). Rezultatele obţinute au condus la definirea combinaţiilor de structuri ale matricei multistrat.

Cuvinte-cheie: *elasticitate, anizotropie, statistică, antimicrobian, microorganism, hemolitic*

INTRODUCTION

Wounds are complex and there is no universal single dressing to treat all types of wounds [1]. The selection of the most adequate wound dressing for a specific wound requires specialist knowledge and clinical assessment; however, the most fitting dressing for wound management depends not only on the type of wound but also on the stage of the healing process. Wound dressings are costly to many developed countries' total annual healthcare budgets. The market potential for healthcare and medical textiles is considerably increasing. It has been predicted that there would be substantial market potential for advanced wound dressings. Some of the major requirements related to a wound dressing are: to alleviate pain, absorb exudates, prevent infection and contaminant contact with the wound, sustain non-toxicity, have a moist environment, optimum gaseous permeability, temperature, and pH. A great number of desirable properties are also expected from a modern wound dressing, including biodegradability, bioabsorbability, and ease of application, to be flexible, comfortable, and impermeable to bacteria.

The antibacterial property is one of the most frequently desired properties from a wound dressing, as the growth of microorganisms is controlled/eliminated by the presence of antimicrobial agents that are embedded into the fibre structure.

Wound dressing materials can play a vital role in wound healing management. An ideal wound dressing not only acts as a physical barrier for a wound against mechanical trauma but also speeds up the healing process and prevents bacterial infection. In this regard, the development of wound dressings can be discussed taking into consideration traditional and modern (advanced, smart) dressings.

The treatment of burn wounds is complex and involves many components [2].

Recent developments in dressing and bioengineering technology have introduced dressings and gels containing naturally occurring glycosaminoglycan and chitin [3–6], with the incorporation of growth factors into gel [7, 8]. These dressings have been reported to prevent early extension of burns [9] express antimicrobial properties [10, 11] and promote fibroblast proliferation, angiogenesis, and wound healing [12].

It is known that the diameter of the fibres, the hydrophilicity, the roughness and the stiffness of the surfaces are factors directly correlated with the ability of bacteria to attach and proliferate on the surface and in the section of the networks. On the other hand, simulations (CAD-FEM) of the behaviour of multilayer matrices in contact with the wounds have shown that the excess fluid causes both the movement of the yarns in the textile structure and its deformation [13], which is in close correlation with the elastic properties (figure 1).

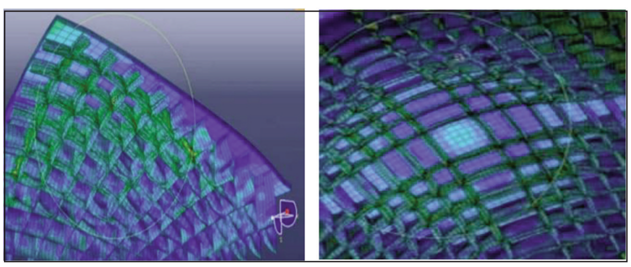


Fig. 1. Deformation of the structure

The paper shows the relation between the elastic properties on antimicrobial features of the textile structures (Layers I and III) treated with active substances, which make up a three-layer composite material with well-defined features, aimed at the treatment of burn wounds. The elastic characteristics were studied by applying descriptive statistics methods and antibacterial activity was evaluated on Gram-positive microorganisms (*Staphylococcus aureus* ATCC 6538) and Gram-negative (*Escherichia coli* ATCC 8739) and *Candida albicans*, variety ATCC 10231 by determining the logarithmic and percentage reduction of microorganism populations. The hemocompatibility was determined by evaluating the hemolytic index (ASTM F756-13) and the coagulation kinetics. The results obtained led to the definition of the combinations of structures of the multilayer matrix.

METHODS

To obtain the first layer, 5 types of woven textile structures were used, differentiated by: the nature of the raw material, the linear density of weft yarns, weft thickness, the structure type, for which the technological flows, installation and adjustment parameters, programming schemes were established. For Layer III, 3 variants of planar structures made by non-conventional techniques were selected, differentiated by the nature of the raw material. To increase the level of biocompatibility and the wound healing rate, the textile structures used for Layers I and III were functionalized by padding or spraying, with antibiotics and active substances, recognized for their antibacterial properties: colloidal silver (V1), hyaluronic acid (V2), clay (V3), CMC (V4), collagen (V5), polyurethane (6),

Table 1

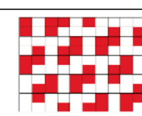
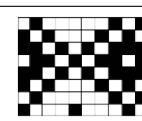
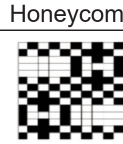
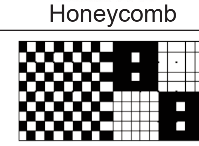
MAIN DESIGN PARAMETERS OF WOVEN STRUCTURES						
Woven textile code	Design parameters					Structure type
	Fibre composition (%)		Linear density (Tex/Nm)		The density of warp (yarn/10 cm)	
	Warp	Weft	Warp	Weft		
BZNT1	100% Cotton	80% Cotton/20% ZnO fibres	20×2(50/2)	14.7×2(68/2)	240	 Satin
BBT1	100% Cotton	100% Bamboo	20×2(50/2)	29.4×1(34/1)	250	 Honeycomb
BLT1	100% Cotton	100% Lenpur	20×2(50/2)	29.4×1(34/1)	200	
BAT1	100% Cotton	100% Tencel®	20×2(50/2)	130 dtex	350	 Honeycomb
BBT2	100% Cotton	100% Cotton	20×2(50/2)	16.6×2(60/2)	255	 Combined pattern

Table 2

PHYSICAL-MECHANICAL CHARACTERISTICS OF WOVEN STRUCTURES						
No.	**Characteristics**	**UM**	**BZNT1**	**BBT1**	**BAT1**	**BBT2**
1	Mass on the surface unit	g/sqm	177	170	137	170
2	Thickness	mm	0.546	0.520	0.448	0.624
3	Water vapours permeability	%	40.9	41.9	41.9	43.2
4	Air permeability	100 Pa, l/sqm/s	292.2	323.4	316.6	460.6
		200 Pa, l/sqm/s	533.6	590.4	583.0	792.4

Table 3

PHYSICAL-MECHANICAL CHARACTERISTICS OF NON-WOVEN STRUCTURES				
Feature / **Variant**	**UM**	**Non-woven textile code**		
		100HS	**50HS**	**20HS**
Fibre composition	%	100% Chitosan	50/50% Chitosan/Tencel®	20/80% Chitosan/Tencel®
Mass	g/m^2	108.16	54.68	43.12
Thickness	mm	1.38	0.3	0.23
Long./transv. Breaking strength,	N	35.39/44.07	33.37/45.64	57.42/70.70
Long./transv. Breaking elongation	%	54.37/45.37	33.05/43.34	29.19/44.2
Long./transv. tearing strength	N	9.1/9.11	4.29/4.43	6.96/7.49

treated with Ringer's solution (S). The physical-mechanical characteristics were determined: mass (g/m^2), thickness (mm), breaking strength (N), breaking elongation (%), air permeability ($l/m^2/s$), etc. antimicrobial activity, and hemolytic potential. Table 1 presents the main design parameters of woven structures. Tables 2 and 3 present the physical-mechanical characteristics of woven structures and non-woven structures, respectively.

To determine the elastic properties, the elastic modulus and the anisotropy of the functionalized textile structures designed for Layer I and Layer III of the composite structure were calcu-lated (table 4).

Specific methods of descriptive statistics were used to characterize populations of variables, elasticity modulus, and anisotropy of plane structures from the point of view of the elastic features, used for Layers I

Table 4

ELASTIC PROPERTIES OF THE COMPOSITE STRUCTURE									
No.	**Variants**	**Strength (N)**	**Lo (cm)**	**L1 (cm)**	**ΔL (cm)**	**A (sqcm)**	**G (mm)**	**Elasticity (N/cm^2)**	**Anisotropy**
1	BBT2-5-weft	30	5	5.2615	0.2615	204.67	0.934	2.8026275	–0.04455969
	BBT2-5-warp	52.5	20	21.652	1.652	204.67	0.934	3.1054538	
2	BAT1-3-weft	80	5	5.206	0.206	203.2	0.6	9.5289552	1.230
	BAT1-3-warp	12.5	20	22.19	2.192	203.2	0.65	0.561054	
4	BAT1-5-weft	80	5	5.177	0.177	202.9	0.58	11.10437	1.189
	BAT1-5-warp	17.5	20	22.4	2.4	202.9	0.58	0.718603	
5	BBT1- 6 weft	20	5	5.2305	0.2305	203.26	0.652	2.1344066	–0.72346913
	BBT1-6-warp	70	20	20.61	0.61	203.26	0.652	11.291361	
9	BZNT1-6-weft	30	5	5.288	0.288	203.4	0.68	2.5606359	–0.310173375
10	BZNT1-6-warp	45	20	20.846	0.846	203.4	0.68	5.2302349	
11	100HS-6 Long.	11.25	5	5.067	0.067	203.33	0.666	4.1290132	0.331533051
12	100HS-6 Trans.	4.5	20	20.23	0.23	203.33	0.666	1.9244792	
13	50HS-S Long.	10.4	5	5.923	0.293	203.3	0.66	0.2771177	0.003169157
14	50HS-S Trans.	10.0	20	23.57	3.576	203.3	0.66	0.2751029	
15	20HS -5Long.	15.2	5	5.265	0.2565	202.22	0.444	1.4652176	–0.009226377
16	20HS-5Trans.	16.97	20	23.576	3.576	202.22	0.444	0.4693429	

and III of the multilayered matrix. Thus, a special software program made it possible to describe the distributions as a result of the tests performed. The following fundamental statistical indicators of variables, elasticity modulus, and anisotropy, were calculated for the values of the warp/weft elasticity (woven) and longitudinal/transversal (non-woven) modules, and anisotropy: mean, dispersion and standard deviation, median and quartiles, skewness and kurtosis for asymmetry and the cases where interventions should be performed were highlighted.

Testing the antimicrobial effect involved measuring the ability of some microorganisms to survive under the effect of an antimicrobial agent, or in the presence of a compound/material with antimicrobial potential, at an imposed or determined concentration and for a prescribed period. The antimicrobial activity of textile structures was evaluated concerning Gram-positive microorganisms – *Staphylococcus aureus* ATCC 653 and Gram-negative – *Escherichia coli* ATCC 8739 and *Candida albicans*, variety ATCC 10231 by calculating the percentage and logarithmic reduction of the populations of microorganisms.

The hemolytic potential of the materials was investigated according to the ASTM F756-13 standard: Standard practice for assessment of hemolytic properties of materials. The materials were conditioned in 10 mL saline solution 0.9% NaCl and incubated for 30 min at 37°C; then, 200 µl of diluted ACD blood (collected in a vacutainer over an anticoagulant mixture consisting of trisodium citrate, citric acid, and dextrose) was added, and the mixture was incubated for 60 minutes at 37°C. A separate sample of 100% hemolysis induced by 10 ml of deionized water was used as a positive control, and the sample for 0% hemolysis consisted of 0.9% NaCl saline solution, without material, used as a negative control. After incubation, all samples were centrifuged at 2000 rpm for 5 minutes, and the absorbance of the supernatant was determined at 545 nm. The percentage of hemolysis was calculated as follows:

$$\text{Hemolysis (\%)} = [(A_{sample} - A_{negative}) / (A_{positive} - A_{negative})] \cdot 100 \quad (1)$$

where A_{sample} is the absorbance value of the sample, $A_{negative}$ – the absorbance value of the hemolysis produced by the saline solution (0.9% NaCl) and $A_{positive}$ – the absorbance value of hemolysis produced by deionized water. The hemolysis results are the average of three determinations.

RESULTS AND DISCUSSIONS

The module of elasticity

The analysis of the results obtained for the elasticity modulus highlights the following:

- the textile structures aimed for Layer I and Layer III, which display a high modulus of elasticity in a certain direction or both directions, which is characterized by low elongation value, offering a strong mechanical reinforcement of multilayer structures, but with the cost of increasing shear forces between layers. Of the textile structures designed for layer I, about 95% fall into this category, and of the textile structures designed for layer III, about 15%.
- textile structures aimed for Layer I and Layer III with a lower elasticity modulus on both warp/ weft or longitudinal/transversal direction, which do not generate high shearing forces, but have a higher degree of deformation. Among the textile structures aimed for Layer I, around 5% fall in this category, whereas from the textile structures aimed for Layer III, around 85%.

Anisotropy

The anisotropy of the textile structures aimed for Layer I has values within the –0.30 ÷ 1.23 range, whereas that of the textile structures aimed for Layer III, within the –0.03 ÷ 0.49 interval, these ensuring adequate environments to use in the multilayered structure of the polyurethane hydrogel.

Descriptive statistical analysis – Layer I

Table 5 shows the main statistical indicators for the modulus of elasticity, whereas table 6 shows the anisotropy of the textile structures aimed for Layer I. Figure 2, *a* and respectively figure 2, *b* show the histograms of the warp and the weft elasticity modulus, respectively. Figure 2, *c* shows the histogram for the anisotropy variable. Figure 3, *a* weft and figure 3, *b* warp show the box-plot graphs for the modulus of elasticity variables, whereas figure 3, *c* shows the anisotropy, box-plot graphs.

Table 5

STATISTICS FOR THE MODULUS OF ELASTICITY – LAYER I

Indicators		Weft	Warp
N	Valid	17	22
	Missing	5	0
Mean		8.1088	4.2111
Std. Error of Mean		2.99750	0.87209
Median		4.2750	1.9500
Mode		2.56*	1.81*
Std. Deviation		12.35900	4.09045
Variance		152.745	16.732
Skewness		3.665	1.110
Std. Error of Skewness		0.550	0.491
Kurtosis		14.251	–0.206
Std. Error of Kurtosis		1.063	0.953
Range		52.34	12.73
Minimum		2.03	0.43
Maximum		54.37	13.16
Sum		137.85	92.65
Percentiles	25	2.6800	1.4278
	50	4.2750	1.9500
	75	9.8740	6.3250

Note: * Multiple modes exist. The smallest value is shown.

Table 6

STATISTICS FOR THE ANISOTROPY – LAYER I		
Indicators		**Value**
N	Valid	28
	Missing	56
Mean		0.2456
Std. Error of Mean		0.11280
Median		0.1976
Mode		–0.72*
Std. Deviation		0.59688
Variance		0.356
Skewness		0.291
Std. Error of Skewness		0.441
Kurtosis		–0.902
Std. Error of Kurtosis		0.858
Range		1.95
Minimum		–0.72
Maximum		1.23
Sum		6.88
Percentiles	25	–0.3031
	50	0.1976
	75	0.5056

Note: * Multiple modes exist. The smallest value is shown.

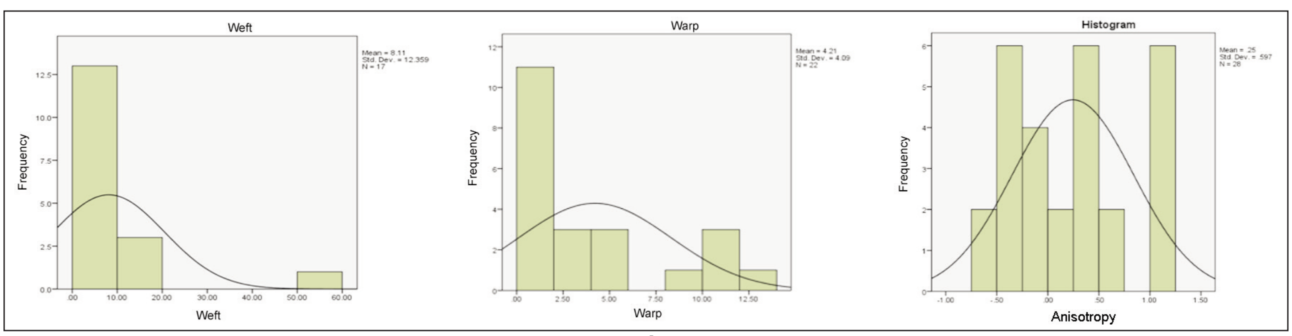
Layer I: statistical analysis result interpretation

1. The variable's modulus of elasticity in the weft/warp and the anisotropy do not present a high variability of results for any of the variants included in the-study. The value with code 12 – value 9.5 N/cm^2 for the BAT1-3 variant (100% cotton in warp and 100% acetate in the weft), functionalized with clay, the variable modulus of elasticity in the horizontal direction, is located at a distance of more than 3 lengths of the box and must be excluded from the series of determinations.

2. The variable modulus of elasticity in the weft and the variable anisotropy shows the distribution of 50% of the values directed to the left, the median being directed to the bottom edge of the box, so small values are predominant. For the variable modulus of elasticity in the warp, the median is directed towards the upper edge of the box, so it can be stated that the distribution is directed to the right, and large values are predominant.

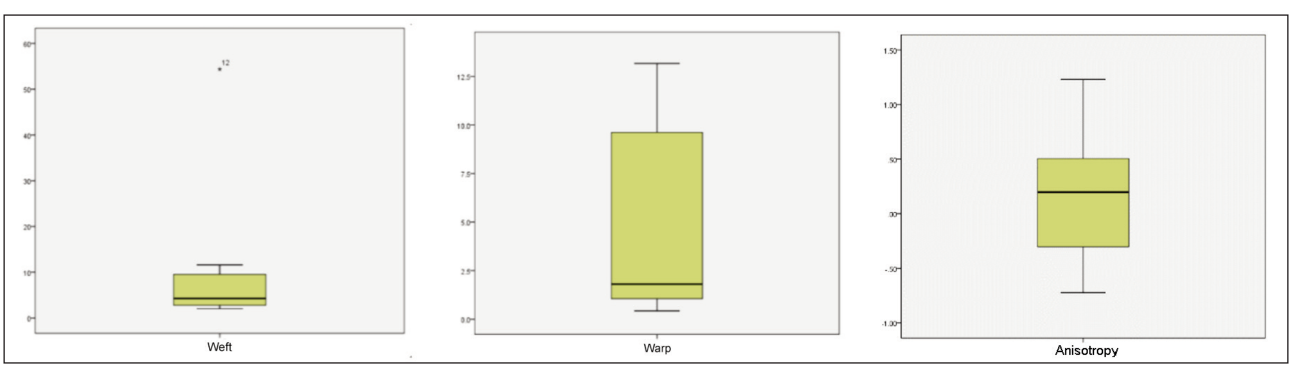
3. Distribution shape indicators:
   - for the modulus of elasticity in the weft: 50% of the values are under 4.27 N/cm^2, 25% are under the 4.27 ÷ 9.87 N/cm^2 range, whereas 25% over 9.87 N/cm^2;
   - for the modulus of elasticity in the warp: 50% of the values are under 1.95 N/cm^2, 25% of the values are within the 1.42 ÷ 1.95 N/cm^2 range, whereas 25% of the values are over 1.95 N/cm^2;
   - for the anisotropy: 50% of the values are under 0.19, whereas 25% of the values are within the –0.3 ÷ 0.19 limits and 25% of the values go over 0.19.

4. Skewness indicators have the following values: 3.66 for the modulus of elasticity in the weft, 1.11 for the modulus of elasticity in the warp, and 0.291 for



a ***b*** ***c***

Fig. 2. Layer I histograms: *a* – weft elasticity; *b* – warp elasticity; *c* – anisotropy



a ***b*** ***c***

Fig. 3. Layer I box-plot graphs: *a* – weft elasticity; *b* – warp elasticity; *c* – anisotropy

the anisotropy, which highlights the extent to which the mean departs from the median and, as a result, the normal distribution curves depart from the middle, going to the right.

5. Kurtosis indicators have a positive value, of 14.25 for the modulus of elasticity in the weft – the curve is leptokurtic, whereas the modulus of elasticity in the warp and the anisotropy have negative values of –0.206 and –0.902, respectively, and the curves are platykurtic.

Descriptive statistical analysis – Layer III

Table 7 shows the main statistical indicators for the modulus of elasticity, whereas table 8 for the anisotropy of the textile structures aimed for Layer III. The histograms of the variable modulus of elasticity in the horizontal direction and modulus of elasticity in the vertical direction are presented in figure 4, *a* and figure 4, *b*, respectively. The histogram for the anisotropy variable is presented in figure 4, *c*. The box-plot graphs for the modulus of the elasticity variable are presented in figure 5, *a* longitudinal direction and figure 5, *b* transversal direction and for anisotropy in figure 5, c.

Table 7

STATISTICS FOR THE MODULUS OF ELASTICITY – LAYER III

Indicators		Weft	Warp
N	Valid	11	11
	Missing	0	0
Mean		0.9427	1.0873
Median		0.4680	0.5550
Mode		0.03*	0.47*
Std. Deviation		1.18806	1.40126
Variance		1.411	1.964
Skewness		2.221	2.744
Std. Error of Skewness		0.661	0.661
Kurtosis		5.519	7.898
Std. Error of Kurtosis		1.279	1.279
Range		4.10	4.80
Sum		10.37	11.96
Percentiles	25	0.2770	0.4350
	50	0.4680	0.5550
	75	1.4650	1.1180

Note: * Multiple modes exist. The smallest value is shown.

Layer III – interpretation, results, statistical analysis

1. The variables modulus of elasticity and anisotropy does not show high variability of results with any of the studied variants.

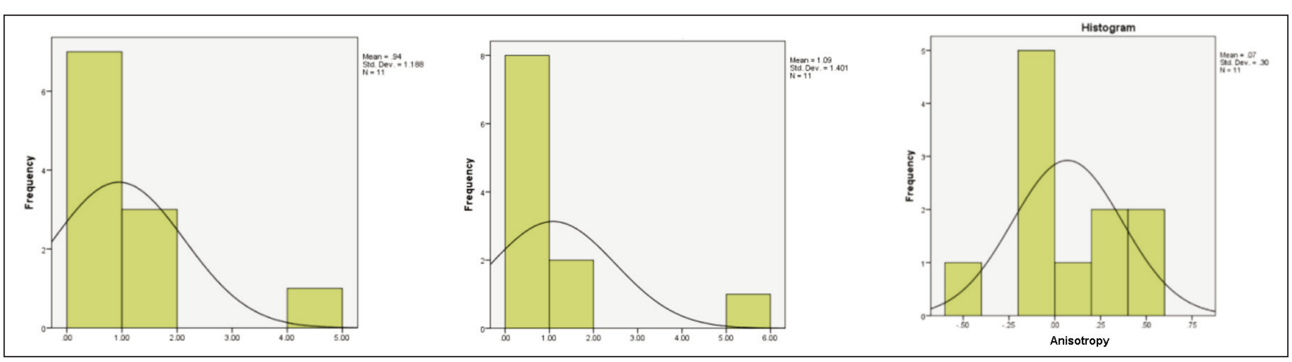
2. The values with code 11 – value 0.275 N/cm^2, variable modulus of elasticity in the longitudinal direction, and code 11, modulus of elasticity in the transversal direction, with a value of 1.074 N/cm^2 for the 50HS variant, is located at a distance of 1–3 box lengths and must not be excluded from the series of determinations. The value with code 2, value 5.071 N/cm^2 for the 20 HS-1 variant, made up of 20% Chitosan/80%

Table 8

STATISTICS FOR THE ANISOTROPY – LAYER III

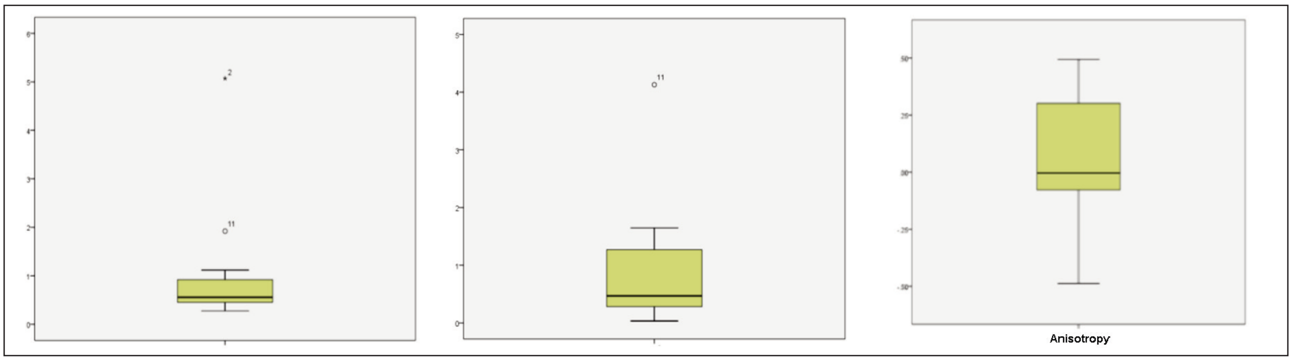
Indicators		Value
N	Valid	11
	Missing	12
Mean		0.694
Std. Error of Mean		0.9043
Median		–0.0038
Mode		–0.49*
Std. Deviation		0.29992
Variance		0.090
Skewness		–0.071
Std. Error of Skewness		0.661
Kurtosis		–0.259
Std. Error of Kurtosis		1.279
Range		0.98
Minimum		–0.49
Maximum		0.49
Sum		0.76
Percentiles	25	–0.0826
	50	–0.0038
	75	0.3315

Note: * Multiple modes exist. The smallest value is shown.



a *b* *c*

Fig. 4. Layer III histograms: *a* – elasticity-longitudinal; *b* – elasticity-transversal; *c* – anisotropy



a *b* *c*

Fig. 5. Layer III box plot graphs: *a* – elasticity-longitudinal; *b* – elasticity-transversal; *c* – anisotropy

viscose, treated with colloidal silver, variable modulus of elasticity in the transversal direction is situated at a distance of more than 3 box lengths and must be excluded from the series of determinations.

3. The variable modulus of elasticity in the longitudinal direction and the transversal direction and the variable anisotropy show the distribution of 50% of the values directed to the left, the median being directed to the bottom edge of the box, so small values are predominant.

4. Distribution shape indicators:
- for the modulus of elasticity in the longitudinal direction: 50% of the values are below the value of 0.468 N/cm^2, 25% being within the 0.468 ÷ 1.46 N/cm^2 range, whereas 25% over 1.46 N/cm^2;
- for the modulus of elasticity in the transversal direction: 50% of the values are under 0.55 N/cm^2, 25% of the values are within the 0.55 ÷ 1.11 N/cm^2 range, whereas 25% of the values over 1.11 N/cm^2;
- for anisotropy: 50% of the values are below the value of –0.038 and 25% of the values are within the limits of –0.038 ÷ –0.33, and 25% of the values are above 0.33.

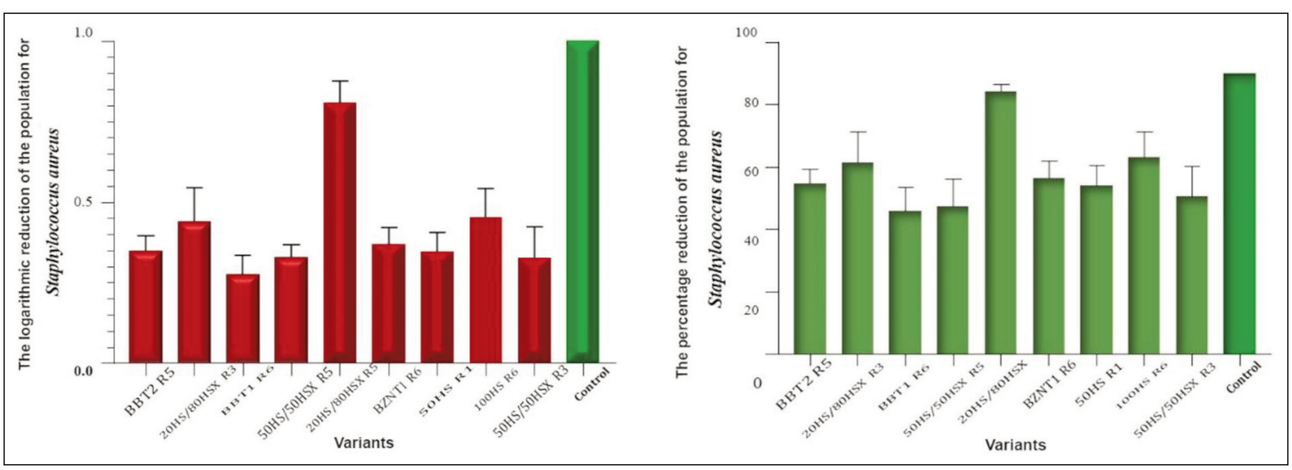
5. Skewness indicators have the following values: 2.221 for the modulus of elasticity in the longitudinal direction, 2.744 for the modulus of elasticity in the transversal direction, which highlights the extent to which the average departs from the median and implicitly the normal distribution curves depart from the middle, these moving to the right and –0.071 for anisotropy, which highlights the extent to which the average moves away from the median and implicitly the normal distribution curves also move away from the middle, moving to the left.

6. The kurtosis indicators have positive values, of 5.519 for the modulus of elasticity in the longitudinal direction and 7.898 for the modulus of elasticity in the transversal direction – the curves being leptokurtic and negative values for anisotropy: –0.259, the curve being platykurtic

Woven textile structures have a higher modulus of elasticity in one direction (95%) compared to non-woven structures, which present a low value of modulus of elasticity in both directions (85%). The anisotropy of woven structures is higher compared to non-woven structures (–0.3 ÷ 1.23 against –0.03 ÷ 0.49). Woven structures are more rigid compared to non-woven ones.

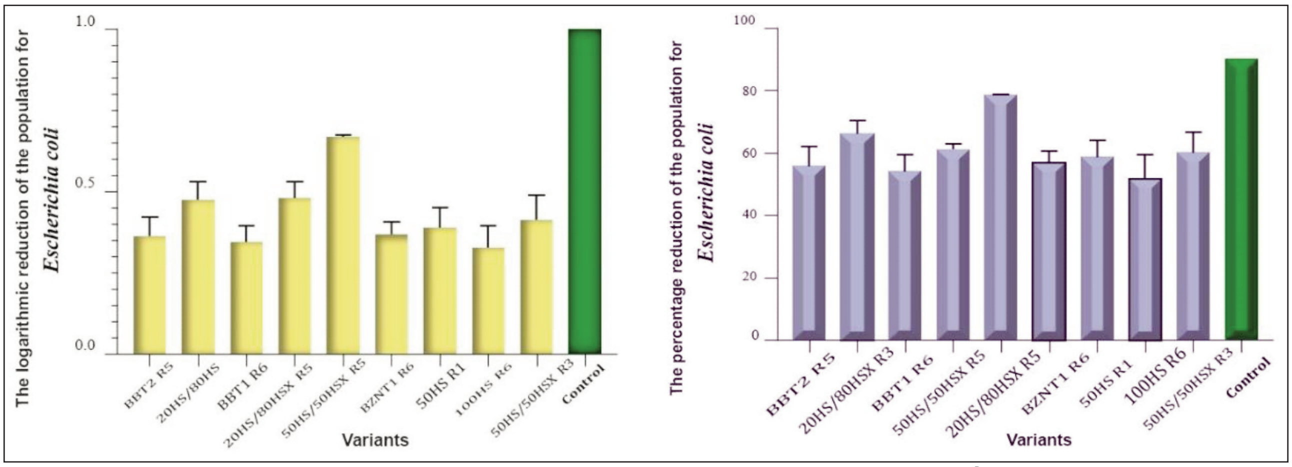
Antimicrobial activity

The graphic expressions of the logarithmic reduction and the percentage reduction of the population of *Staphylococcus aureus* are presented in figure 6, *a* and figure 6, *b*.



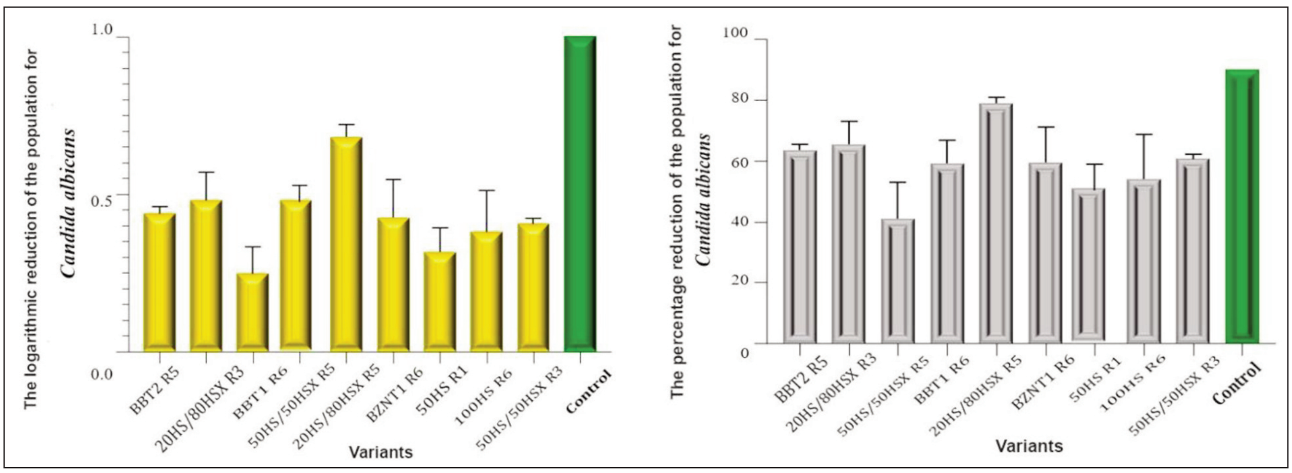
a *b*

Fig. 6. Reduction of *Staphylococcus aureus* population: *a* – logarithmic; *b* – percentage



a *b*

Fig. 7. Reduction of the *Escherichia coli* population: *a* – logarithmic; *b* – percentage



a *b*

Fig. 8. Reduction of *Candida albicans* population: *a* – logarithmic; *b* – percentage

For the control sample (noted: Control), the logarithmic reduction has the default value of 1, a value corresponding to a 90% efficiency in reducing microbial populations.

For the tested samples, logarithmic reductions between 0.2759 and 0.8089 were obtained. The textile samples that provide the most effective antibacterial effect are those that include chitosan (50HS and 20HS). These non-woven structures have a low level of anisotropy (0.003 and –0.009) but the presence of Tencel® fibre together with that of chitosan enhances the antibacterial effect of the mixture, ensuring a percentage reduction in the population of *Staphylococcus aureus* close to 90%, a value considered as a reference in the inhibition of bacterial cultures.

Figures 7, *a* and 7, *b* show the graphical expressions of the logarithmic reduction and respectively of the percentage reduction of the *Escherichia coli population.*

For the tested samples, logarithmic reductions between 0.3269 and 0.6663 were obtained. The textile samples that ensure the most effective antibacterial effect are those that include chitosan, along with Tencel fibres, treated with Collagen(R5), which ensure percentage reductions in the population of *Escherichia coli* (Gram-negative bacteria) of about 78%, lower than those against *Staphylococcus aureus* (Gram-positive bacteria), for which the percentage reduction was almost 90%. The woven structure with the highest percentage reduction (58%) is BZNT1 (R6) treated with Polyurethan, with the module of elasticity very law in both directions (warp: 0.052 N/cm^2, weft: 0.025 N/cm^2) and anisotropy with a value 0.3.

In figures 8, *a* and 8, *b*, the graphical expressions of the logarithmic reduction and respectively of the percentage reduction of the population of *Candida albicans* are presented.

The logarithmic reductions obtained are between 0.2468 and 0.6805, and the percentage reductions are between 41% and 78%. Also in the case of inhibiting the development of Candida albicans, the mixture of Chitosan/Tencel 20/80% fibres, treated with Collagen (R5) is the most effective in reducing fungal populations.

Hemolytic potential

The hemolytic potential was evaluated based on the degree of erythrocytes and haemoglobin dissociation induced by the materials put in contact with ram blood.

The degrees of hemolysis of the samples with values lower than 5% are under international regulations regarding the hemocompatibility of medical devices (according to ASTM F756-00, Standard Practice for Assessment of Hemolytic Properties of Materials). Thus, the materials BBT2 R5 (5.89 ± 0.58%), 100HS R6 (9.42 ± 0.68%) and BZNT 1-R6 (10.38 ± 1.12%) are hemolytic. The materials with the lowest hemolytic indices are: BBT1-R6 (0.16 ± 0.09%), 20HS/80HSX-R5 (0.59 ± 0.17%), 50HS/50HSX-R5 (0.64 ± 0.17%) and 50HS-R1 (0.71 ± 0.17%).

According to the obtained results, it can be stated that the 100% chitosan textile (100HS) sample and the sample containing ZnO (BZNT1) are strongly hemolytic. In the case of non-hemolytic samples, it was observed that by spraying with clay dispersion, the hemolytic index increases. It is recommended to use textile materials that were not sprayed with clay dispersion.

CONCLUSIONS

- The elasticity module and anisotropy for textile functionalized structures (woven and non-woven) were calculated whereas to characterize statistical populations, descriptive statistics-specific methods were used. The distributions as a result of the tests performed were described.
- The analyzed textile structures are adequate from the point of view of the elastic features to be used in the multilayered composite material structure aimed for the treatment of burn wounds, as they achieve a balance between the shearing and the deformation potentials.
- The study of inhibiting the development of microorganisms and evaluating their ability to adhere to the surface of textile materials showed for all the strains tested, that the best results were obtained for the sample of 20HS (20/80% chitosan – Tencel®) treated with Collagen (R5). The efficiency of this type of material could be because the surface of the fibres does not favour the retention of bacterial cells. Thus, a synergistic effect of Tencel fibres with chitosan could reduce the effect of low anisotropy (–0.009).
- The antimicrobial activity of all textile samples is moderate, however, bacterial growth is sufficiently inhibited to be able to respond to the specific applications of medical devices used as a wound dressing able to ensure a hemostatic effect. It is mentioned that the antimicrobial properties are only necessary until the systemic treatment with antibiotics starts (maximum 4–5 hours from the moment of application wound dressing application).
- The content of active substances in textile structures (ZnO, chitosan, polyurethane, etc.) compensates for their lower rigidity and is characterized by very small anisotropies (<1.0), which favour the development of microorganism cultures. In this way, it is possible to obtain appropriate levels of the reduction of microorganism populations and use them as medical devices.
- The textile structures from 100HS (100% chitosan) treated with Collagen and BNZT1 (containing ZnO) treated with Polylysine are strongly hemolytic.
- Three combinations of structures were selected to create layers I and III of the multilayer matrix: BZNT1/BZNTI, BZNTI/20HS, and 20HS/20HS.

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