Katarzyna Ławińska[1,*], Wioleta Serweta[1], Izabela Jaruga[1], Nataliia Popovych[2]

Examination of Selected Upper Shoe Materials Based on Bamboo Fabrics

DOI: 10.5604/01.3001.0013.4472

[1] **ŁUKASIEWICZ Research Network – Institute of Leather Industry,**
Zgierska 73, 91-462 Lodz
* e-mail: k.lawinska@ips.lodz.pl

[2] **Lviv University of Trade and Economics,**
Tuhan-Baranovskoho Street, 10, Lviv, Ukraine

Abstract
In this paper the authors describe the creation of new material packages based on bamboo textile materials for upper shoe material. These packages were made up of three layers: an inner layer in the foot skin neighbourhood, outer layer – which contacted with the surrounding environment, and a medium layer – polyurethane foam of a thickness of 2 mm. Experimetal tests consisted in the measurement of hygienic parameters (water vapour absorption and permeability) and some mechanical indicators important from the user's point of view, like the elongation property and maximum force at break. The packages based on bamboo materials were compared with a standard composition: cotton – polyurethane foam – cotton. The results obtained showed, that in a lot of cases, the use of bamboo materials as lining or an outer layer is a good possibility to improve the hygienic and mechanical properties of newly formed material compositions.

Key words: *bamboo fibers, children footwear, foot prevention.*

Introduction

Physiological comfort in footwear use is one of the most important determinants which describes its ergonomics [1]. This aspect is closely related to the individual requirements of users, which depend on a lot of factors – especially age, type of physical activity and the inter – individual variability of the human system, like sweat secretion and thermal sensitivity. Enhanced sweat secretion causes the effect of an increase in frictional forces between the foot skin and footwear surface [2]. Correct construction of footwear should correlate with individual physiological limits. In respect of a child's foot, it is known that the epidermal foot layer is not fully formed. Thus, the probability of injury as a result of the occurrence of frictional forces is higher and more dangerous [3-5].

An important element of the functionality of children's footwear is also antimicrobial and antifungal prevention. The growth of microorganisms (bacteria or fungi) in a shoe interior has an adverse impact on the health of feet and may cause a lot of dermatological diseases [6].

Therefore, there is great interest in finding safe and ecological materials to formulate new footwear compositions which can improve the hygienic and parallel mechanical properties of footwear [7-9].

The main goal of this paper was to create upper combinations based on accessible bamboo textiles, conduct an investigation of their hygienic and mechanical properties and make a comparison with standard cotton materials commonly used. These measures were done in order to extract a set of bamboo materials which can be used as an outer (or inner) layer in a three – layered upper footwear material.

The fibre and textile industry is a diverse sector that covers the entire production chain of transforming natural and chemical fibers into end-use products [10]. The structure of bamboo textiles [11, 12] and their application opportunities as garment elements have been under scientific consideration over the last two decades [13-15]. Bamboo textiles have a lot of advantages [16]. From an ecological point of view bamboo raw materials are renewable and biodegradable. Moreover, because bamboo is the fastest growing plant in the world, irrigation, chemical pesticides and fertilisers are unnecessary.

From the point of view of fabric properties, the abundance of gaps in the cross-section of bamboo fibre improve the absorbance and evaporation of skin moisture. Another bamboo textile characteristic is soft feel, comparable to cashmere or ramie. From the hygienic point of view, important is the ability to stay warm in cool weather and stay cool in warm weather due to the quick moisture absorption and drying capability. In a literature review, a lot of examples of bamboo textile applications were found. In [17, 18] authors investigated the influence of yarn properties of bamboo fibre on the air and water vapour permeability of double – layered weft knitted fabrics based on regenerated bamboo yarns. The fabrics based on bamboo fibres were used as an outer layer of leisure clothing. In another paper [19] authors determined the influence of the loop length and linear density of yarn on bamboo knitted fabric properties like air permeability, thermal resistance and relative water vapour permeability. On the other hand, the moisture management properties of compositions of wool – bamboo were examined in [20] as a base layer of sportswear. In work [21], the functional parameters of lining fabrics, such as the friction coefficient, tensile strength, tensile elongation and water vapour permeability were evaluated. In paper [22] authors showed the thermal insulation properties of compositions based on, inter alia, bamboo fabrics.

This work is the second in a sequence focused on the possibility of applications of bamboo fabrics as footwear elements.

Materials and method

In order to examine the mechanical and hygienic properties of upper materials, three- layered materials based on bamboo fabrics were moulded. The set of fabrics used is listed in ***Table 1***. As a control sample, a cotton composition (B1/B2) was used. Polyurethane perforated foam (with self – adhesive surfaces) of a thickness of 1.2 mm was used as a connection between two layers of fabrics. The density of perforation was 6 holes per square inch. In the three – layered composition prepared, material B1 was substituted by materials M1 – M7, undertaken to extract upper bamboo materials. Material B1 was used as an outer layer, while bamboo materials M1 – M7 played the inner role. The next step was to replace B2 by materials M1 – M7 in order to check their lining destination in comparison with B2.

Table 1. Characteristics of materials with bamboo fibers tested.

Sample	Material type	Mass per square metre, g/m^2	Thickness, mm	Raw composition, %
M1	Woven	170	0.40	100% bamboo
M2	Woven	500	1.74	100% bamboo
M3	Woven	300	0.61	95% bamboo+5% polyester
M4	Woven	170	0.35	50% bamboo+50% flax
B1 B2 M5	Woven Woven Knitted	230 145 290	0.58 0.37 1.20	100% cotton 100% cotton 85% bamboo+15% polyester
M6	Knitted	220	0.38	95% bamboo+5% elastane
M7	Knitted	320	0.86	97% bamboo+3% elastane

Table 2. Characteristics of packed materials tested.

Sample	Mass per square metre, g/m^2	Thickness, mm	Raw materials, %
B1/B2	375	2.77	cotton 100%/PU/cotton 100%
B1/M1	400	2.91	cotton 100%/PU/bamboo 100%
B1/M2	730	4.82	cotton 100%/PU/bamboo 100%
B1/M3	530	3.05	cotton 100%/PU/95% bamboo+5% polyester
B1/M4	400	2.86	cotton 100%/PU/50% bamboo+50% flax
B1/M5	520	4.23	cotton 100%/PU/85% bamboo+15% polyester
B1/M6	450	3.02	cotton 100%/PU/95% bamboo+5% elastane
B1/M7	550	3.30	cotton 100%/PU/97% bamboo+3% elastane
M1/B2	315	2.55	bamboo 100%/PU/cotton 100%
M2/B2	645	4.35	bamboo 100%/PU/cotton 100%
M3/B2	445	2.84	95% bamboo+5% polyester/PU/cotton 100%
M4/B2	315	2.62	50% bamboo+50% flax /PU/cotton 100%
M5/B2	435	3.01	85% bamboo+15% polyester/PU/cotton 100%
M6/B2	365	2.78	95% bamboo+5% elastane/PU/cotton 100%
M7/B2	465	3.15	97% bamboo+3% elastane/PU/cotton 100%

Table 3. Results of hygienic properties of materials tested.

Material compositions used in tests		Water vapour permeability, mg/cm^2·h	Water vapour absorption, mg/cm^2	Water vapour coefficient, mg/cm^2
Control sample	B1/B2	7.72	2.22	64.0
Samples with bamboo woven fabrics	B1/M1	7.06	3.77	60.3
	M1/B2	6.03	3.80	52.0
	B1/M2	7.54	4.75	65.1
	M2/B2	5.22	4.01	45.8
	B1/M3	7.34	4.57	63.3
	M3/B2	6.91	4.00	59.2
	B1/M4	7.42	3.18	62.5
	M4/B2	5.05	2.84	43.2
Samples with bamboo knitted fabrics	B1/M5	7.67	3.15	64.5
	B1/M6	5.62	3.92	48.9
	B1/M7	6.18	4.28	53.7
	M5/B2	9.72	2.90	80.7
	M6/B2	5.47	3.23	47.0
	M7/B2	6.27	4.34	54.5

The new compositions formed, listed in ***Table 2***, were examined with a view to hygienic and mechanical properties. With respect to hygienic properties, the water vapour permeability (W_{VP}) and water vapour absorption (W_{VA}) were measured according to methodology described in the ISO standard [23].

As a result of the above-mentioned quantities, the water vapour coefficient (W_{VC}) was calculated according to the following ***Equation (1)***:

$$W_{VC} = t \cdot W_{VP} + W_{VA} \quad (1)$$

where, t – time (8 hours).

The water vapour coefficient describes the total amount of vapour diffusion through air gaps of the material tested.

In order to determine mechanical properties, the samples were stretched axially at a constant velocity equal to 50 mm/min using a Zwick/Roell Z010 testing machine. The samples were stretched in two directions: along the weft (or row for knitted fabrics) and warp (or column for knitted fabrics). The quantities measured were the tensile strength, elongation at the prescribed force, and the maximum force at break.

Results and discussion

Hygienic properties

The functional properties of footwear materials have some relationships between each other. It is necessary to test hygiene and mechanical properties because these are important indicators for creating a comfortable and functional final product. Under normal circumstances the water vapour permeability of materials has a positive correlation relationship with air permeability, corresponding to good shoe ventilation between the shoe interior and external environment, which is important to improve comfort sensitivity. On the other hand, water vapour permeability has a negative correlation relationship with heat preservation ability. An important aspect is also antimicrobial ability because certain microorganisms grow very well in specific temperature and humidity conditions [24-26].

In ***Table 3*** the hygienic properties of the materials tested are summarised. It can be observed that for the newly formed material compositions, the water vapour absorption was higher than for the control sample B1/B2 for all compositions with bamboo fabrics. The differences ranged between 131% (for M4/B2) and 214% (for B1/M2) in favour of compositions made with the use of bamboo materials. Consequently, water vapour is absorbed and eliminated to the outer environment faster than for the B1/B2 composition. This is the best confirmation of the fact that fabrics based on bamboo fibres are better than the standard connection between a cotton outer and cotton inner layer, due to the water vapour absorption property.

Thus, to conclude, it can be seen that all compositions made with the use of bamboo fabrics are situated over the minimal

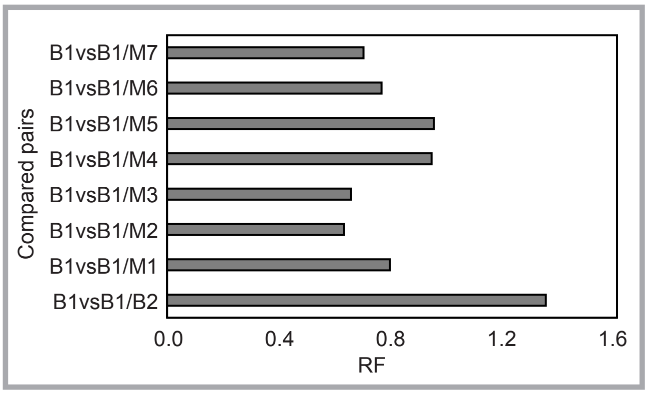

__Figure 1.__ RF coefficient between B1 and packages B1/M-B1/M7.

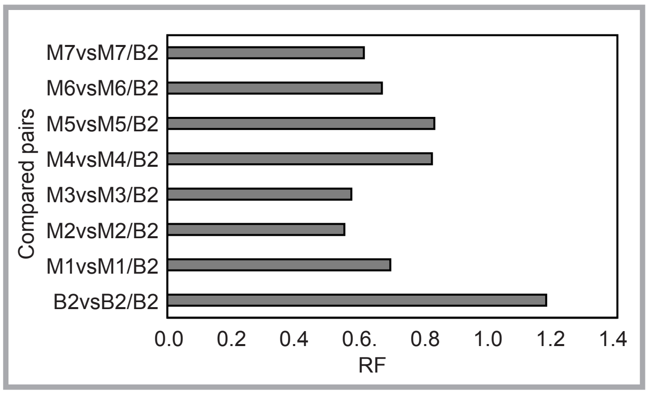

__Figure 2.__ RF coefficient between B2, M1-M7 and packages B2/B2, B2/M1-B2/M7.

acceptable level (for water vapour permeability it is 2 mg/cm^{2}h for lining materials and 0.8 2 mg/cm^{2}h for the upper layer), and for the water vapour coefficient it is 20 mg/cm^2 for linings and 15 mg/cm^2 for uppers, respectively.

To find the statistical significance of differences between the control sample and each of the other compositions, the T-test was done at the confidence level $\alpha = 0.05$. Exemplary results for water vapour absorption are listed in ***Table 4***.

*__Table 4.__ Water vapour absorption differences between the newly formed composition and control sample. __Note:__ * means a statistically significant difference at the confidence level $\alpha = 0.05$.*

Treatment pair	t-value	p-value
B1/B2 vs B1/M1	-15.738	0.004*
B1/B2 vs M1/B2	-4.540	0.045*
B1/B2 vs B1/M2	-17.291	0.003*
B1/B2 vs M2/B2	-11.002	0.008*
B1/B2 vs B1/M3	-7.990	0.015*
B1/B2 vs M3/B2	-7.616	0.017*
B1/B2 vs B1/M4	-1.786	0.216
B1/B2 vs M4/B2	-1.763	0.220
B1/B2 vs B1/M5	-1.589	0.126
B1/B2 vs M5/B2	-6.990	0.020*
B1/B2 vs B1/M6	-17.553	0.003*
B1/B2 vs M6/B2	-7.106	0.019*
B1/B2 vs B1/M7	-15.312	0.004*
B1/B2 vs M7/B2	-6.769	0.021*

As shown in ***Table 4*** water vapour absorption was changed at a satisfactory level, as described by the statistically significant differences for the majority of compositions. Moreover, according to the water vapour permeability, the change of material from B1 to M5 for the M5/B2 composition gives a result in the form of the maximum level of this parameter.

In order to show the impact of bamboo fabrics on the water vapour absorption property, the reference factor (RF) between a single fabric and its composition was calculated, according to the following ***Equation (2)***:

$$RF_{WVA} = \frac{WVA_S}{WVA_C}, \qquad (2)$$

Where, means the water vapour absorption for a single material (B1, B2, M1-M7) and – the same parameter for the composition of materials: B1 with B2 or M1-M7. The values of RF coefficients are shown in ***Figures 1*** and ***2***.

On the basis of the above-mentioned results, it is possible to state that the following materials: M1, M2, M5, M6, M7 have good properties for the inner layer of the material package. This is an important aspect because inner materials have a direct contact with foot skin, and a high level of absorption gives better conditions inside the shoe volume. Due to the high level of the water vapour permeability factor, all of the materials tested are good for footwear elements (uppers and linings). Currently, the development of effective methods to improve thermal and moisture transfer is very strong. One of the most important ways is making a material packages in order to improve thermo – physiological and sensorial comfort. For example, Ren and Ruckman [27] proved that decreasing the thickness of a waterproof membrane and outer layer fabric or increasing the average diffusion coefficient of the outer layer and membrane can improve water vapour transfer out of the fabric. These three – layered packages were used as components of waterproof breathable fabrics for clothing. The same mechanism could be desirable for footwear materials in order to improve comfort sensation. In experimental works done by Oh [28], hydrophilic and hydrophobic materials in different combinations were used in order to improve the moisture transport mechanism through the multilayer structure. Currently, the wide spectrum of possible configurations of materials gives a possibility to improve specific material properties which are necessary from a physiological comfort point of view. In paper [29] the authors presented results obtained for two – layer systems composed of fabrics made of synthetic and hygroscopic fibres. This analysis showed that these configurations can give high – utility material packages which can help in eliminating sweat from human skin. In paper [30] the authors developed a structural computational model in order to investigate the heat and air – water vapour mass exchange between multilayered packages of fabrics and the human body.

Mechanical properties

From the user's point of view, knowledge of the tensile properties of fabric's used as footwear materials is very important. The elastic properties of fabrics and their packages are desirable in chil-

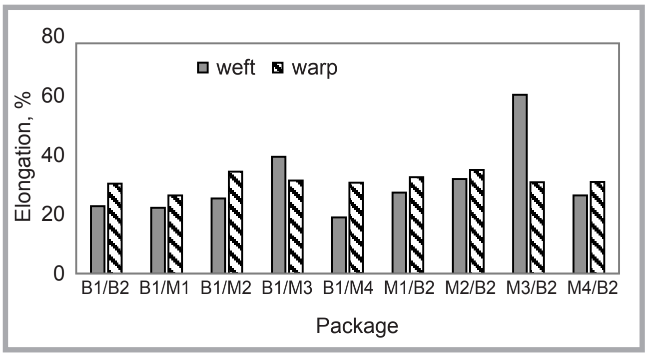

Figure 3. Elongation at break of fabric package (across the weft and warp) with bamboo and cotton woven fabrics.

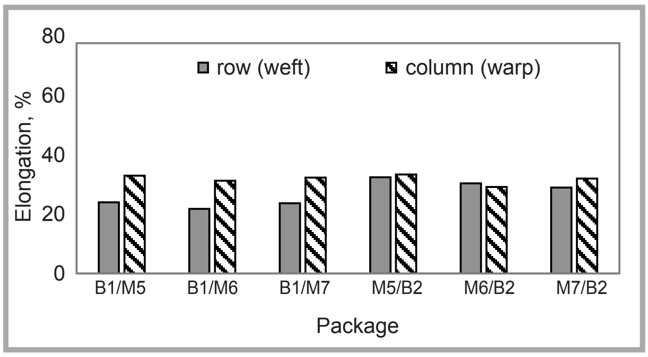

***Figure 4.** Elongation at break of fabric package across the row (weft) and column (warp) with bamboo knitted fabrics and cotton woven fabrics.*

dren's footwear. The literature survey in [31] sjhowed that small children should have a shoe which is as flexible as their foot, which is very important because the strength of tissue and the flexibility of joints stops developing at the age of 15. The most static and dynamic foot characteristics, connected with the right posture, change during growth and maturation periods [32, 33].

In this work the authors examined several mechanical properties, like strength and elongation induced during a tensile test under an external breaking load, which are the most important performance parameters of fabrics. The tensile properties of fabrics mostly depend on those of the single fibres from which they are made [34]. ***Figures 3*** and ***4*** show the elongation properties of packages based on bamboo materials. Elongation was measured along the weft and warp for fabrics and along a column and row for knitted fabrics. In the weft direction, we can observe that almost all cases are better than the B1/B2 composition. For the worst values (22.8% for B1/M1 and 19.5% for B1/M4) the differences from the control sample are not statistically significant (the p-value is equal to 0.11 and 0.25, respectively, for the t-Test two-tailed hypothesis). In the warp direction, statistical significance occurs for the B1/B2-B1/M2 difference (the p-value is equal to 0.004 for the same assumptions as below).

Although direct comparison of these compositions with B1/B2 is impossible (because of the different structures of their components), we can also observe that these compositions are similar to the B1/B2 characteristics.

Thus, to conclude, we can observe that in compositions B1/M1-M7, elongation values across the weft change from 19.5% for B1/M4 to 40.6% for B1/M3. In turn, in the warp direction the values fluctuate between 27.2% (for B1/M1) and 35.4% (for B1/M2).

For reversed compositions, where B1 material was replaced by M1-M7 fabrics, elongation values across the weft change between 27.2% for M4/B2 62.1% and M3/B2. In turn, in the warp direction the values measured lie between 31.8% for M3/B2 and 36.0% for M2/B2.

Analysing the elongation values for packages with knitted fabrics, we can observe that the coefficient of variation of these results is equal to 15% for rows and 5% for columns. Both of these values are less than 20%, which is a low variation.

The next parameter connected with the previously mentioned elongation at break is the breaking force. Because in plain weave the maximum number of interlacing points is connected with higher tensile strength in the warp direction, only the maximum forces across the weft determine the maximum force at the breaking point [35]. The tests undertaken showed that the replacement of woven cotton B2 by woven bamboo gave a better result for M1 and M3. The values of forces grew from 2.4% for M1 to 11% for M4 in comparison with the B1/B2 package. Hence, in these cases the positive result of woven bamboo implementation was visible. The same tendency was observed for knitted fabrics moulded with bamboo components. The values of maximum forces at break lay between 691 N and 728 N. In the case where replacement took place with regard to the outer layer, a similar result was observed (***Figure 5***).

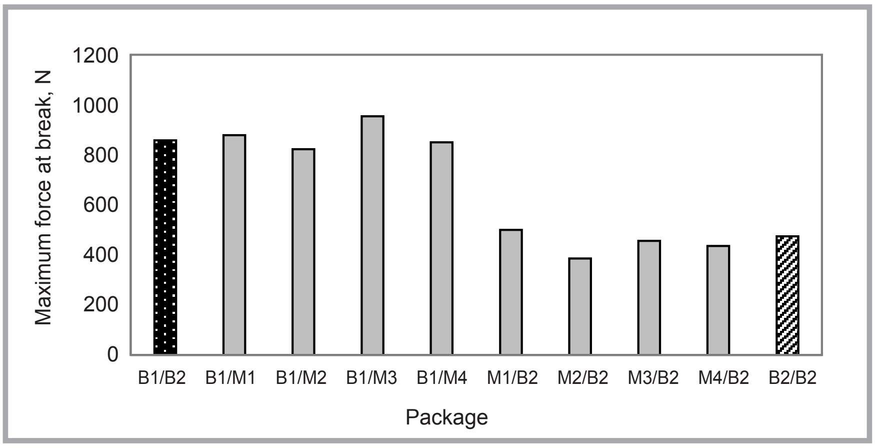

***Figure 5.** Maximum force at break distribution for material packages.*

For example, the maximum force at break was observed for the M1/B2 package and was stronger than that of the B2/B2 package by 5%. In the case of knitted fabrics mixed with inner B2, the maximum forces at break were between 242 N for M5/B2 and 256 N for M6/B2. These results gave confirmation that the replacement of common footwear materials like cotton by bamboo materials, with better foot friendliness properties, is a good way to improve the mechanical properties, which produces tougher and more comfortable shoes. This aspect is very important from the point of view of the anatomy of a child's foot. From an ecological point of view, this replacement is also crucial because in the textile sector the implementation of natural processing and materials is desirable [36].

The testing of some properties (especially mechanical or hygienic) of multilayered fabric packages is quite a popular method of making a qualitative and quantitative analysis of utility properties (i. e thermal comfort), especially of clothing [37, 38]. Other modes of construction of multi-layered structures are ballistic applications, where multi – layered fabric packages have high impact resistance [39]. Also, layers are relevant in other compositions i.e. for medical textiles [40]. Packages of fabrics are also applied for footwear. In paper [41] upper compositions were created from fabrics based on polypropylene yarns with different weaves. The materials used were laminated with the use of solvent adhesive or porous film. In this paper the authors used polyurethane foam with perforation.

The results of this work confirm that bamboo materials can be applied as components for footwear elements, like as uppers and linings. Some parameters – both hygienic (water vapour absorption) and mechanical (elongation at break) – are better than for the cotton materials commonly used. Based on this information, better comfort conditions inside a footwear volume can be predicted.

Investigations on the possibility of creating footwear elements based on bamboo fabrics will be continued in order to construct a final children's shoe with better functionality.

Conclusions

- New material compositions based on bamboo fabrics were developed and made for experiment purposes. Bamboo materials were used as the outer (M1-M7/B2) and inner layer (B1/M1-M7). A test sample was created from cotton B1 (for the outer layer because of the mass per square metre) and cotton B2 (for the inner layer for the same reason).
- Bamboo fabrics, as shown in this paper, can be a good alternative for the cotton materials commonly used. They can be used both as an outer and inner layer of a textile upper package.
- The statistical significance of differences in some hygienic and mechanical parameters favours them for use as footwear elements.
- Textile compositions based on bamboo fabrics are better if we take into account the water vapour property (as a hygienic parameter) and elongation at break (as a mechanical parameter). For the remaining indexes examined, bamboo fabrics are comparable with the compositions commonly used, where for the outer and inner layer cotton is utilised.
- In the cases examined, improvement of the water vapour absorption property was observed in comparison to the cotton – cotton control package. This solution could be competitive in relation to cotton materials, which are commonly used nowadays.
- The resulting mechanical properties (especially elasticity) gave a possibility to predict good footwear profiling for the foot shape.

Acknowledgements

The research work has been carried out within project: "Use of bamboo extract and fibres in the elements of leather, textile and combined leather and textile children's footwear" financed by the National Centre for Research and Development (Agreement No. LIDER/16/0091/L-8/16/NCBR/2017).

References

1. Serweta W, Matusiak M, Olejniczak Z, Jagiełło J, Wójcik J. Proposal for the Selection of Materials for Footwear to Improve Thermal Insulation Properties Based on Laboratory Research. *FIBRES & TEXTILES in Eastern Europe* 2018; 26, 5(131): 75-80. DOI: 10.5604/01.3001.0012.2535.
2. Taylor N A S, Caldwell J N, Mekjavic IB. The sweating foot: local differences in sweat secretion during exercise – induced hyperthermia. *Aviation Space and Environmental Medicine* 2006; 77 (10): 1020-1027.
3. Błaszczyk-Kostanecka M, Wolska H. Dermatologia w praktyce. *PZWL Wydawnictwo Lekarskie*, Warsaw, 2009.
4. Hoath S B, Maibach H I. Neonatal skin structure and functions. Second Edition. *Revised and Expanded,* Marcel Dekker Inc., New York 2003.
5. Rajchel-Chyla B, Skrzyńska B, Wierzbicka I. Tests and Facultative Certification of Footwear Designed for Children as well as People with Sensitive Feet, Suffering Diabetes Mellitus and Rheumatoid Arthritis. *Footwear safety and functionality* 2012: 182-207.
6. Sanchez-Navarro MM, Perez-Liminana MA, Cuesta-Garotte N, Maestre-Lopez MI, Bertazzo M, Martinez-Sanchez MA, Orgiles-Barcelo C, Aran-Ais F. Latest Developments in Antimicrobial and Functional Materials for Footwear. *Microbial Pathogens and Strategies for Combating Them: Science, Technology and Education* 2013; 1: 102-113.
7. Ławińska K, Serweta W, Modrzewski R. Qualitative Evaluation of the Possible Application of Collagen Fibres: Composite Materials with Mineral Fillers as Insoles for Healthy Footwear. *FIBRES & TEXTILES in Eastern Europe* 2018; 26, 5(131): 81-85. DOI: 10.5604/01.3001.0012.2536.
8. Ławińska K, Serweta W, Modrzewski R. Studies on Water Absorptivity and Desorptivity of Tannery Shavings-Based Composites with Mineral Additives. *Przemysł Chemiczny* 2019; 98(1): 106-109.
9. Ławińska K, Modrzewski R, Serweta W. Tannery shavings and mineral additives as a base of new composite materials. *FIBRES & TEXTILES in Eastern Europe* 2019; 27, 5(137): 89-93.
10. Dziuba R, Jabłońska M, Sulak K, Ławińska K. Textile Sector of the Visegrad Group Countries in Trade with the European Union. *FIBRES & TEXTILES in Eastern Europe* 2018; 26, 6(132): 24-29. DOI: 10.5604/01.3001.0012.5160.
11. Haiyan N, Yonggui L, Shiwei F. Morphological Structure and Properties of Bamboo Shell Fiber. *Journal of Natural Fibers* 2018; 15 (4): 586-595.
12. Lipp-Symonowicz B, Sztajnowski S, Wojciechowska D. New Commercial Fibres Called 'Bamboo Fibres' – Their Structure and Proper. *FIBRES & TEXTILES in Eastern Europe.* 2011; 19, 1(84): 18-23.
13. Erdumlu N, Ozipek B. Investigation of Regenerated Bamboo Fibre and Yarn Characteristics. *FIBRES & TEXTILES in Eastern Europe* 2008; 16, 4(69): 43-47.
14. Čiukas R, Abramavičiūtė J. Investigation of the Air Permeability of Socks Knitted from Yarns with Peculiar Properties. *FIBRES & TEXTILES in Eastern Europe* 2010; 18, 1(78): 84-88.
15. Karthikeyan G, Nalakilli G, Shanmugasundaram OL, Prakash C. Moisture Management Properties of Bamboo Viscose/Tencel Single Jersey Knitted Fabrics. *Journal of Natural Fibers* 2017; 14, 1:143-152.
16. Ławińska K, Serweta W, Gendaszewska D. Applications of Bamboo Textiles in Individualised Children's Footwear. *FIBRES & TEXTILES in Eastern Europe* 2018; 26, 5(131): 87-92. DOI: 10.5604/01.3001.0012.2537.
17. Bivainytė A, Mikučionienė D. Investigation on the Air and Water Vapour Permeability of Double-Layered Weft Knitted Fabrics. *Fibres & Textiles in Eastern Europe* 2011; 19, 3(86): 69-73.
18. Bivainytė A, Mikučionienė D. Investigation on the Dynamic Water Absorption of Double-Layered Weft Knitted Fabrics. *FIBRES & TEXTILES in Eastern Europe.* 2011; 19, 6(89): 64-70.

19. Chidambaram P, Govind R, Chandramouli Venkataraman K. The Effect of Loop Length and Yarn Linear Density on the Thermal Properties of Bamboo Knitted Fabric. *AUTEX Research Journal* 2011; 11 (4):102-105.
20. Troynikov O, Wardiningsih W. Moisture management properties of wool/polyester and wool/bamboo knitted fabrics for the sportswear base layer. *Textile Research Journal* 2011; 26: 621-631.
21. Ertekin G, Oglakcioglu N, Marmarali A, Kadoglu H, Blaga M, Ciobanu R, Mihai A, Costea M. Analysis of knitted footwear linings for diabetic patients. *Textil ve Konvesiyon* 2016; 26(4): 358-367.
22. Serweta W, Matusiak M, Ławińska K. Research on Optimising the Insulation of Footwear Materials Using Statistical Methods. *FIBRES & TEXTILES in Eastern Europe* 2019; 27, 4(136): 81-87. DOI: 10.5604/01.3001.0013.1823.
23. PN-EN ISO 20344: 2012. Personal protective equipment – Test methods for footwear.
24. Schols EH, van der Eijnde WA, Heus R. A Method for Assessing Thermal Comfort of Shoes Using A "Sweating" Foot. *European Journal of Applied Physiology* 2004; 92(6): 706- 709.
25. Shaolanc D, Xiaohua Z, Peng Y. Contrastive Study on the Hygienic Properties of Different Kinds of Shoe Upper and Lining Materials. *China Leather.* 2004; 11: 008.
26. Tan J, Peng W, Ding S. State and Trends of Test Technology on Hygienic Properties for Leather Shoes. *Advanced Materials Research 2012;* 382: 375- 378.
27. Ren YJ, Ruckman JE. Condensation in Three – Layer Waterproof Breathable Fabrics for Clothing. *International Journal of Clothing Science and Technology* 2004; 16 (3): 335-347.
28. Oh A. The Measurement of Water Vapour Transfer Rate Through Clothing System with Air Gap Between Layers. *International Journal of Heat and Mass Transfer 2008;* 44: 375-379.
29. Bartkowiak G, Szucht E. Liquid Sorption in Two – Layer Packets of Structurally Differentiate Knitted Materials. *FIBRES AND TEXTILES in Eastern Europe*. 2002; 10(4): 45- 48.
30. Barauskas R, Abraitiene A. A Model for Numerical Simulation of Heat and Water Vapor Exchange in Multilayer Textile Packages with Three Dimensional Fabric Ventilation Layer. *Textile Research Journal*. 2011; 81(12): 1195-1215.
31. Walther M, Herold D, Sinderhauf A, Morrison R. Children Sport Shoes – A Systematic Review of Current Literature. *Foot and Ankle Surgery* 2008; 14(4): 180-189.
32. Muller S, Carlsohn A, Muller J, Baur H, Mayer F. Static and Dynamic Foot Characteristics in Children Aged 1 – 13 Years: A Cross – Sectional Study. *Gait and Posture* 2012; 35: 389 -394.
32. Aiyer A, Hennrikus W. Foot Pain in the Child and Adolescent. *Pediatric Clinics of North America* 2014; 61(6): 1185-1205.
33. Grosberg P. The Tensile Properties of Woven Fabrics, In: *Structural Mechanics of Fibres, Yarn and Fabrics 1*, John Wiley and Sons, 339-354, ISBN 471-36669-2, 1969.
34. Dubrowski PDD. Woven Fabric Engineering. InTechOpen. London 2010.
35. Jain M. Ecological Approach to Reduce Carbon Footprint of Textile Industry. *International Journal of Applied Home Science* 2017; 4 (7/8): 623-633.
36. Matusiak M. Investigation of the Thermal Insulation Properties of Multi-Layered Textiles. *FIBRES AND TEXTILES in Eastern Europe*. 2006; 14, 5(59): 98-102.
37. Surdu L, Ghituleasa C, Michai C, Ene A, Radulescu I, Subtrica A, Cioara I. Comfort Properties of Multilayer Textile Materials for Clothing. *Industria Textila* 2013; 64 (2): 75-79.
38. Bilisik K, Yolacan G. Experimental Determination of Bending Behaviour of Multi-Layered and Multidirectionally-Stitched E-Glass Fabric Structures for Composites. *Textile Research Journal* 2012; 81(17): 1748-1761.
39. Ramachandran T, Manohari BG. Comfort an Thermos Physiological Characteristics of Multi-Layered Fabrics for Medical Textiles. *Journal of Textile and Apparel, Technology and Management* 2011; 7(1): 1-15.
40. Matusiak M, Rymarz T, Sikorski K. Układy włókiennicze przeznaczone na wierzchy obuwia tekstylnego zapewniające podwyższony komfort fizjologiczny – Część I. *Przegląd Włókienniczy – Włókno, Odzież i Skóra*. 2010, 6: 29-31.

Received 07.12.2018 Reviewed 03.06.2019