Influence of an Antimicrobial Treatment on the Strength Properties of Polyamide/Elastane Weft-Knitted Fabric

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ABSTRACT: Polyamide/elastane weft-knitted fabric, as a suitable compression material, was treated with gentamicin sulfate and a natural antimicrobial preparation of the autochthonous essential oil of *Picea abies*. The antimicrobial bioactivity of the treated fabric *in vitro* was tested for different groups of bacteria and a fungus (*Staphylococcus aureus*, *Escherichia coli*, *Klabsiella*, and *Candida albicans*). The results of the experiment showed that the antimicrobial-treated knitted fabric expressed a wide range of bactericidal, fungicidal, and bacteriostatic activity versus the various groups of microorganisms. The influence of the antimicrobial treatments on the tensile strength and elongation, tear strength and elongation, stiffness, and elasticity of the chosen test material was also examined. These properties of the fabric were changed after the antimicrobial treatments. Both the tensile strength and tear strength increased about 14% after the treatment. The scope of the experiment also included the testing of the compression distribution at the skin/knitted fabric interface on the legs of human test subjects. Pressure generated by the application of the knitted fabric on the leg surface increased in correlation with a decrease in the leg circumference. On the basis of these observations, it was concluded that the knitted fabric could be used as a compression textile before and after the treatment. © 2006 Wiley Periodicals, Inc. J Appl Polym Sci 103: 4012–4019, 2007

Key words: coatings; compression; polyamides; stiffness; strength

INTRODUCTION

Antimicrobial, bioactive textile materials have become necessary in many areas for protection and healthcare as well as medical therapy because of the presence of numerous pathogens on human skin.[1–3] A textile is treated with a finishing textile with antimicrobial agents (posttreatment) or by the introduction of additives to spun polymers (chemical treatment). The advantage of the posttreatment is the simplicity of its application process. The posttreatment enables the modification of a textile regardless of the raw material composition, thus giving it the desired antimicrobial properties.

A primary requirement for modern medical textiles is the correct pressure and the uniformity of this pressure in the application area throughout the application period. The application of external compression by means of elastic bandages increases the velocity of blood flow within the veins by providing support to the calf muscles.[4] Excessively high compression pressure might lead to the formation of bandage-induced ulcers. Therefore, a correct level of pressure throughout the limb is essential.

Certain properties of textile materials used for compression therapy may change under the influence of mechanical load, temperature, or humidity. These variables may degrade the material quality during its use. Thus, the durability of the fabric under these conditions is crucial if it is used for prolonged compression-treatment periods. The durability depends on the elasticity, which can be estimated from the strength-related properties of the fabric.

The objective of this project was to explore the effect of an antimicrobial treatment on some strength-related properties of the knitted fabric. The pressure distribution on a leg imposed by the knitted fabric was also included in the analysis.

EXPERIMENTAL

Materials

The experiment was conducted with commercially produced plain polyamide/elastane single-weft-knitted fabric as a suitable textile in part because of the values of its compression levels, which must be appropriate for use in various kinds of medical treat-

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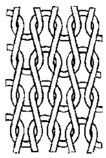
TABLE I
Basic Structural Characteristics of the Knitted Fabric

Material composition	Fabric structure	Yarn fineness (tex)	Wale (dm)	Course (dm)	Fabric mass (g/m^2)	Fabric thickness (mm)	Fabric density (g/m^3)
Polyamide 6.6/elastane (80%/20%)		18	173	249	223	0.593	0.376

ments. The basic structural characteristics of the investigated knitted fabric are given in Table I.

Antimicrobial treatment

The polymer matrix of chitin, chitosan, or alginate that polysaccharide gels possess has already been proven to have a positive therapeutic effect when applied to the skin.[5–7] The bioactive effects of such polysaccharide gels on living tissue include a certain level of antimicrobial activity even without the addition of antimicrobial agents, which promotes successful wound-healing action. An increase in the antimicrobial effect of the polymer matrix can be achieved by the addition of antimicrobial agents. In this experiment, two antimicrobial agents were used and tested. One, gentamicin sulfate, provides antimicrobial activity for an extended period of time (>7 days) and was used because it is the antibiotic with the widest spectrum of effectiveness. The second agent was the autochthonous essential oil of *Picea abies*, which has both suitable antimicrobial and toning effects on human tissue. With the application of these agents, a textile material can be used for prolonged, therapeutic treatment without the genesis of microorganisms such as gram-positive or gram-negative bacteria.

The fixation of gentamicin sulfate or essential oil of *P. abies* molecules in the porous structure of the knitted fabric by a process of inclusion creates a bioactive textile. The inclusion process is a physicochemical modification in which the molecules of the two antimicrobial preparations are incorporated into the polymer matrix of a chitosan-based polysaccharide gel, which is then applied as an adhesive coating to the knitted fabric being investigated. The amount of immobilized gentamicin sulfate used was 0.15 mg/cm^2, and the amount of essential oil used was 0.30 mg/cm^2 per test sample of fabric. The antimicrobial activity on the fabric was determined according to a method developed by the Fiber Laboratory of Textile Engineering at the Faculty of Technology and Metallurgy in Belgrade, Serbia.[8] In the experiments, the antimicrobial treatments with gentamicin sulfate were marked as treatment G, and those with the autochthonous essential oil of *P. abies* were marked as treatment J.

The antimicrobial-treated fabric was examined according to a standard microbiological method with a fungus and gram-positive and gram-negative bacteria [*Staphylococcus aureus* (ATCC 25923), *Escherichia coli* (ATCC 25922), *Klabsiella*, and *Candida albicans*] as indicator microorganisms. The antimicrobial efficiency and inhibition activity of the bioactive textile material were examined with the diffusion method on an agar plate seeded with the indicator microorganisms. After 24 h of incubation at 37°C, the presence or absence of visible colonies on the agar surface, directly above the fibrous textile material, was recorded. With visual inspection, the inhibition zone of the microorganisms on the agar surface was determined.[9,10]

Mechanical properties of the treated fabrics

To establish the influence of the antimicrobial treatments on the strength-related properties of the polyamide/elastane knitted fabric, the fabric's stiffness, elasticity, and tensile and tear strength were examined. These properties can be considered to be important concerning the quality of the investigated material for its different medical purposes.

A standard fabric constant-rate-of-loading machine (Textest, Schwerzenbach, Switzerland) was used for the determination of the elongation and tensile and tear strength of the investigated fabric.[11]

The distance between the clamps on the machine was adjusted to 4 cm. For this investigation, a trapezoidal-shaped sample was used with the following dimensions: AB = 10 cm, CD = 15 cm, and BE = 5 cm (Fig. 1). A template used for cutting was placed on each test sample in such a way as to mark the segments AB and CD in a wale direction, that is, lengthwise. For investigation widthwise, segments AB and CD were positioned in a course direction. Regardless of the direction of the investigation, a 1-cm sample was cut out in the middle of segment AB. Afterwards, the test sample was fixed by the top

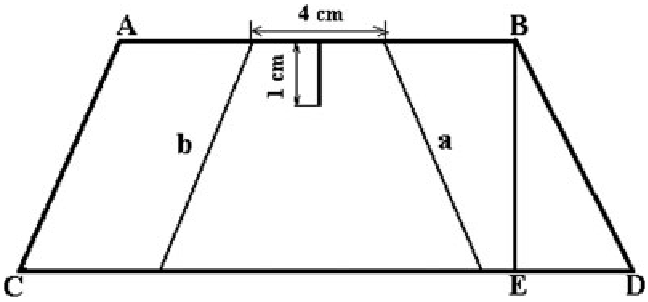


Figure 1 Template for sample cutting.

clamp along line a and by the lower clamp along line b. When the lower clamp moved, the fabric was ripped in the direction of the cut.

The bending elasticity of the investigated fabric was monitored through the value of the bending modulus (E_b):[12]

$$B_s = E_b \cdot I_x \tag{1}$$

$$E_b = \frac{B_s}{I_x} \tag{2}$$

where B_s is the bending stiffness (N m^2) and I_x is the principal moment of inertia of the surface (m^4).

I_x was given by the following relationship:[13]

$$I_x = \frac{b \cdot d^3}{12} \tag{3}$$

where b is the sample width (0.03 m) and d is the fabric thickness (m).

For the determination of the fabric's B_s, the cantilever method was used.[14] A diagram of the apparatus used for determining the stiffness of the fabric is presented in Figure 2.

The relative deflection (f_o) was calculated with the following formula:[14]

$$f_o = \frac{f_{av}}{l} \tag{4}$$

where f_{av} is the average deflection of both ends of the fabric strip (cm) and l is the length of the down-hanging ends of the test strip. This length was determined with the following formula:[14]

$$l = \frac{L - 2}{2} \tag{5}$$

where L is the length of the test strip, which in this case was 16 cm.

f_o was not allowed to be greater than 0.65, and f_{av} was not allowed to be less than 1 cm. If, at the length of 16 cm on the test strip, these conditions were not satisfied, the length of the strip was reduced by 1 cm, and f_o and f_{av} were redetermined. The procedure of reducing the length of the test strip was repeated as long as was needed to obtain values of f_o and f_{av} that satisfied the aforementioned limited conditions.

B_s of the test fabric was calculated according to the following formula:[14]

$$B_s = \frac{m \cdot l^3}{A} \tag{6}$$

where m is the weight of the test strip (N/m) and A is a dimensionless value dependent on f_o (Table II).

The elasticity of the test fabric under the stress of tensile force was estimated with the value of the tensile modulus [E_t (N/m^2)] on the basis of the relation known as Hook's law. According to this law, the tension (σ) is proportionate to the relative deformation (ε):[15]

$$\sigma = E_t \cdot \varepsilon \tag{7}$$

That is,

$$\frac{T}{S} = E_t \cdot \frac{\Delta l}{l_0} \tag{8}$$

where T is the tensile force (N); S is the surface on which T acts (m^2); Δl is the elongation of the knitted fabric (m); and l_0 is the original length of the sample, which in this case was 0.1 m.

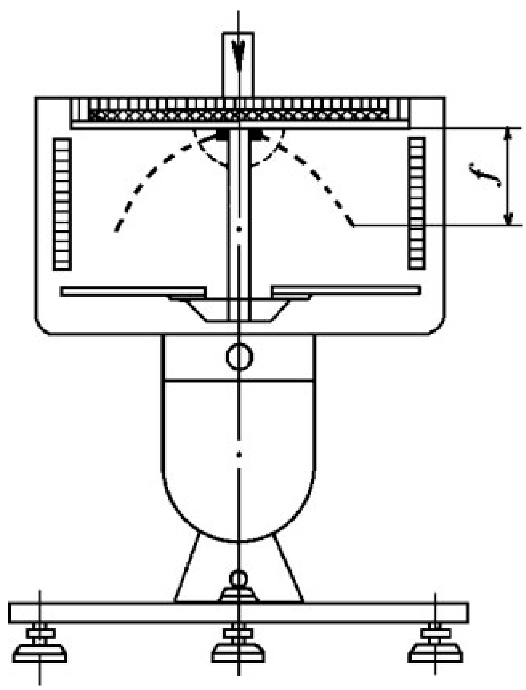


Figure 2 Apparatus for determining the stiffness of the knitted fabric at bending.[14]

TABLE II
A Versus f_o

f_o	A	f_o	A	f_o	A	f_o	A	f_o	A
0.01	0.10	0.14	1.18	0.27	2.32	0.40	3.75	0.53	5.64
0.02	0.18	0.15	1.25	0.28	2.42	0.41	3.87	0.54	5.84
0.03	0.26	0.16	1.35	0.29	2.53	0.42	4.04	0.55	6.06
0.04	0.35	0.17	1.43	0.30	2.63	0.43	4.17	0.56	6.26
0.05	0.42	0.18	1.51	0.31	2.74	0.44	4.29	0.57	6.47
0.06	0.51	0.19	1.60	0.32	2.83	0.45	4.42	0.58	6.68
0.07	0.60	0.20	1.69	0.33	2.94	0.46	4.56	0.59	6.92
0.08	0.68	0.21	1.76	0.34	3.05	0.47	4.70	0.60	7.18
0.09	0.76	0.22	1.84	0.35	3.15	0.48	4.83	0.61	7.50
0.10	0.84	0.23	1.95	0.36	3.26	0.49	4.98	0.62	7.79
0.11	0.92	0.24	2.04	0.37	3.38	0.50	5.13	0.63	8.12
0.12	1.01	0.25	2.14	0.38	3.49	0.51	5.33	0.64	8.44
0.13	1.08	0.26	2.23	0.39	3.61	0.52	5.51	0.65	8.76

The data were taken from ref. 14.

Keeping in mind that the tensile force and elongation must be within the parameters established by Hook's law, which is within defined limits of proportionality, we determined the elongation and the amount of force that caused only elastic deformation with the force–elongation diagram. The breaking force and elongation were determined at the limit point of the linear part of the curve (Fig. 3).[16]

S was calculated on the basis of the following relationship:

$$S = b \cdot d \tag{9}$$

where b is the sample width (0.05 m) and d is the thickness of the knitted-fabric test sample (m).

RESULTS AND DISCUSSION

The results of the investigation of the knitted-fabric antimicrobial activity after treatment and specifically its effects on the bacteria *S. aureus*, *E. coli*, and *Klabsiella* and the fungus *C. albicans* with gentamicin sulfate (treatment G) and autochthonous essential oil of *P. abies* (treatment J) are presented in Figure 4 and Table III.

The test fabric, as an antimicrobial textile, showed a wide range of bactericidal, bacteriostatic, and antifungal activity for all groups of examined microorganisms. The bactericidal zone refers to the killing of microorganisms, whereas the bacteriostatic zone indicates growth-inhibiting effects on microorganisms. The test samples treated with gentamicin sulfate had a wider range of antimicrobial activity than the samples treated with essential oil of *P. abies* [Fig. 4(a–c)]. In the case of *C. albicans*, total inactivity was achieved with both antimicrobials, as shown in Figure 4(d).

The antimicrobial effects of the treated test fabric on microorganism growth is also presented in Table III, demonstrating the width of the inhibition zone of the microorganisms' growth.

From the values shown in Table III, it can be concluded that the bactericidal zone (zone I) of the tested microorganisms (except for *C. albicans*) was two times greater with gentamicin sulfate applications than with applications of essential oil of *P. abies*. The magnitude of the bacteriostatic zone (zone II) for both antimicrobial agents was approximately the same for all the examined microorganisms: *S. aureus*, *E. coli*, *Klabsiella*, and *C. albicans* (Table III).

The results obtained from the study of the strength-related properties of the chosen experimental material, that is, the tensile strength and elongation, tear strength and elongation, stiffness, and elasticity, are presented in histogram form in Figures 5–7. The results for the monitored characteristics are based on the average value of 10 lengthwise and 10 widthwise measurements of the tested textile samples. The bending elasticity is expressed as the bending modulus, and the tensile elasticity is expressed as the

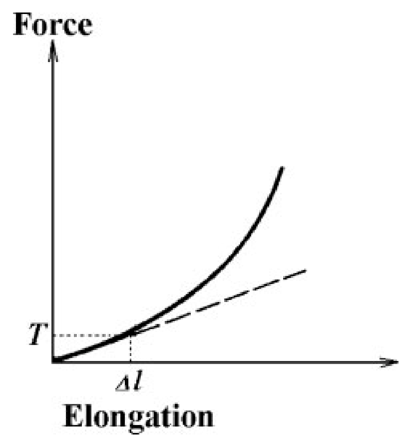


Figure 3 Determination of the force that causes the elastic deformation of the knitted fabric.[16]

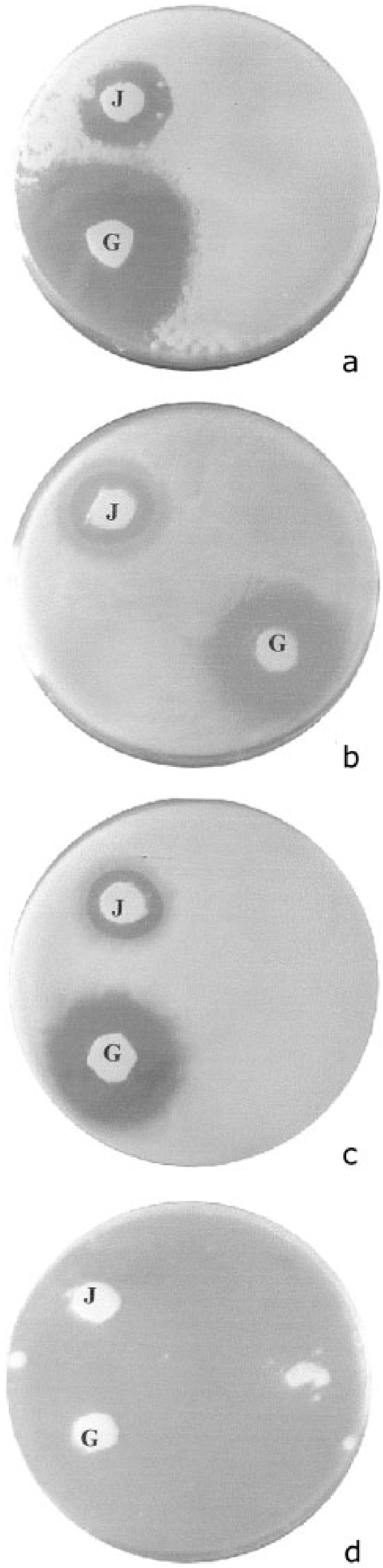


Figure 4 Antimicrobial activity range of the treated knitted fabric: (a) *S. aureus*, (b) *E. coli*, (c) *Klabsiella*, and (d) *C. albicans*.

tensile modulus. The results and values for the tensile and tear strength tests as well as their corresponding elongations are presented in Figure 5.

The results given in Figure 5 testify to the increase in the tensile strength and tensile elongation lengthwise as well as widthwise in the investigated material after treatment with either of the antimicrobial agents. The lengthwise tensile strength of the treated samples increased by 20%, and their tensile elongation increased by 18%. The widthwise changes in the values of the monitored characteristics were less pronounced with respect to the correlating lengthwise figures. The total increase in the tensile strength and elongation in the treated samples was 8%. Statistical experimental data processing, by the application of a *t*-test at a level of significance of $\alpha = 0.05$, showed the significant influence of both antimicrobial treatments on the values of the lengthwise tensile strength and elongation properties in the test fabric. A significant influence on the widthwise values of the tensile strength and elongation was not demonstrated.

The results of the tear experiments after the antimicrobial applications demonstrated increases in the test fabric's tear strength of 17% lengthwise and 11% widthwise; the elongation increased 12.5% lengthwise and 15% widthwise. The results of the *t*-test confirmed statistically significant changes in the tear strength and elongation in both structural directions for the monitored material.

In reviewing references from the field of antimicrobial treatment of knitted materials, we found the study of Karamuk et al.[17] In their work, an interlocking, knitted fabrics, both uncoated and gelatin-coated, were compared to gelatin-coated and uncoated embroidered fabrics. Their study concluded that the tensile strength of the knitted fabrics used in their experiment decreased after the gelatin treatment.

With respect to the different experimental outcomes of Karamuk et al.[17] and ourselves, the special importance of our work with antimicrobial treatments of knitted fabric becomes especially apparent; not only were we able to prevent a decrease in the tensile strength, but we were actually able to increase it as a result of the treatment process.

The results of the experiments to determine the stiffness and bending modulus of the knitted-fabric test samples are presented in Figure 6.

From the histograms in Figure 6, it is possible to conclude that the antimicrobial treatments cause an increase in both the stiffness and bending modulus in correlation with an increase in the tensile and tear strength and their corresponding elongations. Specifically, both antimicrobial treatments lead to an increase in the stiffness and bending modulus 3 times lengthwise and 7 times widthwise over the values found for untreated fabric samples. On the basis of

TABLE III
Width of the Inhibition Zone of the Microorganism Growth

	Inhibition zone (mm)						
	S. aureus		*E. coli*		*Klabsiella*		
Antimicrobial agent	Zone I	Zone II	Zone I	Zone II	Zone I	Zone II	*C. albicans*
Essential oil of *P. abies*	6	1	5	4	4	3	+*
Gentamicin sulfate	14	2	9.5	3.5	8	2	+

Zone I is the bactericidal zone, and zone II is the bacteriostatic zone. The plus sign indicates the total inhibition of the growth of the indicator culture over the whole surface of the Petri dish, and the asterisk indicates the occurrence of the individual microorganism colony on the Petri dish.

data obtained by the application of the *t*-test, it was confirmed that both antimicrobial treatments significantly influenced the stiffness and bending modulus of the fabric samples. This phenomenon might be explained by the fact that in knitted and woven textiles, mechanical deformation of the textile structure first occurs as a relative displacement in the threading within the weave. A coated polymer matrix deposit transforms the threads into bundles that have a higher bending stiffness. Simultaneously, friction between the threads increases because of blocking of the textile bonds. This effect considerably increases the fabric's stiffness.[17]

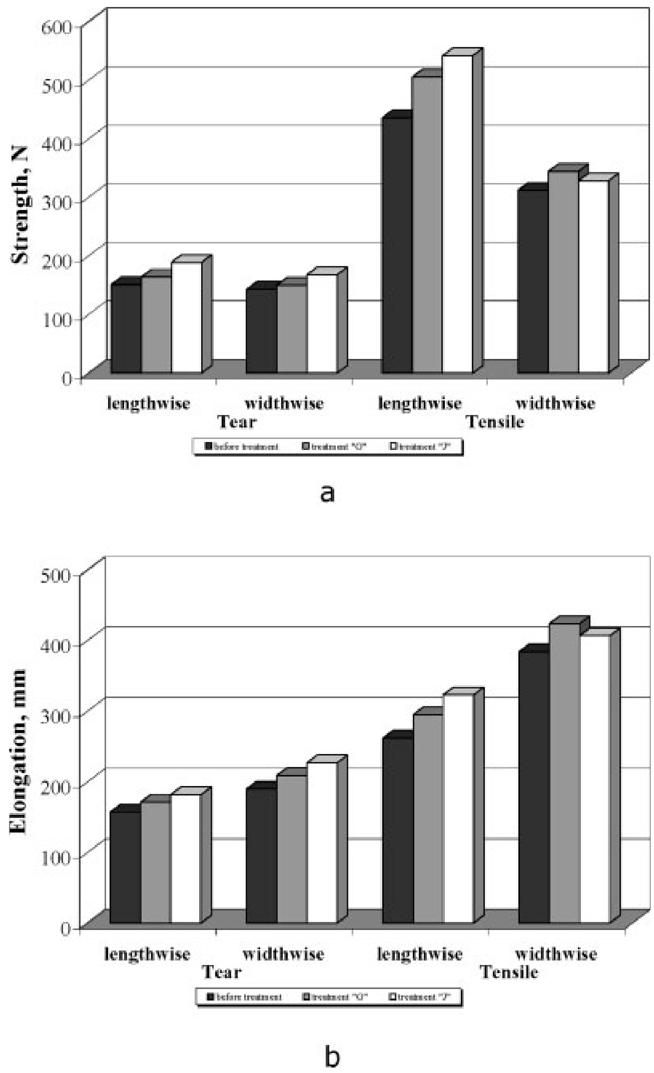


Figure 5 Influence of the antimicrobial treatment on (a) the tear and tensile strength and (b) the corresponding elongations of the investigated knitted fabric.

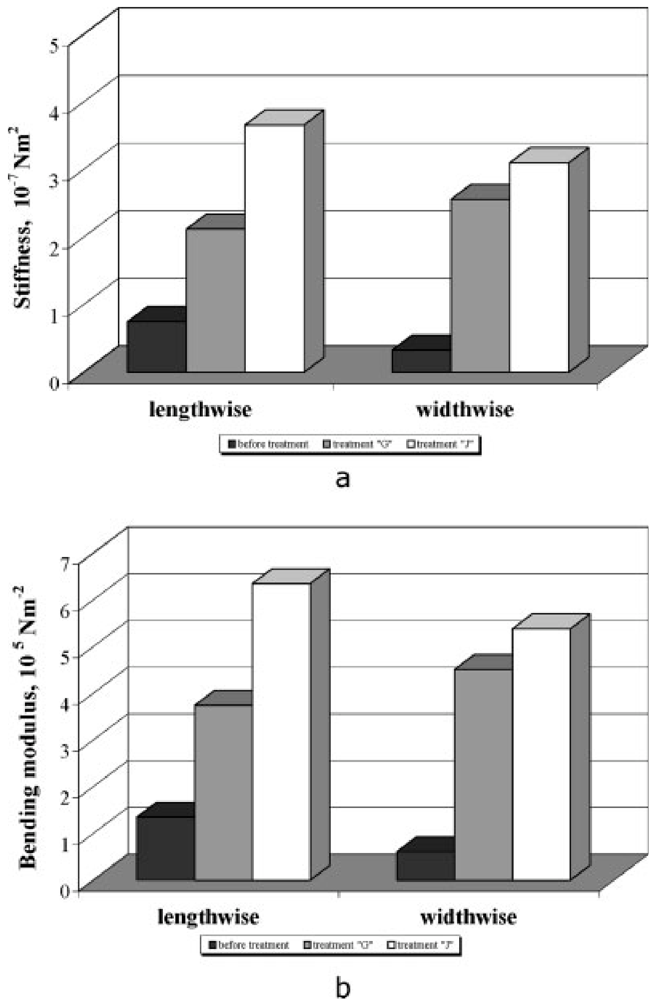


Figure 6 Influence of the antimicrobial treatment on (a) the stiffness and (b) the bending modulus of the investigated knitted fabric.

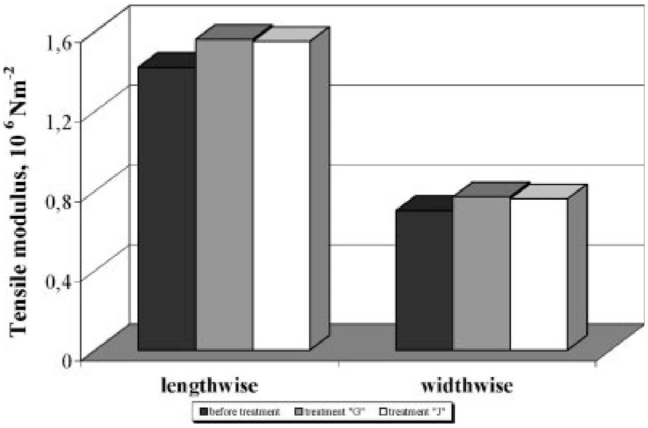


Figure 7 Influence of the antimicrobial treatment on the tensile modulus of the investigated knitted fabric.

The results of the investigation on the knitted-fabric tensile elasticity, which is expressed as the tensile modulus, are given in Figure 7.

The fact that the antimicrobial treatments caused little increase in the tensile modulus in either structural direction has particular importance from the perspective of investigating the usage of knitted fabric as a compression material. The *t*-test results confirmed that there was no statistically significant difference in the tensile modulus values before and after the antimicrobial treatments. Also of note, the tensile modulus values after treatments G and J were almost identical for both lengthwise and widthwise values of the test samples.

Taking into consideration that the investigated knitted fabric is intended for use as a compression material in medical treatment, we must achieve a suitable compression level at the skin/knitted fabric interface throughout the period and area of wear. Keeping this in mind, we examined the compression ability of the test fabric based on the pressure values generated at the skin/fabric interface. For this purpose, the pressure distribution performance along the right legs of 10 females was investigated. To permit the determination of the pressure values, the real leg shape was approximated to the shape of a truncated cone, the geometric figure that the most closely corresponds to the real shape of a human leg.

The pressure [P (N/m^2)] generated by the knitted-fabric test samples at each measurement position of the leg was determined by the application of the La Place equation:[4]

$$P = \frac{T}{r \cdot b} \qquad (10)$$

where T is the tensile force (N), r is the radius of curvature of the leg (m), and b is the width of the knitted-fabric sample (0.05 m).

The amount of force that caused elastic deformation and elongation was determined from the force–elongation diagram (Fig. 3). The values for the radius of curvature were calculated on the basis of the values of the leg circumference measured at certain points on the leg (upper part of the thigh, middle part of the thigh, above the knee, the knee, below the knee, and at the ankle).

To determine the test fabric's appropriateness for compression, the pressure values from the testing were compared with the recommended pressure value, which according to British Pharmacopoeia is a pressure that produces a tensile force of 1 kg/cm.[18] The pressure distribution performance on the right leg skin/knitted fabric interface, before and after the antimicrobial treatment, and the recommended pressure value are presented in Figure 8.

The diagram in Figure 8 highlights the importance of the radius of curvature when we consider the degree of compression-based pressure at certain positions on the leg. From this diagram, it can be estab-

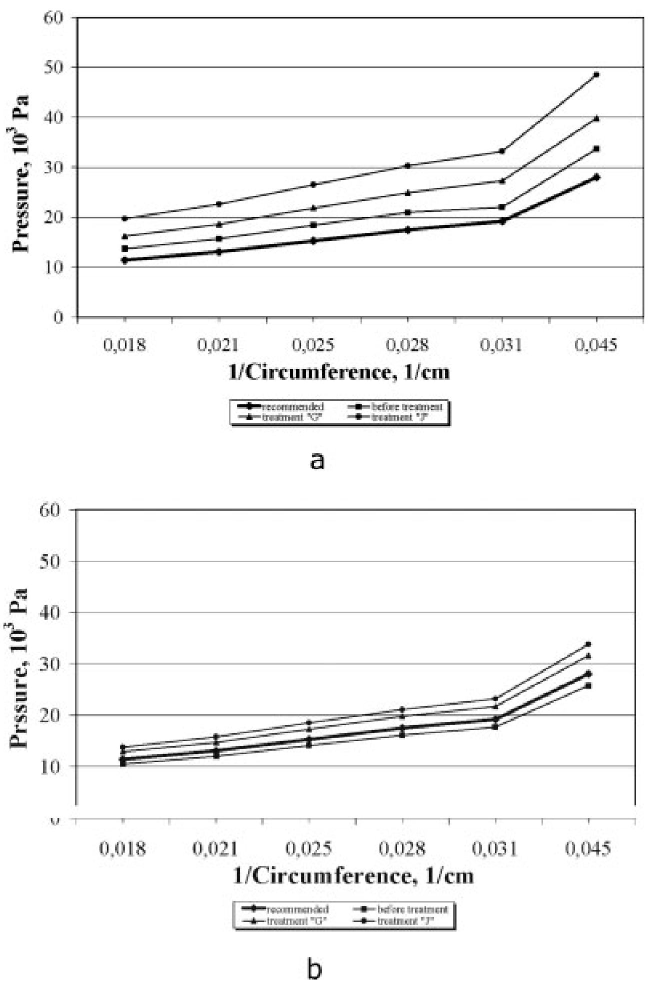


Figure 8 Pressure distribution performance at the leg skin/knitted fabric interface: (a) lengthwise for the knitted fabric and (b) widthwise for the knitted fabric.

lished that the pressure, generated by the application of the experimental material on the leg surface, increased with a decrease in the leg circumference. The greatest pressure was at the ankle, whereas the lowest was at the upper part of the thigh. In addition, the test samples of the knitted fabric both before and after the antimicrobial treatment achieved pressures that, to a certain extent, deviated from the recommended value. This deviation was less expressed in widthwise values than in lengthwise values. However, it is possible to state that the regularity of the recommended pressure value, before and after the antimicrobial treatments, was not disturbed in the tested materials. The results of our investigation on the pressure distribution performance at the leg skin/knitted fabric interface are confirmed by data in literary sources.[4,19]

CONCLUSIONS

On the basis of the results of the experiments, it is possible to conclude that polyamide/elastane knitted fabric as used in this investigation, chemically modified by gentamicin sulfate and essential oil of *P. abies*, shows a wide range of bactericidal, bacteriostatic, and antifungal activity for all the groups of examined microorganisms: *S. aureus*, *E. coli*, *Klabsiella*, and *C. albicans*.

It can also be concluded that the application of the two antimicrobial treatments used in the experiment changes the strength-related properties of the knitted fabric. These treatments also lead to a positive change in the tensile and tear strength of the treated fabric and the corresponding elongations. That is, the values of the tensile and tear strength as well as the tensile and tear elongation increase lengthwise as well as widthwise in the investigated material. In the case of the bending elasticity, it has been shown that the values of the stiffness as well as the bending modulus are increased. Concerning the tensile elasticity, the type of treatment does not have an influence; the tensile modulus remains almost unchanged, regardless of the applied treatment.

The investigated knitted fabric has satisfied the requirements of suitability for compression, as confirmed by its pressure distribution performance along a female leg. The compression ability is more expressive widthwise than lengthwise in the knitted fabric because of the lower deviation of the pressure values from the recommended value. The results of this investigation constitute conclusive evidence that the monitored knitted fabric can be successfully used for medical purposes as a compression material. Thus, by varying a knitted fabric's structural parameters, by selecting an adequate technique for its production, and by choosing appropriate parameters for the antimicrobial treatment, we can obtain a compression material that will produce pressure at the skin/fabric interface whose values are completely suited for the recommended or required pressure value.

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References

1. Alekseev, A. A.; Krutikov, M. G.; Bobrovnikov, A. E.; Vasilyeva, T. S.; Grishina, I. A.; Paltsyn, A. A. Ann Burns Fire Disasters 2002, 15, 22.
2. Öztürk, E.; Agalar, C. J Biomater Appl 2004, 18, 291.
3. Parsons, D.; Bowler, P. G.; Myles, V.; Jones, S. Wounds 2005, 17, 222.
4. Rigby, A. J.; Anand, S. C.; Miraftab, M. Presented at the International Conference of Medical Textiles, Bolton, United Kingdom, Aug 1999; Session 2, p 62.
5. Giri Dev, V. R.; Neelakandan, R.; Sudha, S.; Shamugasundram, O. L.; Nadaraj, R. N. Text Mag 2005, 46, 83.
6. Mi, F. L.; Wu, Y. B.; Shyu, S. S.; Schoung, J. Y.; Huang, Y. B.; Tsai, Y. H.; Hao, J. Y. J Biomed Mater Res 2002, 59, 438.
7. Willi, P.; Chandra, P. S. Trends Biomater Artif Organs 2004, 18, 18.
8. Skundric, P.; Kostic, M.; Simovic, L.; Medovic, A.; Mihailovic, T.; Asanovic, K.; Dimitrijevic, S. Project TR-6713 B; Faculty of Technology and Metallurgy: Belgrade, 2005.
9. Joiner Gresham, B. In Bioactive Fibers and Polymers; Edwards, J. V.; Vigo, L. T., Eds.; American Chemical Society: Washington, DC, 2001; Chapter 12.
10. Annual Report; National Textile Center: Research Triangle Park, NC, 2000; C 98–A14.
11. BS Handbook: Methods of Test for Textiles; British Standards Institution: London, 1974; Vol. 11, Section 4/107.
12. Buzov, B. A.; Modestova, T. A.; Alymenkova, N. D. Materialovedenie Shveynogo Proizvodstva; Legprombytizdat: Moscow, 1986.
13. Raskovic, D. Strength of Materials; Scientific Book: Belgrade, 1987.
14. Luvishis, L. A.; Birenbaum, E. I. Tekhnicheskii Kontrol' v Tkachestve i Otdelke Sherstyanykh Tkanei; Legkaya Industriya: Moscow, 1971.
15. Sivukhin, D. V. Obshchiy Kurs Fiziki; Nauka: Moscow, 1979.
16. Mihailovic, T. Doctoral Thesis, Faculty of Technology and Metallurgy, 2002.
17. Karamuk, E.; Mayer, J.; Düring, M.; Wagner, B.; Bischoff, B.; Ferrario, R.; Billia, M.; Seidl, R.; Panizzon, R.; Wintermantel, E. Presented at the International Conference of Medical Textiles, Bolton, United Kingdom, Aug 1999; Session 5, p 200.
18. Kininmonth, J.; Evans, J. C. U.S. Pat. 5,647,842 (1997).
19. Ng, S. F.; Parkinson, J. M.; Schofield, B. Presented at the International Conference of Medical Textiles, Bolton, United Kingdom, Aug 1999; Session 2, p 55.