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# IDENTIFICATION OF WEARING COMFORT OF THE TEXTILE UPPERS OF COMMERCIAL FOOTWEAR

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## ABSTRACT

Knitting technologies have contributed to the production of textile footwear not only to reduce waste, but also to increase their physiological comfort. In this study, the functional properties of twelve commercially available knitted uppers and two footwear leathers were identified. For each of the tested variants, the following parameters were determined: thickness, mass per square meter, air and water vapor permeability, and selected parameters related to the thermal insulation and moisture sorption. On the basis of conducted research, it was shown that the best parameters were characteristic for knitted fabrics with jacquard weaves produced on cylindrical crocheting machines of large diameters.

## KEYWORDS

Footwear, comfort, footwear uppers, microclimate, knitted fabrics.

## INTRODUCTION

The outside parts of footwear (uppers) are now more and more often produced in the form of fitted textile elements. The need for an innovation in this area has created new opportunities for the knitting industry, which is the only potential producer of textile footwears in the world. The upper is, next to the sole, the main construction element of each shoe. Its main tasks include stabilizing and positioning the foot in relation to the sole [1]. In addition, it has a protective and ventilation function by the thermoregulation and moisture removal.

The production of the upper in the form of a fitted textile element allows the use of structures with a heterogeneous structure (anisotropic) for individual functional areas of the foot [2]. Knitted fabrics of this type can be produced on flat, warp and cylindrical knitting machines of large and small diameters. The aim of this study was to analyze the functional properties of physiological comfort of textile and leather materials used in the commercially produced footwear from Puma, Reebok, Under Armor, The North Face, Adidas or Nike.

## MATERIALS AND METHODS

The subject of research were twelve different fully fitted uppers made in knitting technologies (variants numbered 1-12) and two variants of shoe leather (variants numbered 13 and 14). The first four variants were produced using the Mayer & Cie cylindrical crocheting technology. The first variant (Fig. 1) with a weave of modified, incomplete four-color double-crop jacquard with a weft filling in each row was made of polyester yarns with a linear density of 167 dtex and 330 dtex. The yarns that were used in the second variant with a two-color full two-color jacquard weave, which in some areas has a jacquard with a modified structure causing an openwork effect, are polyester 167 dtex and elastane 44 dtex. The third variant is an incomplete four-color double crop jacquard, which is also made of 167 dtex polyester yarn. The fourth variant has an incomplete three-color jacquard weave. The raw material in this variant is also polyester 167 dtex. The fifth variant was made of polyester on a small diameter cylindrical crochet machine, i.e., on the so-called sock and hosiery machine. The weave of this variant is a striped jacquard, characterized by the alternating stripes of the left-right and jacquard weave. The next five variants (6-10) are fitted knitted fabrics, which were produced on flat knitting machines by the Stoll company. The yarns used in their production are mainly polyester 167 dtex with the addition of Elastane 156 dtex or Lycra 156 dtex. Variant number six is a double-layer knitted fabric with a tuck stitch system. The seventh variant is a two-layer knitted fabric composed of three systems of weaves: jacquard, openwork and tuck stitches. The eighth and ninth variants are two-layer knitted fabrics with openwork weave areas. The tenth variant is a two-layer knitted fabric composed of jacquard and openwork weave systems. The eleventh and twelfth variants are fitted textile elements obtained from commercial footwear from "Adidas" and "Sprandi", respectively. The upper of the variant number 11 is composed of a system of two knitted fabrics connected with each other with an embroidery thread, the top of the package is a double-layer knitted fabric joined with tucks, and the bottom is an interlock knit. Variant number 12 is a double-layer knitted fabric combined with an openwork weave. The thirteenth and fourteenth variants are leathers representing traditional footwear materials.

**Figure 1. View of the right and left side of the upper part of the footwear produced on a large diameter cylindrical crochet machine (option 1).**

The following structural parameters were determined for the analyzed variants:

- thickness (g),
- mass per square meter (Mp),
- The physiological comfort performance parameters measured are:
- air permeability (P),
- thermal conductivity (Λ),
- thermal resistance (r),
- relative water vapor permeability (RWVP),
- cumulative one-way transport index (R),
- overall moisture management capability (OMMC).

The thickness (g) of materials was determined according to PN-EN ISO 5084: 1999, the-mass per square meter (Mp) according to the PN-P-04613: 1997 standard, while the air permeability (P) was determined according to the PN-P-04618: 1989 standard for the size a pressure difference of 10 daPa.

Thermal conductivity (Λ) and thermal resistance (r) were measured using the Alambeta instrument. The Alambeta device is a two-disc device, in which the upper plate simulates a dry human skin [3]. The method of its operation is based on the mathematical processing of the course of heat flowing through the material in time under the influence of the temperature difference between the plates of the device (the phenomenon of steady heat exchange). The upper plate heats up to 32˚C, while the lower plate maintains a temperature of around 20˚C. After placing the sample between the plates of device, the upper head falls on the sample, then the computer processes the data on the heat flow and as the final result shows the interpretation of thermophysical properties of the tested material on the display.

Relative water vapor permeability (RWVP) was determined using the Permestest device, which is a measuring device used to determine the water vapor permeability of textiles [4]. The principle of operation of the device is based on the concept of the 'artificial skin model'. It relies on measuring the water vapor resistance of the material by creating a one-way flow of heat flux. The tested sample is placed in a ventilated chamber on a membrane-covered heating plate simulating wet skin. Then, based on the measurements of the plate temperature as well as the temperature and relative humidity in the chamber, the results are presented.

One way cumulative transport index (R) and overall moisture management (OMMC) are parameters closely related to the sorption properties of materials. These parameters were measured on the M290 Moisture Management Tester by SDL Atlas according to the AASTCC standards [5-6]. In order to measure the dynamic process of moisture transport, a material sample is positioned horizontally between two sensors. A solution representing human sweat is then applied to the center of the upper sensor. Measurement results are given on the basis of changes in the electrical resistance as the sample wets.

## RESULTS AND DISCUSSION

The obtained results of structural and functional parameters of the analyzed variants are summarized in Table 1.

**Table 1. Test results of selected structural and functional parameters.**

| Nb | g | Mp | P | Λ | r | RWVP | R | OMMC |
|---|---|---|---|---|---|---|---|---|
| | mm | $g/m^2$ | $dm^3/(m^2 \cdot s)$ | $10^{-3}$ $W \cdot m^{-1} \cdot K^{-1}$ | $10^{-3}$ $W^{-1} \cdot K \cdot m^2$ | % | - | - |
| **1** | 1.91 | 729.7 | 417.355 | 51.2 | 47.6 | 41.4 | -45.5656 | 0.076 |
| **2** | 1.56 | 371.9 | 1422.800 | 42.4 | 36.1 | 61.0 | 261.5708 | 0.420 |
| **3** | 1.70 | 487.5 | 1014.930 | 55.6 | 31.0 | 52.1 | 129.8662 | 0.315 |
| **4** | 1.48 | 348.4 | 1588.790 | 48.8 | 31.3 | 56.1 | 13.6217 | 0.362 |
| **5** | 3.55 | 973.4 | 275.075 | 55.3 | 76.2 | 22.7 | 9.4215 | 0.100 |
| **6** | 3.18 | 1218.6 | 882.135 | 59.0 | 55.1 | 51.0 | - | - |
| **7** | 3.15 | 1023.7 | 1688.390 | 51.9 | 69.3 | 33.2 | - | - |
| **8** | 3.44 | 984.3 | 882.135 | 53.2 | 79.2 | 31.1 | -936.6894 | 0 |
| **9** | 3.48 | 1173.4 | 1432.285 | 50.9 | 93.6 | 22.7 | -29.6734 | 0.023 |
| **10** | 3.49 | 1088.6 | 264.640 | 66.3 | 52.8 | 24.2 | - | - |
| **11** | 2.42 | 915.3 | 986.475 | 51.4 | 54.0 | 28.0 | -941.8987 | 0 |
| **12** | 2.47 | 1146.9 | 327.245 | 47.0 | 98.8 | 29.5 | 97.7320 | 0.298 |
| **13** | 1.80 | 1009.4 | 0 | 55.1 | 28.6 | 0 | - | - |
| **14** | 1.45 | 904.7 | 0.855 | 56.1 | 25.2 | 31.1 | 6.7166 | 0.06 |

The thickness (g) of tested variants ranged from 1.55 mm (variant 14) to 3.55 mm (variant 5). The leather variant turned out to be the thinnest, while the thickest variant of the knitted fabric was due to the two-layer structure. The variants of knitted fabrics produced on flat knitting machines (variants 6-10) were characterized by similar thickness values.

The obtained mass per square meter (Mp) of tested materials ranged from 348.4 $g/m^2$ to 1218.6 $g/m^2$. The tested variants can be divided into three groups: low mass per square meter - below 700 $g/m^2$, average mass per square meter - below 1000 $g/m^2$ and high mass per square meter above 1000 $g/m^2$.

The variants with the low mass per unit area included variants: 2, 3 and 4, while variants with the medium mass per unit area were variants: 1, 5, 8, 11 and 14. The variants with the high mass per unit area were variants: 6, 7, 9, 10, 12 and 13.

The lowest value of air permeability (P), equal to 0, was obtained for the variant 13, and the highest for variant 7. The obtained results indicate a low 'breathability' of leathers and their low porosity. For textile variants, better air permeability results were obtained for knitted fabrics with openwork weaves.

The highest value of thermal conductivity (Λ) was characteristic for the variant 10, while the lowest was for the variant 2. It should be noted that the values of thermal conductivity were at a very similar level and ranged from $42.4 \cdot 10^{-3}$ to $66.3 \cdot 10^{-3}$ W / (m·K). The thermal conductivity of textile materials is similar to that of leather materials.

The thermal resistance (r) is expressed as the ratio of the variant thickness and the conductivity coefficient. The highest value of thermal resistance was shown in the variant 12, while the lowest was in the variant 14. Variant 12 was characterized by the highest thermal insulation among the tested materials. The leather variants (13 and 14) dissipate heat to the outside best.
The values of the relative water vapor permeability (RWVP) of tested materials ranged from 0 to 61%. It was shown that the leather variant number 13 does not have the ability to transmit water vapor. Variant 14, on the other hand, was characterized by a relative air permeability of 31.1%, which is due to the porous structure of this skin. Among textiles, the best results were obtained for items produced on large diameter cylindrical crocheting machines.

The cumulative one-way transport index (R) is used to evaluate a material for one-way transport of moisture from the inside to the outside. The higher the value of this parameter, the better the material drains away sweat. The obtained results of the cumulative one-way transport index can be divided into positive and negative. The variants: 2, 3, 4, 5, 12 and 14 were characterized by positive values, while the negative values were for: 1, 8, 9 and 11 variants. Based on this division, it can be assumed that the variants with positive results are materials that transport moisture well. The best option from the point of view of transporting sweat from the inner to the outer layer is the variant 3.

The tested materials in terms of general moisture management can be divided into good and poor OMMC materials. Materials with a good general moisture management capacity are variants 2, 3, 4 and 12. The remaining variants are materials with poor overall moisture management capacity.

## CONCLUSION

Among the analyzed variants of textile uppers and natural leathers, knitted fabrics 2, 3 and 4 produced on large diameter crochet machines deserve an attention, because they showed the most desirable functional characteristics. Their values of mass per square meter were the lowest, while maintaining the high air and water vapor permeability and good moisture transport properties from the inner to the outer layer.

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