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Analysis of Insole Material Impact on Comfort During Physical Exertion

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Abstract
Insole material is an important factor determining the hygienic properties of shoes. It has a significant impact on health and comfort while wearing them. In this paper, the authors describe a scenario of three insole materials: flank leather, cellulose material and composite leather. Quantitative research was done using five upper materials: calfskin full and top grain leather, "buffalo" bovine leather, a soft type of grain leather, and aniline veal skin type "cool". Qualitative analysis was performed using 3D knitted fabrics as lining. The statistical significance of the differences obtained within the groups analysed is that they prove the impact of insole material on comfort.

Key words: *footwear comfort measurement, insole materials, discomfort index, physical effort.*

Introduction

The problem of comfortable shoes is an important factor for many occupational groups and individual people. Long-lasting exposure to environmental conditions with heat stress can be a cause of decreased work efficiency or occupational diseases for workers. Footwear microclimate is also a crucial element for performing physical activities, because it is a part of energy balance for the whole body. Moisture and water vapour change continuously with the surrounding environment during outdoor or indoor activities [1, 2].

The choice of footwear materials is very important in shoe design. However, comfort is perceived differently by different subjects. General comfort assessment has not been done yet, because there is a wide range of variables – from external conditions to ontogenetic and psychological or neurophysiological features [3, 4].

The fundamental factor which provides comfort is shoe construction. The choice of materials in the triad of upper – lining – insole has a great impact on hygienic properties from the user's point of view.

In this work the authors focused on analysing the impact of insole materials and their contribution to determining comfort. Nowadays the most popular insole materials include synthetic cellulose leather (75%) and less often – recycled insole leathers, natural leather or nonwoven materials [5].

Because these materials are in direct contact with the foot, their ability to absorb and accumulate moisture away from the skin is important. It is especially crucial from the usability point of view, because insole materials are able to absorb between 85 and 90% of sweat in different environmental conditions, like extreme physical effort at a high temperature [6].

The physical properties of materials which determine comfort include moisture absorption and desorption, the water vapour evaporation rate, thickness, porosity, which is a measure of empty spaces in a material, and the impact on the moisture absorbing capacity. The kinetics of sorption and desorption processes depend on the pH range. It is slower in alkaline and faster in acid environments [7]. All of these details can be applied to a set of shoe components like uppers, linings and, in particular, insole materials.

Currently we can find many reserved solutions, like absorbing inners [8-9] or layered composite materials which are able to absorb and transfer moisture away from the foot surface. The objective of this is to improve the exchange of biophysical mediums between the interior and the environment. The best effects are achieved by dividing the insole material into a hydrophobic (away from the skin) and hydrophilic (close to the skin) layer. The layer which is nearest to the foot is superabsorbent and the other one accumulates moisture due to environmental conditions [10].

In this work, with the use of the ANOVA tool, relations between the insole material and changes in the shoe microclimate have been shown. Discomfort indexes for a set of shoe materials: upper, lining and insole have been calculated and compared.

Table 1. *Types of insole materials used in study.*

Type of insole material	Symbol	Thickness, mm (according to [11])
Flank leather	SPP1	2.2
Cellulose material "texon"	MPP1	1.7
Composition leather "salamander"	MPP2	2.0

Materials and method

The studies involved three kinds of insoles: natural leather, synthetic cellulose material under the trade name "texon", and recycled leather under the name "salamander" (***Table 1***).

The construction materials were either fixed in a shoe (midsole, uppers and some linings) or had a form of removable inputs – as a sort of sock. The model of shoe which was used represents the class of laced outdoor footwear with an integral ankle support with an adjustable stoutness level according to the nomenclature given in [11]. Phase changes in the shoe microclimate were detected during simulation of the shoes used via an elliptical trainer for a group of 7 men at the age of 59.4 ± 1.9, which have a BMI equal to 24.9 ± 3.7. Changes in humidity and temperature were continuously recorded using T/RH sensors (***Figure 1***). T/RH sensors were located between the toe cap and forefoot in front of the arch (upper sensor) and inside of the filler (lower sensor). The measurement cycle encom-

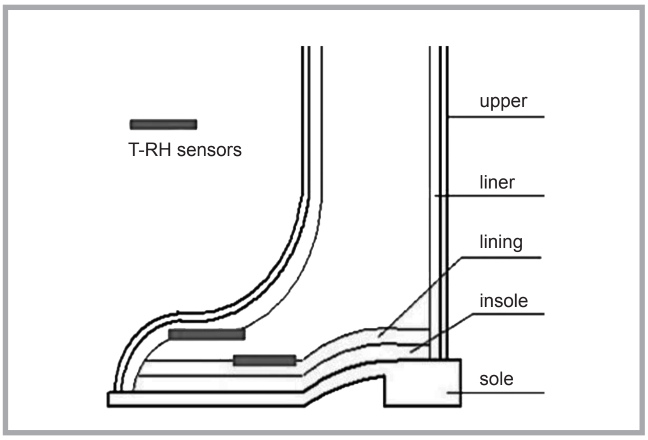

Figure 1. Distribution of T/RH sensors on measurement stand.

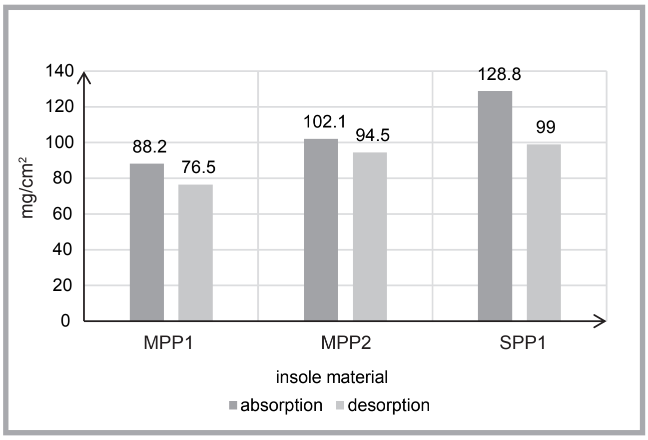

Figure 2. Water absorption and desorption ratio for insole materials studied (according to [11]).

passed 90 minutes divided between three parts: rest (30 min), exertion (30 min), relaxation (30 min). The test stand was located in an air-conditioned room, where the temperature and air relative humidity were 21 °C and 45%, respectively.

The final shoe was analysed according to the composition of three combinations of elements: insoles, linings and uppers. Some kinds of knitted fabrics were used as lining materials. The shoes had leather uppers (***Table 2***).

On the basis of the literature sources [12-14], the range between 70 and 85% for relative humidity was considered a partial discomfort zone, and over 85% – a total discomfort zone. Thus the following indicators are true:

$$T_{RH>70\%} = \frac{T_{70\%}}{T}, \qquad (1)$$

where $T_{70\%}$ is time when relative humidity is higher than 70% and T is the total time period.

Therefore the discomfort index for relative humidity higher than 70% is defined as follows:

$$DI_{RH>70\%} = \frac{APPROX_{RH>70\%} - 70\%}{30\%}, \qquad (2)$$

where $APPROX_{RH>70\%}$ is the approximate value of the relative humidity result from a set of values exceeding 70%.

Hence a generalised discomfort index is defined as:

$$DI = T_{RH>70\%} \cdot DI_{RH>70\%}. \qquad (3)$$

Results of experiment

One of the most important material characteristics from the comfort measurement viewpoint is the water absorption and desorption ability, because they can

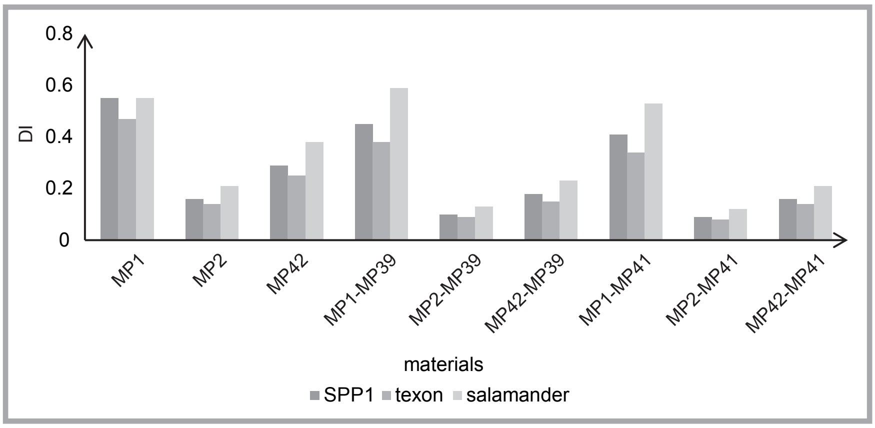

Figure 3. The values of discomfort index for materials combined with L1 upper.

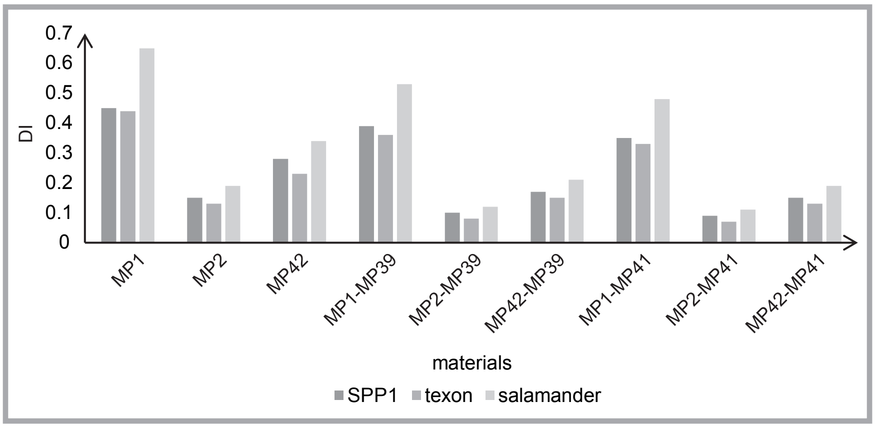

Figure 4. Values of discomfort index for materials combined with L4 upper.

Table 2. *Types of lining and upper materials used in study.*

Lining material	Symbol	Basic weight, g/cm²	Upper material	Symbol
Smooth knitted fabric with compact structure	MP1	288	Calfskin full – grain leather	L1
Knitted fabric with openworks	MP2	320	Calf skin top – grain leather	L2
Knitted fabric with polyester (5%)	MP42	320	Bovine leather ‘buffalo’	L3
Silky polyester fabric (sock – input)	MP39	140	Grain leather type ‘soft’	L4
Nonvowen fabric – sock input (polyester 65% + 35% viscose)	MP41	250	Aniline veal skin type ‘cool’	L5

Table 3. *Post hoc analysis values for given materials: L1 (upper) – MP2 (lining).*

Treatment pair	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inferference
SPP1 vs MPP1	4.0819	0.0623909	insignificant (p > 0.05 = α)
SPP1 vs MPP2	4.72624	0.0356644	significant (p < 0.05 = α)
MPP1 vs MPP2	0.6445	0.8881731	insignificant (p > 0.05 = α)

Table 4. *Post hoc analysis values for given materials: L1 (upper) – MP42 (lining).*

Treatment pair	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inferference
SPP1 vs MPP1	4.1944	0.0565032	insignificant (p > 0.05 = α)
SPP1 vs MPP2	4.7269	0.0341663	significant (p < 0.05 = α)
MPP1 vs MPP2	0.5826	0.8999947	insignificant (p > 0.05 = α)

Table 5. *Post hoc analysis values for given materials: L2 (upper) – MP1 (lining).*

Treatments pair	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inferference
SPP1 vs MPP1	0.8152	0.8245787	insignificant (p > 0.05 = α)
SPP1 vs MPP2	3.9504	0.0701089	insignificant (p > 0.05 = α)
MPP1 vs MPP2	4.7655	0.0344980	significant (p < 0.05 = α)

Table 6. *Post hoc analysis values for given materials: L4 (upper) – MP2 (lining).*

Treatmentpair	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inferference
SPP1 vs MPP1	4.0833	0.0623160	insignificant (p > 0.05 = α)
SPP1 vs MPP2	4.8038	0.0333983	significant (p < 0.05 = α)
MPP1 vs MPP2	0.7206	0.8598232	insignificant (p > 0.05 = α)

Table 7. *Post hoc analysis values for given materials: L4 (upper) – MP42 (lining).*

Treatment pair	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inferference
SPP1 vs MPP1	4.5714	0.0407052	significant (p < 0.05 = α)
SPP1 vs MPP2	5.4286	0.0199802	significant (p < 0.05 = α)
MPP1 vs MPP2	0.8571	0.8089343	insignificant (p > 0.05 = α)

Table 8. *Post hoc analysis values for given materials: L5 (upper) – MP41 (lining).*

Treatment pair	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inferference
SPP1 vs MPP1	1.5639	0.5455517	insignificant (p > 0.05 = α)
SPP1 vs MPP2	3.0301	0.1606513	insignificant (p > 0.05 = α)
MPP1 vs MPP2	4.5940	0.0399235	significant (p < 0.05 = α)

predict the amount of moisture and sweat which the material will absorb at a given level of humidity (***Figure 2***).

Further statistical analysis was based on discomfort indexes, which were computed during the experiment procedure described above. For certain combinations of materials in the field: uppers (L1, L2, L3, L4, L5), linings (MP1, MP2, MP42, MP39, MP41) and insoles (SPP1, MPP1, MPP2), discomfort index contingency maps were prepared (e.g. ***Figures 3*** and ***4*** for L1 and L4, where the statistical significance was obtained for more than one lining material) and statistical analysis performed.

Results of statistical analysis

Analysis of the experimental method was performed using one way ANOVA, where discomfort indexes in relation to footwear material were independent variables. Hypotheses H_0 and H_1 were given as follows:

- H_0 – means of values of discomfort indexes are equal,
- H_1 – some differences between values of discomfort indexes exist.

To determine which groups of materials differ from each other, the Tukey post hoc test was performed, where the confidence interval was computed and fixed at 95%. In ***Tables 3-8*** Tukey post hoc interferences are disclosed for different kinds of upper and lining materials.

ANOVA analysis of groups of insole materials provided the information that the discomfort index is different because of insole materials applied in finished footwear. Significant differences occurred for specific sets of upper and lining materials: L1 – MP2, L1 – MP42, L2 – MP1, L4 – MP2, L4 – MP42, L5 – MP1. In accordance with the direct calculation of the impact rate for individual insole materials, the d-Cohen coefficient was obtained. Then for lining material MP2 and compositions MP2-MP39, MP2-MP41 in connection with the L1 upper, the d-Cohen coefficient was equal to 0.66 (between SPP1 and MPP2), which means a medium strength of dependency. A slightly higher coefficient (0.74) was obtained for the group of MP42 materials i.e. MP42-MP39, MP42-MP41. For the L2 upper the largest differences appeared between MPP1 and MPP2 in compositions with MP1: MP1-MP39 and MP1-MP41. The d-Cohen coefficient was equal to 1.47, which means a large effect size between these insole materials. For L2 upper material, significant differences occurred between SPP1 and MPP2 (0.67) and SPP1 versus MPP2 (0.49) with the use of MP2 and MP42 linings. Then for the L5 upper, a difference described by the d-Cohen coefficient exceeding 2 was observed between MPP1 and MPP2. The size effect is the highest of all combinations of materials. For the L4 upper statistically significant differences did not occur.

Summary

The analysis of dependences between discomfort indexes performed shows that for the materials applied these dependences exist and are statistically significant. The optimal choice of materials in the triad of upper, lining and insoles makes it possible to establish a correct level of comfort in the shoe interior. It is especially important for work and sports shoes, where the risk of intense sweating or water permeability is high. The hygienic properties of shoes have a great impact on health and comfort from the user's point of view. Shoe materials like insoles are very important for the establishment

Table 9. *Recommendations for insole materials for certain compositions: upper and lining.*

Upper and lining combination	Insole material	Discomfort index ratio	Recommendation
L1 – MP2	SPP1 vs MPP2	0.76	SPP1
L1 – MP42	SPP1 vs MPP2	0.77	SPP1
L2 – MP1	MPP1 vs MPP2	0.71	MPP1
L4 – MP2	SPP1 vs MPP2	0.81	SPP1
L4 – MP42	SPP1 vs MPP1	1.18	MPP1
L4 – MP42	SPP1 vs MPP2	0.81	SPP1
L5 – MP1	MPP1 vs MPP2	0.75	MPP1

of temperature and humidity conditions inside footwear. In the case where all materials create a barrier against circulation between the foot and the environment, the temperature inside rises rapidly, the foot sweats intensely, and fungi and other microorganisms appear.

In accordance with the methodology described in [14], during a simulation of exertion, differences between the dorsum and sole fluctuate between 21% and 76%. This fact shows that in certain environmental conditions it is necessary to drain the moisture from the sole surface. In this case, the role of insole materials is pivotal.

Based on previous analysis, we can highlight the best insole materials for specific combinations of upper and lining materials which can reduce the discomfort index for users (***Table 9***).

Results obtained from the analysis above correspond to a commonly known fact that from the user's point of view natural leather has better hygienic properties than other materials, like cellulose material or leather from recovery. But when footwear manufacturers want to use alternative, often cheaper materials, it is possible to create other combinations which could be equally healthy and comfortable for consumers [15].

References

1. Kuklane K, Holmér J. Effect of sweating on insulation of footwear. *International Journal of Occupational Safety and Ergonomics* 1998; 4(2): 123-136.
2. Heus R, Schols E, Van den Eijnde W. Water vapour transport as a determinant of comfort in evaluating shoes. *Elsevier Ergonomics Book Series* 2005; 3: 445-448.
3. Mundermann A, Nigg B M, Stefanyshyn D J, Neil Humble R. Development of a reliable methods to assess footwear comfort during running. *Gait and Posture* 2002; 16: 3-45.
4. Hole L G. Sweat health disposal from footwear and hygiene of foot skin. *Journal of the Society of Cosmetic Chemists* 1973; 24: 43-63.
5. Falkiewicz-Dulik M. Charakterystyka materiałów stosowanych na podpodeszwy. *Technologia i Jakość Wyrobów* 2016; 61: 86-94.
6. Smith C J, Havenith G. Body mapping of sweating patterns in male athletes in mild exercise – induced hyperthermia. *European Journal of Applied Physiology* 2011; 111(7): 1391-1404.
7. Irzmańska E, Brochocka A. Influence of the physical and chemical properties of composite insoles on the microclimate in protective footwear. *FIBRES & TEXTILES in Easter Europe* 2014; 22, 5(107): 89-95.
8. US5763335A: Composite material for absorbing and dissipating body fluids and moisture, 1998.
9. US5727336A: Footwear insole with a moisture absorbent inner layer, 1998.
10. Matusiak M. Investigation of the thermal insulation properties of multilayer textiles, *FIBRES & TEXTILES in Eastern Europe* 2006; 14 (5): 98-102.
11. PN-EN ISO 20344:2012: Środki ochrony indywidualnej – Metody badania obuwia.
12. Langmaier F. Hygiena a komfort obuté nohy. *Kozarstvi* 1990; 40: 345-348.
13. Serweta W, Olejniczak Z, Woźniak B. Influence of the thermal and humidity properties of multi – layered lining fabrics on microclimate of leather footwear. In: Frydrych I, Bartkowiak G, Pawłowa M, editors. *Innovations in Protective and E-textiles in Balance with Comfort and Ecology*. Lodz: Lodz University of Technology; 2017.
14. Weiner J S. The regional distribution of sweating. *Journal of Physiology* 1945; 104: 32-40.
15. Tatano F, Acerbi N, Monterubbiano C, Pretelli S, Tombari L, Mangani F. Shoe manufacturing wastes: characterisation of properties and recovery options. *Resources, Conservation and Recycling* 2012; 66: 66-75.

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