BREATHABLE, IMPERMEABLE AND ODOURLESS LINING FOR ORTHOPAEDIC FOOTWEAR APPLICATION

Joaquim PEIXOTO; Paulo FLORES & António Pedro SOUTO

Abstract: *Is has been recognized that the breathability and impermeability of the shoes lining play a crucial role on the performance and comfort of footwear. The main goal of this work is to study the application and behaviour new materials and new finishing to improve comfort in orthopaedic footwear associated with orthosis. This desideratum is reached through the selection and application of advanced materials, such as, breathable membranes and fabric finished with anti-fungal and anti-bacteria treatments. In this study, water vapour permeability was evaluated to determine the water vapour transport property produced by skin transpiration. Furthermore, a new lining with hydrophilic breathable membrane and anti-odour finishing has been developed and tested. Water vapour permeability of the new lining was compared with other conventional materials. From the obtained results, it can be drawn that the application of membranes with weave fabric by lamination decreases the breathability of material. The possibility to use fabrics with anti-odour finishing's, laminated with a hydrophilic breathable membrane, for lining proposes has been demonstrated.*

Keywords: *Orthopaedic footwear, lining, breathable membranes, comfort, textile finishing*

1. Introduction

Over the last few decades several researches work have been performed in the field of new materials and new production techniques, directly related to the orthopaedic footwear. However, the developments in the footwear associated with orthosis did not have significant attention, being the robustness and durability of the system's elements the only design variables. Other important aspects, such as the application of new advanced materials to achieve functionality and give better aesthetic values are in general neglected.

It is known that problem of bromidrosis is particularly important in orthopaedic footwear due to the intense utilization. Bromidrosis is body odour that is related to the sweating [1]. In some cases, bromidrosis can become pathological when it interferes with person who suffers from this condition life [2]. The body zones most that can be affected by this problem are the axils and feet [3]. The development of odours or bromidrosis is due to proliferation of bacteria and fungi, when inside the shoes the conditions of temperature and humidity for their proliferation are established [4]. The conventional material to produce orthopaedic shoes is leather because it combines different proprieties like breathability, softness and ability to get foot form [5]. On one hand, leather is not a waterproof material and it does not ensure good foot breathability. On the other hand, shoe uppers parts are frequently made of man-made materials more durable such as fabric and polymers.

A recent development in shoe upper technology uses elastic materials (e.g., neoprene) that easily stretch around deformities [6]. The latest developed materials which own this desired property are breathable membranes. The breathable membranes are polymers films that exhibit a good permeability, allows for the water vapour go out but still impermeable to liquids. Two different types of breathable membranes can be applied on lining shoes, namely micro-porous and a hydrophilic. The micro-porous membranes have millions of micropores per square inch. These micropores are small enough to not permit the passage of liquid water but allow for the passage of molecules of water vapour (20,000 times smaller than liquid water and 700 times larger than a water molecule) thus permitting breathability skin [7]. In turn, the hydrophilic membranes are nonporous membranes in which the water vapour is transmitted by a molecular mechanism [8].

The water vapour permeability of fabrics is an important property because the human body cools itself by sweat production and evaporation during daily routine activity. The clothing system must be able to remove this moisture in order to maintain comfort. Thus, one of interesting material to incorporate on fabrics is polymer layer, such as breathable membranes. This solution makes the fabric waterproof and still allows for the water vapour to pass through [9]. Moreover, the comfort properties are ensured by water vapour permeability of materials. In most cases the breathability of footwear depends on materials proprieties, namely upper shoe parts, linings and vamp, and the capability of midsole absorb/release water. The breathable properties of materials help to eliminate, or at least to reduce, the bromidrosis problem.

In this work textiles laminated with polymer membranes have been applied as lining in orthopaedic shoes. The high breathability of polymer membranes is the core aspect to increase comfort. With this lining a barrier to water is created but it is still vapour permeable. Hence, the sweat can be transported through the lining. This laminate textile in association with an anti-odour finishing's significantly reduces the bromidrosis.

2. Materials

2.1 Breathable membranes

The membranes are breathable polymeric films which have good permeability to permit the passage of water vapour and impermeable to liquids such as rain [10]. The waterproof and breathable proprieties of the lining were obtained by selecting a hydrophilic membrane (BM). In the present study polyurethane hydrophilic membrane film by Epurex films, reference Walatex 2202 AC, has been utilized. The table 1 shows the main characteristics of breathable membrane.

Table 1: Characteristics of breathable membrane Walatex 2202 AC

Density	1.25 (g m^{-2})
Softening range (Kofler bench Knife)	145-155 ºC
Tensile stress	25.0 (MPa)
Tensile Strain	550.0 (%)
Water vapour transmission	4500 (g m^{-2} day^{-1})
Thickness	0.20 (µm)

2.2 Weaving fabric

Plain weave is the most common weave structures in which the filling threads pass over and under successive warp threads. Table 2 shows the main characteristics of weave fabric (WF) used to develop the shoe lining.

Table 2: Characteristics of weave fabric

Weave	Plain
Warp yarn	9.93 (tex)
Weft yarn	12.50 (tex)
Warp density	75.0 (cm^{-1})
Weft density	27.0 (cm^{-1})
Thickness	0.23 (mm)
Fabric weight	137.56 (g m^{-2})
Composition	95% cotton 5% elastane

2.3 Lining fabric

The lamination technique combines two or more materials resulting in modification of physical properties of individual characteristics in the separate components. In general, laminated fabrics are used in waterproof and breathable materials like protective clothing, car seat upholstery, and footwear [11]. Lamination of any material produces a laminate that is stiffer than either starting materials [12]. The lining fabric (LF) sample used in this study was prepared, with three layers, namely weave fabric/hydrophilic, membrane/weave and fabric finished with odourless treatment. With the purpose to develop the LF, the hydrophilic membrane is bonded between two layers of plain fabric. The lining is waterproof, windproof and breathable. The lining is made by laminating process. Then, the layer in contact with the skin is finished with anti-odour treatment. Table 3 shows main characteristics of laminate fabric considered here.

Table 3: Characteristics of laminate fabric

Fabric weight	256.44 (g m^{-2})
Thickness	0.40 (mm)

In this research study the water vapour permeability of developed lining fabric (LF) was compared with several commercial materials: Leather Lining (LL), Lining with Membrane (AQUA), Breathable Membrane (BM) and Weave Fabric (WF).

3. Methods

This study used two different but complementary methodologies in order to solve the problem of bromidrosis. With the application of a lining laminate with a breathable membrane it is possible to transfer the sweat from inside of the shoe to outside thereof, thus avoiding the development of bacteria and fungi. The use of breathable lining intended to further enhance the breathability of the footwear. An anti-odour finish was also applied to the lining, with a mechanism that consists of chemical modification of the molecules that causes odour neutralization. To validate the methods described several tests were carried out, which include the water vapour permeability and air permeability.

3.1 Water vapour permeability

Water vapour permeability was determined according to "British Standard 7209-British Standard Specifications for Water Vapour Permeable Apparel Fabrics". According to this method the specimen under test is sealed over the open mouth of a dish containing water and placed in the standard testing atmosphere. Then, after a period of time, to establish equilibrium, successive weightings of the dish are made and the rate of water vapour transfer through the specimen is calculated.
The Water Vapour Permeability (WVP) in g m^{-2} day^{-1} can be determined by the following relation

$$WVP = \frac{24M}{AT} \qquad (1)$$

where M is the loss in mass of assembly over the time period (grams), T denotes the time between successive weightings of the assembly (hours) and A represents the area of exposed test fabric - equal to the internal area of the test dish (m^2).
The water permeability Index, I, is given by means of following expression

$$I = \frac{(WVP)f}{(WVP)r} X100, \qquad (2)$$

in which the $(WVP)_f$ is the mean water vapour permeability of the fabric under test and the $(WVP)_r$ is water vapour permeability of the reference fabric and is test in three samples, with 96 mm diameter.

3.2 Air permeability

The air permeability refers the ability of a fabric to be crossed by the air through the pores or interstices. The rate of passage of air through the material depends primarily on the size and distribution of pores or interstices between the fibres. The air permeability is determined by measuring the velocity of air flow perpendicularly crosses a specimen under specified conditions, (area and pressure). In this study the test has been performed with an area of 20 cm^2 and a pressure of 200 Pa. The air permeability test has been carried out following the standard "NP EN 9237-1997 - Determination of the air permeability of textile."

3.3 Finishing Process

Shoes made without breathable materials, when associated with sweating problems, creates the conditions favourable to the development of organisms/agents, such as bacteria and fungi, responsible for odour and occasionally shoes begins to release unpleasant odours.
The finishings that were applied as anti-odour product to the fabric layer, which contacts with the skin, has the following characteristics: slightly cationic and neutralize odours in all types of textiles. In addition, it does not affect the touch and can be applied in all finishing processes.

The impregnation bath was prepared according with the recipe: 40g L^{-1} Bayscent Neutralizer and 12g L^{-1} Persolftal plus. The pickup of foulard was 35%. Afterwards, the samples were dried at 105ºC during 5 minutes.

4. Results and Discussions

4.1 Water vapour permeability

With the intention to confirm the purpose the developed lining, the water vapour permeability of laminated fabric was compared with a breathable membrane; weave fabric, commercial leather lining and a commercial lining with membrane.
Figure 1 shows the differences of Water Vapour Permeability Index for Breathable Membrane (BM), Weave Fabric (WF), Leather Lining (LL), developed lining (LF) and Lining with Membrane (AQUA).

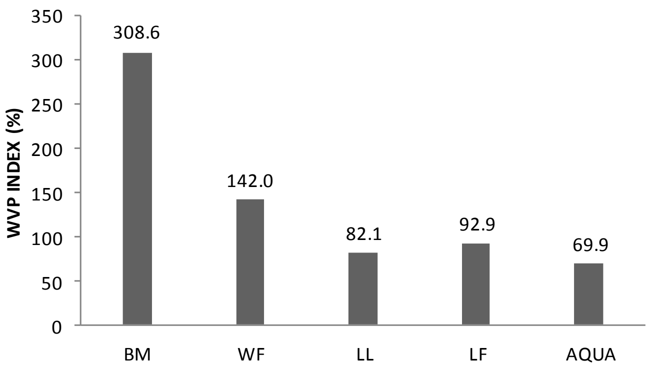

Figure1: Water vapour Permeability of different Materials

By observing figure 1 it can be verified that the application of membrane to WF (lamination process) decrease the breathability of materials. Nevertheless, the LF had better performance than LL and AQUA. The LF is impermeable as well as AQUA.

Breathability in orthopaedic shoes are related to upper part of the shoes (vamp) usually made by leather. In this work a hydrophilic membrane has been applied, by lamination, to a fabric already finished with anti-odour products (LF). This lining has been applied to leather. An evaluation of breathability was made using leather as standard (LL).

Figure 2 shows the results of breathability of lining made only with leather (LL) and Lining Fabric developed in this study (LF), when applied to an upper part made with leather aniline.

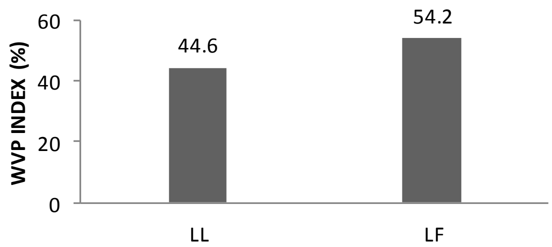

Figure 2: Water vapour permeability of shoe lining associated to vamp

Figure 2 depicts that the decrease of breathability of both linings materials is proportional. In this study the breathability decreased more than 40%, when the linings are applied to leather of the upper part of shoe. Thus, it was possible to confirm that the laminated fabric developed (LF) has better performance than leather lining (LL).

4.2 Air permeability

To confirm the purpose of the developed lining, the air permeability of laminated fabric was compared with a breathable membrane, namely weave fabric, commercial leather lining and a commercial lining with membrane AQUA (Table 4).

Table 4: Air Permeability of different materials

Materials	Air permeability ($l/m^2/s$)
BM	0.00
WF	120.20
LL	1.84
LF	0.58
AQUA	3.27

Table 4 shows the different values obtained for air permeability, and as it was expected the weave fabric exhibits higher air permeability, while the breathable membrane is less permeable to air. It was also observed that all linings had very low permeability when compared with a textile weaving technology.

4.3 Finishing

Another important characteristic in this study deals with the validation of the anti odour finishing process. For this purpose an end-user tested three different orthopaedic shoes with a three deferent's linings: leather lining (figure 3), commercial lining with a membrane – AQUA (figure 4) and a lining fabric with anti-odour finishing laminated with a hydrophilic membrane – LF (figure 5).


Figure 3: Leather lining


Figure 4: Aqua lining


Figure 5: Lining Fabric

A test was carried on daily by an user during a period of three months. During this period the user answered a questionnaire to report the several sensations that he felt: residual humidity, thermal sensation, odour, breathability and general comfort.

Table 5: End-user Opinion

Question / apreciation	**Lining Leather**			**Aqua**			**Lining Fabric**		
	Good	medium	weak	Good	medium	weak	Good	medium	weak
residual moisture		x				x	x		
thermal sensation	x					x		x	
breathability			x		x		x		
odour			2		3		5		
general comfort		x			x		x		
Global		**x**			**x**		**x**		

From the analysis of Table 5, it is possible to conclude that each case has a different accumulation of humidity and it is possible to observe inside of the shoes. In the shoes with lining fabric (LF) it was noticed that them do not have accumulated any humidity, but instead with leather lining it was possible to verify humidity in the insole after an intense use. The shoes with AQUA lining the quantity of humidity were easy to be observed.

The thermal comfort is the user sensation of cool/hot when uses the shoes. The leather lining gives an excellent sensation because it is not very hot neither cold. The lining AQUA seems to be very hot. The lining fabric gives intermediate sensations.

The breathability is the capacity of shoes, when used daily, to permit the feet to breath. In this study only the lining fabric has an excellent capacity of breathability. The leather lining permits a poor breathability and AQUA has sparing breathability propriety.

The evolution of odour was a daily measurement made by the user, who classified the odour in a scale that varies from 1 (unpleasant odour) to 5 (without odour). Linings made of leather and AQUA have an unpleasant odour after several days of use but shoes with lining fabric the user never had felt any odour.

General comfort is the combination of all parameters, already explained, e.g., the user has a subjective opinion about comfort. For him, comfort is to have a shoes never hot or cold, without humidity and odourless. The user classified the shoe with breathable membrane better than others because he doesn't feel humidity, any odour and the user does not feel any problem with temperature of his feet.

5. Conclusions

In this work, particular focus was given to the application of new materials and finishings to improve comfort in orthopaedic footwear. The obtained results proved that it is possible to use hydrophilic breathable membranes with weave fabric to obtain an impermeable lining. Moreover, it was shown that an anti-odour finishing can be applied to the LF to prevent psychological discomfort in an effective manner. All the techniques and new materials adopted in this study have the objective to improve the quality of life to the users of this type of footwear.

Acknowledgments

We gratefully acknowledge the financial support from QREN (Quadro de Referência Estratégico Nacional - National Strategic Reference Framework), for this study "INOVSHOES - Padronizar para Customizar Calçado Ortopédico", project n.º 2010/12032.

References

[1] Bega, A.; *Tratado de Podologia*,Yendis Editora, ISBN 978-85-7728-083-4,São Paulo Brazil, (2006)
[2] Rehmus W., Cheng, Brown K., *Available from* http://emedicine.medscape.com/article/1072342-overview; *Accessed:2012-04-27*
[3] Benohanian, A.: Antiperspirants and De odourants, *Clinics in Dermatology*, vol. (2001) 19, no 4 pp.398-405, ISSN 0738-081X
[4] Pinto, V.: Controlo do odour no interior do sapato, *Sapato-Moda-Tecnologia*. (2006) 45, pp.54
[5] Garcia N., Reis E., Budemberg E., Job A. VII Congresso Brasileiro de Análise Térmica e Calorimetria, *Comportamento térmico do compósito expandido obtido a partir da mistura de resíduo de couro, borracha natural*, São Pedro, April 2010, ABRATEC, São Paulo (2010)
[6] Hsu, J.; Michael, J.; Fisk, J.; Shoes and shoe modifications, *AAOS Atlas of orthoses and assistive devices,* Mosby elsivier, ISBN 978-0-323-03931-4, Philadelphia, (2008)
[7] Fung, W.; Products from coated and laminated fabrics, Coat and laminated textile, Woodhead publishing Ltd, ISBN 1 85573 576 8, Cambridge (2002), pp.152
[8] Gulbinienė, A, et Al. Investigation of water vapour resorption/desorption of textile laminates, Materials Science, Medziagotyra ISSN 1392–1320 Academy of Sciences of Lithuania (2007). Vol. 13, No. 3. 2007, pp 255-261
[9] Saville BP.; Comfort, Physical Testing of textiles, Woodhead publishing Ltd, ISBN 1 85573 367 6, Cambridge (1999), pp.223-224
[10] Lomax G.R. Available from http://pubs.rsc.org | doi:10.1039/B703447B; *accessed*: 2012-05-02
[11] Fung, W.; Materials and their properties, Coat and laminated textile, Woodhead publishing Ltd, ISBN 1 85573 576 8, Cambridge (2002), pp.50
[12] Fung, W.; Production methods, Coat and laminated textile, Woodhead publishing Ltd, ISBN 1 85573 576 8, Cambridge (2002), pp.114

Author(s):

Joaquim Jorge PEIXOTO, Ph.D. Student
University of Minho, Guimarães, School of Engineering, Department of Textile Engineering
Campus de Azurém, 4800-058 Guimarães, Portugal
Phone: +(351) 912782374 Fax: +(351) 253510293 E-mail: jjorge@det.uminho.pt

Prof. João Paulo FLORES, PhD.
University of Minho, Guimarães, School of Engineering, Department of Mechanical Engineering
Campus de Azurém, 4800-058 Guimarães, Portugal
Phone: +(351) 253510220 Fax: +(351) 253510293 E-mail: pflores@dem.uminho.pt

Prof. António Pedro SOUTO, PhD.
University of Minho, Guimarães, School of Engineering, Department of Textile Engineering
Campus de Azurém, 4800-058 Guimarães, Portugal
Phone: +(351) 253510275 Fax: +(351) 253510293 E-mail: souto@det.uminho.pt