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Quality Assessment of Viscose Bamboo Fabrics Intended for Use Inside Children's and Special Footwear

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Abstract
The paper presents physico-mechanical and hygienic parameters testing results of fabrics manufactured from bamboo cellulose fibres (100%) and their combination with cotton fibres (50/50%), as well as treated with: anti-pilling finish, anti-pilling and anti-shrinking finish, and dirt-repellent finish. They were evaluated on implementation in the footwear industry, comparing the results with the requirements for textile products intended for the lining/insole of children's footwear and that of footwear for people with sensitive feet. The fabrics selected were also tested for microbiological resistance, and technological and functional tests of footwear manufactured with these fabrics were performed. It was assumed that the new range of fabrics would improve the physiological-hygienic comfort of the above-mentioned footwear. In laboratory tests, not all fabrics met the requirements, however their processing capabilities were positively assessed for the injection shoe assembly system applied. Promising results were also achieved by the footwear in the preliminary functional tests, for which fabrics made of cellulose bamboo fibres without any finishes were applied. Their usability was confirmed, i.e. resistance to abrasion and dirt, as well as the physiological-hygienic comfort of the footwear tested.

Key words: *viscose bamboo fabrics, physico-mechanical tests, hygienic tests, microbiological tests, functional tests, children's footwear, sensitive feet footwear.*

Introduction

Bamboo belongs to the Poaceae family, a subfamily of Bambusoideae [1]. Having accompanied humans in everyday life since ancient times, it is extremely efficient and easy to grow, among others, thanks to its ability to grow about 4-5 cm/h [2]. The bamboo area exceeds 4,21 million ha [3]. It is assumed that this plant has natural antibacterial properties, is not attacked by parasites, and its cultivation does not require the use of pesticides. Viscose fibres from bamboo cellulose are most often produced in a chemical viscose process [4], during which carbon disulphide (CS_2) and sodium hydroxide (NaOH) [5, 6] are used; although their processing is also known by other methods, for which microorganisms are used, recommended for common use [7]. Currently, these fibres are attracting more and more attention as a new type of natural, ecological raw material for the production of textile yarn. Due to the natural physical properties of the fibres produced from this plant, i.e. elongation at break – 14-24%, dry tenacity – 22-25 cN/tex, wet tenacity – 13-17 cN/tex, and especially moisture absorption – 13%, [8], they are suitable for special textile applications such as surgical clothing, bandages, and food packaging [9-11]. Viscose bamboo cellulose fabrics, manufactured in Poland, are increasingly applied for the production of hygiene, bathing, medical, bedding and clothing products [12, 13]. The properties of these fibres and their application possibilities have been the subject of many researchers in the world [14-19], while their use for footwear is still little known [20, 21]. The natural properties of these fibres suggest the need to apply them especially in children's footwear and footwear for people with sensitive feet, classified as special footwear [22]. The possibility of applying viscose bamboo cellulose fabrics as the internal components of special footwear is a new issue undertaken by the Łukasiewicz Research Network – Institute of Leather Industry (IPS) [23, 24]. While caring for delicate baby feet is obvious for parents, the subject of adult sensitive feet is often underestimated, even though it often occurs, especially in adults (80% of women over the age of 50 have foot deformities) and seniors too. Feet sensitivity is caused, among others, by increased width, longitudinal and transverse flat-footedness, valgus and toe deformities, metatarsal pain, and various changes in soft tissues [25]. A significant part of research on footwear materials is undertaken in order to obtain desired characteristics improving the comfort

Figure 1. *HEALTHY FOOT Trademark (certification – Łukasiewicz Research Network – Leather Industry Institute).* ***Source:*** *own (original in colour) [25].*

Figure 2. *Footwear for Sensitive Feet Trademark (certification – Łukasiewicz Research Network – Leather Industry Institute).* ***Source:*** *own (original in colour) [25].*

Table 1. *Recommended by Łukasiewicz Research Network – Leather Industry Institute, value requirements of indicators for textile materials intended for children's and special footwear lining/insoles.* ***Source:*** *own study based on published data [29].*

Tested parameter	Unit of measure	Requirement recommended by Łukasiewicz Research Network – Leather Industry Institute	Test method
Tear strength	N	≥ 15	PN-EN ISO 13937-2
Abrasion resistant	number of cycles	≥ 25 600 (dry); ≥ 12 800 (wet) – footwear for children ≥ 30 000 (dry); ≥ 13 000 (wet) – footwear for sensitive feet	PN-EN ISO 12947-2
Colour fastness to rubbing	grey scale level	≥ 3	PN-EN ISO 105-X12
Water vapour permeability	mg/(cm²·h)	≥ 4	PN-EN ISO 20344 p.6.6
Water vapour absorption	mg/cm²	≥ 1	PN-EN ISO 20344 p.6.7
Water vapour coefficient	mg/cm²	≥ 33	PN-EN ISO 20344 p.6.8
Note: It is also required that the lining/insole materials are free from chemical substances harmful to the health or within the permissible values [26, 27].			

Table 2. *Characteristics of viscose bamboo fabrics (ZPChr Texpol LLC) intended for the internal components of children's and special footwear.*

Symbol	Yarn composition,%	Specification of fabrics	Mass per square metre, g/m²
1B-F	viscose fibres from bamboo cellulose (100%)	plain woven fabric with double warp yarn (standard finishing)	165
2B-F	viscose fibres from bamboo cellulose (100%)	plain woven fabric with double warp yarn (standard finishing)	230
3B/CO-F	viscose fibres from bamboo cellulose + cotton fibres (50/50%)	plain woven fabric with double warp yarn, woven in stripes (standard finishing)	160
4B/CO-F	viscose fibres from bamboo cellulose + cotton fibres (50/50%)	plain woven fabric with double warp yarn (standard finishing)	190
5B-A	viscose fibres from bamboo cellulose (100%)	pain weave fabric with double yarn in warp and weft (dirt-repellent finishing)	200
6B-A	viscose fibres from bamboo cellulose (100%)	plain woven fabric with double yarn in warp and weft (anti-pilling finishing)	200
7B-A	viscose fibres from bamboo cellulose (100%)	pain weave fabric with double yarn in warp and weft (anti-pilling and anti-shrinking finishing)	230
8B-A	viscose fibres from bamboo cellulose (100%)	plain weave fabric with double yarn in warp and weft (dirt-repellent finishing)	230
9B-WF	viscose fibres from bamboo cellulose (100%)	plain weave fabric with double warp yarn (without finishing)	195

of footwear use. The results of the material's parameters tested are considered when assessing footwear by granting the reserved Trademarks: HEALTHY FEET (***Figure 1***) and Footwear for Sensitive Feet (***Figure 2***). Footwear certified in an independent laboratory is a guarantee of the manufacturer's reliability. In addition, it informs about the high and consistent quality of the product manufactured and is an element of the promotion and strengthening of the manufacturer's position on the market, and it can be an argument in trade negotiations. For the consumer, it is an incentive to buy the product [26]. In order for marks to be awarded, footwear must be examined, among others, in terms of the quality of materials used. In the case of children's and special footwear for sensitive feet, the material's physico-mechanical and hygienic parameters intended for internal footwear elements are of great importance.

Requirements in this range relate to several parameters, presented in ***Table 1***. These materials must also be free of chemical substances harmful to the health or within the limit values in accordance with Oeko-Tex Standard 100 and REACH [27, 28]. Improving the hygienic and health properties of children's and special footwear is the goal of footwear designers and technologists, who are constantly looking for new material solutions that meet the above-mentioned requirements. It is important that these products also meet the technological requirements of the footwear production process in the assembly system used, and that the comfort of footwear with the new material solutions is ensured.

In the design of hygienic footwear, the need to ensure the antimicrobial properties of materials is increasingly recognised, which is particularly important in the case of footwear for children and people with foot dysfunctions who may experience frequent abrasions that cause infection [30]. This type of footwear should have properties that limit the development of microorganisms inside and during use, and provide conditions that reduce the risk of fungi growth [31]. Several years ago, many publications concerned the use of silver nanoparticles (AgNPs) both for the antimicrobial finishing of textiles and for their disinfection [32-34]. Recently, the great interest of researchers has focused on natural substances with bioactive properties [35-37].

The aim of the research presented in the publication was a comprehensive quality assessment of various types of viscose bamboo fabrics in terms of their implementation in the footwear industry as internal components of children's and special footwear for people with sensitive feet. It was assumed that the new assortment of footwear fabrics made of cellulose bamboo fibres produced as part of the project will improve the hygiene and healthiness of the internal elements' properties of such footwear.

Materials and methods

The research material was selected based on the results of preliminary tests conducted on viscose bamboo fabrics. Eight fabrics of linen weave and different surface weights produced for the lining/insole of children's and special footwear were subject to testing of physic-mechanical and hygienic parameters. A mixture of bamboo and cotton fibres (50/50%) was used in two fabrics. Four fabrics sur-

Table 3. *Antibacterial effect and evaluation of fungal growth in an agar environment.* ***Source:*** *own, based on PN-EN ISO 20645 and PN-EN ISO 14119.*

Inhibition zone, mm/ mean value	Growth	Description	Assessment of antibacterial effect
> 1	none	inhibition zone exceeding 1 mm, no growth	good effect
1-0	none	inhibition zone up to 1 mm, no growth	
0	none	no inhibition zone, no growth	
0	slight	no inhibition zone, only some restricted colonies, growth nearly totally suppressed	limited efficacy
0	moderate	no inhibition zone; compared to the control, growth is reduced by half	insufficient effect
0	heavy	no inhibition zone; compared to the control, there is no growth reduction or only slightly reduced growth	
Growth/ mean value	**Evaluation of fungal growth in agar medium**		
0	no visible growth assessed under the microscope (50x magnification)		
1	no visible growth without magnifying devices, but clearly visible under the microscope		
2	visible increase without magnifying devices, covering up to 25% of the tested surface		
3	visible increase without magnifying devices, covering up to 50% of the tested surface		
4	significant increase, covering more than 50% of the tested surface		
5	heavy growth, covering the tested surface		

Table 4. *Characteristics of children's and special footwear in which viscose bamboo fabrics were used as internal elements.* ***Explanation:*** *type a – insole assembly – outer seam; type b – insole assembly – internal seam.*

Symbol	Fabric applied	Footwear characteristics	Footwear mounting system
1	1B-F (lining/insole)	girls' sandals (type a) with covered heel; lining connected to inter-lining and upper cotton fabrics with shoe adhesive – triple-plywood system	injection assembly system
2	1B-F (lining/insole)	girls' sandals (type b) with covered heel; lining connected to inter-lining and upper cotton fabrics with shoe adhesive – triple-plywood system	
3	3B/CO-F (lining/insole)	boys' sandals (type a) with covered heel; lining connected to inter-lining and upper cotton fabrics with shoe adhesive – triple-plywood system	
4	3B/CO-F (lining/insole)	boys' sandals (type b) with covered heel; lining connected to inter-lining and upper cotton fabrics with shoe adhesive – triple-plywood system	
5	1B-F (lining/insole)	girls' ballerinas; lining connected to inter-lining and upper cotton fabrics with shoe adhesive – triple-plywood system	
6	1B-F (lining/insole)	special footwear for sensitive feet; lining connected to inter-lining and upper cotton fabrics with shoe adhesive – triple-plywood system	

face-treated with anti-pilling, anti-pilling and anti-shrinking as well as dirt-repellent finishes (***Table 2***). The ***Table 2*** also includes fabric without finishing, which was analysed for the antimicrobial effect for comparison purposes.

The selection of parameters for fabric testing was based on the requirements of the following trademarks: HEALTHY FOOT (***Figure 1***) and Footwear for Sensitive Feet (***Figure 2***). In the first stage, physico-mechanical tests were carried out. The force causing the tearing (F_T) of the sample over a specific length according to PN-EN ISO 13937-2 was registered continuously [38], calculated with an accuracy of ± 1%. The fabric strength test was expanded to include the testing of strength parameters relevant for footwear material processing, as well as the tensile strength (F_S) and the percentage of the maximum elongation at break (E_M), in accordance with PN-EN ISO 13934-1 [39]. Test fabric samples were stretched at a constant speed until breaking, and the values of F_S and E_M were recorded. To realise the above, physico-mechanical tests were carried out with an INSTRON 4301 type constant-rate-ofextension (CRE) machine, in climatic conditions in accordance with ISO 139 [40]. The fabric's resistance to dry and wet abrasion was also tested using a Martindale apparatus according to PN-EN ISO 20344 [41]. The samples were abraded on a reference abrading material under a pressure of 795 ± 7 g (nominal pressure of 12 kPa), with a cyclic planar motion in the form of a 60 × 1 mm Lissajous figure. Abrasion resistance was assessed by subjecting the sample to a specified number of abrasion cycles, under normal climate conditions (temperature 23 ± 2 °C and relative air humidity 50 ± 5%), at which point it shall not exhibit any holes. Assessment of hygienic properties of the materials tested was based on two parameters: water vapour permeability (W_{VP}) and water vapour absorption (W_{VA}), determined in accordance with the PN-EN ISO 20344 standard [41]. Also, the water vapour permeability coefficient (W_{VC}) was determined, which links the water vapour permeability and water absorption as follows:

$$W_{VC} = t \cdot W_{VP} + W_{VA} \left[\frac{mg}{cm^2}\right] \quad (1)$$

where, t is the test time (t = 8 h).

In the next stage of the project, microbiological tests were carried out. The effects of *Staphylococcus aureus* – Gram-positive bacteria, *Escherichia coli* – Gram-negative bacteria, and the following fungi (incubation at 27 ± 1 °C): *Candia albicans* – yeast, *Aspergillus fumigatus* – moulds and *Trichophyton mentagrophytes* – dermatophytes were studied for selected fabrics (1B-F and 3B/CO-F). In addition, fabric that had not been treated with any finish (9B-WF) was tested. The antimicrobial effect was assessed in accordance with the recommendations of the standard PN-EN ISO 20645 [42]. The fungal growth was evaluated on the basis of observations, according to the scale included in the standard PN-EN ISO 14119 [43] (***Table 3***).

In the last stage of the project, functionality tests were carried out. For the purpose of this research, textile footwear was manufactured (Bielskie Zakłady Obuwia

BEFADO LLC) using the viscose bamboo fabrics tested (***Table 4***). Selected fabrics 1B-F and 3B/CO-F were connected to inter-lining and upper cotton fabrics, thus creating an upper-lining material system. The footwear manufacturing process also allowed us to check that the viscose bamboo fabrics met the technological requirements of the footwear production process.

The children's footwear manufactured were subjected to functional tests of varying intensity over a four-week period. They were used indoors and outdoors. Girls' sandals (1 and 2 – type a and b) and ballerinas (5) were used by children aged five-six and twelve for a month, with varying intensity during the day, about 4-5 hours/day. Boys' sandals (3 and 4 – type a and b) were used by children aged five years for a month, also with varying intensity during the day – about 5-6 h/day. Footwear for sensitive feet (6) were not used; they were organoleptically assessed.

Results and discussion

Results of testing the physico-mechanical parameters of the fabrics are presented in diagrams (***Figures 3 to 5***). In terms of the tearing force parameter F_T (***Figure 3***), underestimated values were shown only in two samples, i.e. 6B-A – towards the warp (10.5 N), towards the weft (11.1 N), and 4B/CO-F – towards the weft (11.3 N). The tensile strength parameters F_S (***Figure 4***) and maximum elongation at break E_M (towards the warp and weft) – (***Figure 5***) showed that all fabrics have the level of strength expected, enabling their effective and proper installation in footwear. Within the abrasion resistance

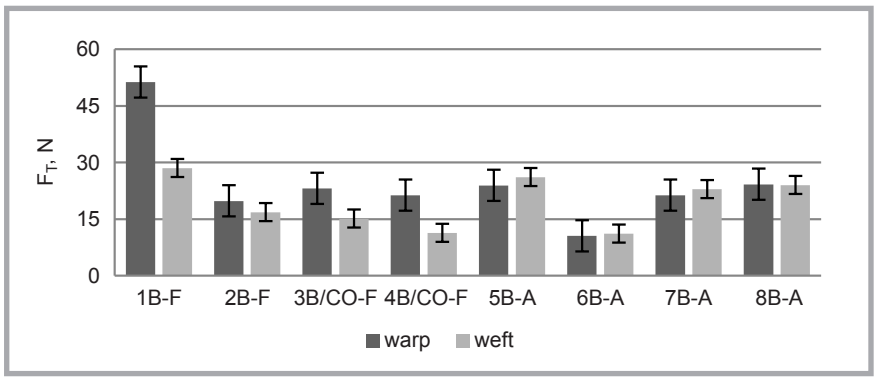

Figure 3. *Tearing force (F_T) of fabrics tested.*

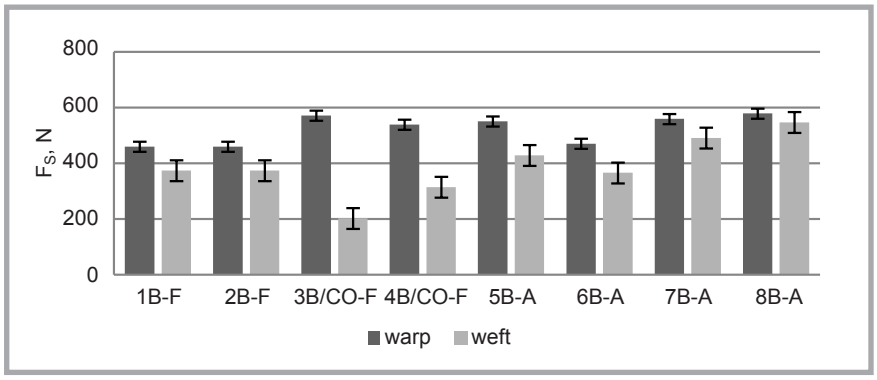

Figure 4. *Tensile strength (F_S) of fabrics tested.*

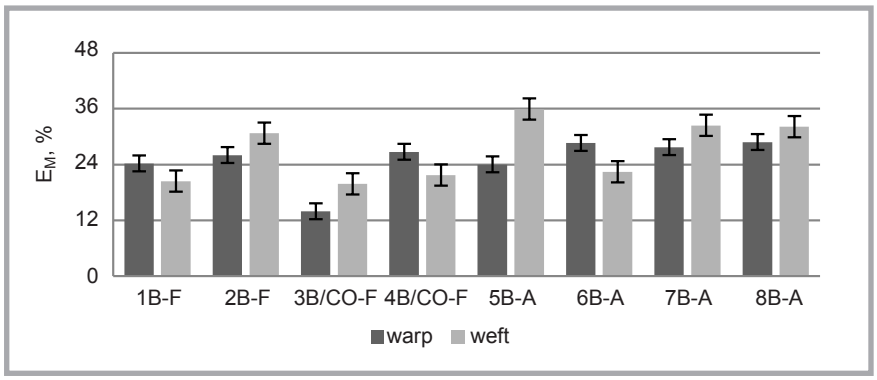

Figure 5. *Maximum elongation at break (E_M) of fabrics tested.*

Table 5. *Assessment of antibacterial properties of viscose bamboo fabrics [36].*

Evaluation/sample	1B-F	3B/CO-F	9B-WF
Staphylococcus aureus			
Growth inhibition zone, mm	no inhibition zone	no inhibition zone	no inhibition zone
Growth on agar under sample	strong growth	strong growth	no growth
Growth on agar sample	single colonies on fibres	single colonies on fibres	no growth
Rating of antibacterial effect	insufficient effect	insufficient effect	good effect
Escherichia coli			
Growth inhibition zone, mm	no inhibition zone	no inhibition zone	no inhibition zone
Growth on agar under sample	strong growth	strong growth	strong growth
Growth on agar sample	single colonies on fibres	colonies present on fibres	single colonies on fibres
Rating of antibacterial effect	insufficient effect	insufficient effect	insufficient effect
Candia albicans			
Growth inhibition zone, mm	no inhibition zone	no inhibition zone	no inhibition zone
Growth on agar under sample	strong growth	strong growth	strong growth
Growth on agar sample	colonies present on fibres	single colonies on fibres	single colonies on fibres
Rating of antibacterial effect	insufficient effect	insufficient effect	insufficient effect

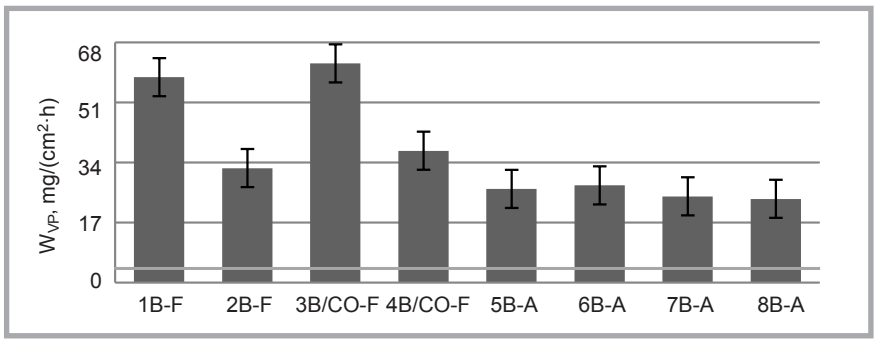

Figure 6. *Water vapour permeability (W_{VP}) of fabrics tested.*

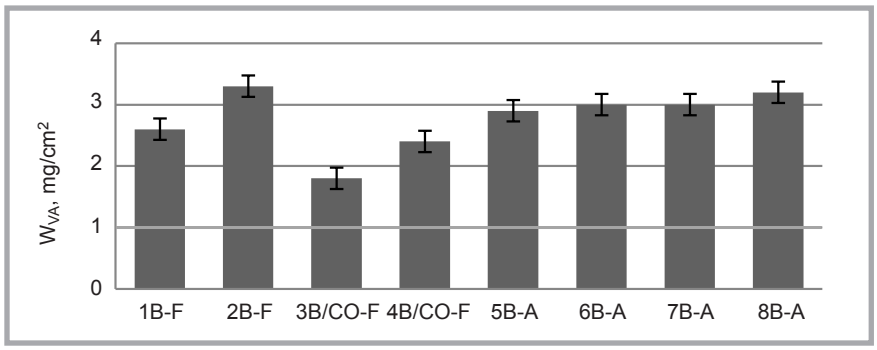

Figure 7. *Water vapour absorption (W_{VA}) of fabrics tested.*

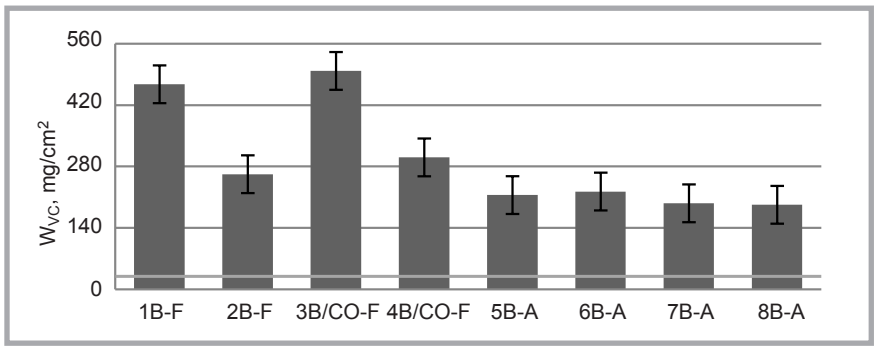

Figure 8. *Water vapour coefficient (W_{VC}) of fabrics tested.*

Table 6. *Evaluation of the action of microfungi on viscose bamboo fabrics [37].*

Evaluation/sample	1B-F	3B/CO-F	9B-WF
Aspergillus fumigatus			
Sample evaluation	5	growth bands*: B – 0; CO – 5	0/1
Evaluation in agar medium	1	growth bands*: B – 1; CO – 5	4
Trichophyton mentagrophytes			
Sample evaluation	5	growth bands*: B – 2; CO – 5	0
Evaluation in agar medium	5	growth bands*: B – 2; CO – 5	0

Explanation: ** on fragments of fabric made of bamboo fibres (B), no visible growth of microfungi (0 and 1) or visible growth covering up to 25% of the surface tested (2) was observed, while on fragments of cotton fabric fibres (CO), there is strong microbial growth covering the entire test surface (5), according to* ***Table 3****.*

parameters tested, it was shown that none of the fabrics met the requirements for wet abrasion resistance. For dry tests, the three fabrics with the largest surface mass (230 g/m^2) met the requirements, i.e. 2B-F – requirements for children's and special footwear (≥ 30,000 cycles), 7B-A and 8B-A – requirements for children's footwear (≥ 25,600 cycles).

Results of testing the hygienic properties of the fabric samples are presented in diagrams (***Figures 6*** to ***8***). The values of parameters W_{VP}, W_{VA} and $W_{VC,}$ shown in the charts, were high for all samples, at a level meeting the requirements for fabrics intended for internal elements of children's and special footwear.

Results of the microbiological tests of selected fabrics are presented in the tables (***Tables 4*** and ***6***). Fabrics 1B-F and 3B/CO-F did not show antimicrobial properties against bacteria and fungi. However, a clear differentiation in properties was observed in relation to fungi for fabric fragments formed from bamboo fibres compared to those from cotton fibres, especially *A. fumigatus* (filamentous fungi clearly increased on the cotton fibre fragments). Untreated fabric 9B-WF showed inhibition of *T. mentagrophytes* dermatophytes and partly *A. fumigatus* mould, as well as a good antibacterial effect on *S. aureus* Gram-positive bacteria, but displayed an insufficient effect on *E. coli* Gram-negative bacteria and *C. albicans* yeast.

All standard technological operations during the footwear assembly, for the purpose of conducting utility tests, were carried out correctly.

While carrying out utility tests of girls' sandals (1, 2) and ballerinas (5) with fabric 1B-F applied, no sweating of the feet was noted in sandals, moderate sweating of the feet in ballerinas, and the interior of each pair of shoes was easy to keep clean. The fabric used in this footwear was also sufficiently resistant to abrasion. The sandals' externally assembled insole had frayed, while in the ballerinas, due to the use of internal seams, the internal elements of the footwear had not undergone fraying. During the use of boys' sandals (3 and 4) with a fabric made of viscose bamboo cellulose and a cotton fibre mixture of 50/50% (3B/CO-F), slight sweating of the feet was noted during the testing of footwear, whose interior could be kept clean quite easily. This fabric was also sufficiently resistant to abrasion. In girls 'and boys' (type a) sandals, the outer insole had frayed. In girls' and boys' sandals (type b) and in ballerinas, due to the use of internal seams, the insoles had not undergone fraying. In footwear for sensitive feet (6) with 100% viscose bamboo fabric (1B-F), use comfort was predicted at a level assessed for closed footwear, in this case ballerinas, which for special footwear can be supported by their construction (with increased width) and adapted to various types of foot dysfunction.

Conclusions

Quality assessment of viscose bamboo cellulose fabrics, carried out based on laboratory tests, as well as utility tests of footwear containing them as a lining/insole, allowed to formulate the following conclusions:

- Viscose bamboo fabrics manufactured for the needs of the footwear industry have an expected level of physico-mechanical parameters (tearing force, tensile strength and maximum elongation at break) ensuring their effective and proper installation in footwear. Not all fabrics tested for abrasion in the laboratory met the requirements of indicators for textile materials intended for children's and special footwear lining/insoles; nevertheless, during footwear functional tests, they did not present signs of abrasion.
- All fabrics showed high hygienic parameter values in laboratory tests (water vapour permeability, water vapour absorption and water vapour coefficient), proving their usefulness in this area. However, the construction and assembly of the closed footwear made of these fabrics tested caused moderate feet sweating.
- Microbiological studies showed that the finishing treatment of bamboo fibre fabrics reduces their antimicrobial properties. In addition, improved antimicrobial properties of bamboo fibre fabric fragments were found compared to those of cotton fibre fabric fragments.
- All standard technological operations proceeded correctly in the shoe assembly system applied with the use of lining/insole viscose bamboo fabrics.
- Preliminary functional tests of footwear in which untreated viscose bamboo fabrics were used confirmed their usefulness, i.e. abrasion resistance, resistance to dirt, as well as physiological-hygienic comfort.

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