STUDIES ON FUNCTIONAL PROPERTIES OF BIOACTIVE COMPOSITE FOOTWEAR INSOLE

MONICA PURI SIKKA[1], MAHENDRA SAHU[2] & DEEPAK KUMAR BHATI[3]

[1, 2&3]DEPARTMENT OF TEXTILE TECHNOLOGY- DR. B. R. AMBEDKAR NATIONAL INSTITUTE OF TECHNOLOGY JALANDHAR-144011 India

Abstract: *In this work composite footwear insoles were prepared and analyzed for their functional and antibacterial properties. A three layered insole composite was prepared with top layer of 100% polyester satin woven fabric, middle layer with three different variants as 100% polyester weft knitted spacer fabric, 100% polyester needle punched nonwoven fabric and polyurethane foam and bottom layer of 100% polyester needle punched nonwoven fabric.Out of all the essential properties of the footwear insole, cushioning property plays the most important role as shock absorber to reduce the ground reaction force. The textile composite material with knitted spacer fabric as middle layer shows both good compression and water vapour permeability. It also has acceptable level of stiffness and antibacterial activity. On the other hand insole composite with polyester nonwoven fabric as middle layer shows the best antibacterial properties. Although in domestic market, shoes having insole manufactured with polyurethane foam as bottom layer (in two-layer insole) are used commercially but this foam shows lower antibacterial activity as compared to nonwoven and spacer fabric.*

Keywords: insole composite, antibacterial properties, compression properties

1. Introduction

In ancient time, footwear was used to protect from rocks, thorns and harsh weather. As years go by, people got aware about the functional foot wears after facing many foot related injuries; problems discomfort (*Kippen C, 2004*). The purpose of insole is to reduce the force transmission and customizing shoe to protect the foot. After continuous research manufactured good comfort insole from different form of polyurethane foam, memory foam these insoles are good in cushioning, resilience and pressure relief.

However, the functional foot wears as well as commercially available insoles are quite expensive so, the textiles composite material may be the alternative solution this problem because some textile structures may offer great cushioning effect, recovery and other positive aspects. Even the shock-absorbing capacity of the insole is the main criteria; wearing comfort also plays a vital role. To achieve this breathable wearing comfort, the foams may not be suitable and the alternate material will be a textile material.

Knitted spacer fabrics are an ideal group of energy absorbers for cushioning applications. They are highly breathable and offer a moisture free environment which in turn reduces the chances of skin maceration and increases the level of comfort when compared to other materials such as foam, neoprene and composites. The key properties of spacer fabrics, together with their light weight construction, support their use in the construction of orthotic insoles(Lo, Wong, Yick, Ng, & Yip, 2016).

In spacer fabrics manufacturing, the commonly used materials are polyester multifilament yarns on its two outer surface and monofilament yarns at the center. This comfort property of the spacer fabric depends on the thickness and structure of the fabric(Rajan, Souza, Ramakrishnan, & Zakriya, 2014).

Besides mechanical comfort also necessary to import bioactive properties to insole to prevent the development of microorganism. The amount of sweat perspired in the footwear depending on the environment condition. Optimum conditions for the foot are a temperature not higher than 28 – 34 °C and a relative humidity within the range of 60 – 65%. According to literature data, the average human foot produces 2.5 – 3.0 g of sweat per hour and after an 8 h work shift, moist insoles constitute perfect conditions for the growth of microorganisms(Irzmańska, Brochocka, & Majchrzycka, 2012).

The hygienic properties of materials used inside footwear may be modelled by using products characterised by high permeability and absorption of water vapour while also having heightened microbiological resistance. Therefore to fulfil the mechanical comfort and hygienic comfort there is great possibility to use textile composite materials in the form of weft spacer fabric; needle punched nonwoven fabric and foam and replace the commercial footwear insoles in making functional shoes. The present study is done by Preparing the composite footwear insole (with middle layer as spacer fabric, foam, needle punch) and then check the functional properties of the prepared footwear insole and the antibacterial activity in top layer and middle layer of composite footwear insole.

2. Material & Methods

2.1 Materials:

2.1.1 Fabrics used:

In this study three layer of different material and construction has been used for constructing the insole. Top layer is 100% polyester satin woven fabric, middle layer has three different variants 100% polyester weft knitted spacer fabric, 100% polyester needle punched nonwoven fabric and polyurethane foam in shoe insole. Bottom layer is also 100% polyester needle punched nonwoven fabric.

2.2 Sample Preparation Method: Sample preparation was done in two steps:

1) Formation of insole
2) Antibacterial treatment of top and middle layer

2.2.1 Formation of bioactive composites insole:

The system designed is a spatial structure (Figure 3.1) with layers of different characteristics. The modelling of the three-layer composite footwear insole (Table 3.1) was done with a view to meet the following criteria.

Top layer - The **t**op layer is polyester satin woven fabric having 200 GSM, thickness 0.4mm, 380 EPI & 92 PPI, 9 Tex warp and 17 Tex weft.
The function of top layer is better wicking, spreading, permeable and drying of moisture vapour, remaining in contact with the user's foot.

Middle layer – The middle layer is treated variants of polyester weft knitted 3D spacer fabric having GSM 435, thickness 3mm; polyester needle punched nonwoven fabric having 420 GSM, 3mm thickness, punch density 350 punch/cm^{2}and pore diameter 35 micron; and polyurethane foam having GSM 27, thickness 3mm.
The function of middle layer is for mechanical comfort better compression, cushioning, recovery, and for hygienic comfort moisture vapour permeable, odourless, protection against bacteria, fungi and improving the hygienic properties.

Bottom layer – The bottom layer is polyester needle punched nonwoven fabric having GSM 265, thickness 2mm, punch density 200 punch/cm^2 and pore diameter 73 micron.
The function of bottom layer is extra cushioning and arch support to the foot.

Table 2.1 Variants of bioactive composites produced for protective footwear insoles.

Variant	**Structure of bioactive composites for protective footwear insoles**		
	Top layer	**Middle layer**	**Bottom layer**
1	Polyester satin	Polyester spacer	Polyester needle punch
2		Polyurethane Foam	
3		Polyester needle punch	

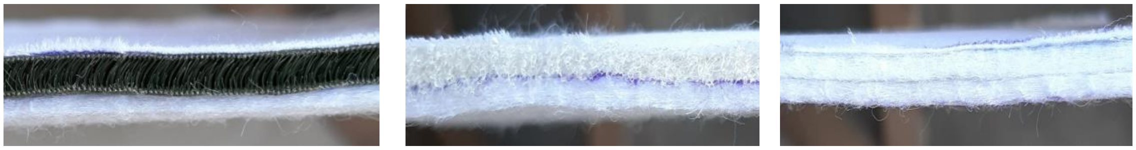

Figure 2.1 Schematic of the layers of the composite footwear insole.
Figure 2.1(a) variant 1 Figure 2.1(b) variant 2 Figure 2.1(c) variant 3

2.2.2 Antibacterial treatment of top and middle layer:
The polyester satin and spacer fabric were first swollen at 90-95°C for 2-3 hr in a solvent-nonsolvent system consisting of 1,2-dichloroethane/water(20/80v/v). Dichloroethane was **re**moved from the fabric completely by treatment with boiling water. The swollen fabric were used forgrafting.
In the case of acrylonitrile, 1 g of the fabric was added to a solution containing 0.05-0.15 g benzoyl peroxide in 5-10 ml acetone diluted with 80-90 ml water and 4 ml monomer. The grafting was carried out at70-73°C for 4-8 hr. After the completion of reaction, the fabric were thoroughly washed with boiling water, and the homopolymers adhering were removed by extraction with boiling water for 4-5 hr for polyacrylonitrile(Kale, Lokhande, Rao, & Rao, 1975).

3. RESULTS & DISCUSSION

3.1 Insole Specification: The construction and functional properties of insoles are shown in Table 3.1. The requirement for the thickness for the samples as fabric in the literature review is 3mm to 7 mm and water vapour permeability should be minimum 2 mg/(cm^2 h)and the results are shown in Table 3.2. Also resistance to abrasion for top layer was measured which was around 23,308 cycles.

Table 3.1 Average values of parameters of the composite insoles.

Parameter	**Mechanical parameters**				**Hygienic parameters**
	Thickness (mm)	**GSM (gm/m^2)**	**Bulk Density(kg/m^3)**	**Stiffness(Newton)**	**W.V.P. mg/(cm^2 h)**
Standard	**EDANAWSP 120.6 (05)**	**ASTM D 6242**	_	**ASTM D 4032**	**BS3424-34**
1	5.4	931	172.4	39.16	52.29
2	5.3	499	94.15	23.83	47.14
3	5.1	872	170.9	70.16	49.5

3.2 Stiffness: It is observed from Table 3.2 that insole combination 2 has lowest stiffness and insole combination 3 has highest stiffness. It may be due to low GSM and low bulk density of insole combination 2 having low bulk density polyurethane foam in middle layer material where insole combination 3 have high bulk density polyester nonwoven fabric in middle layer material. Insole combination 1 has mid value of stiffness due to presence of knitted structure of spacer fabric in middle layer material.

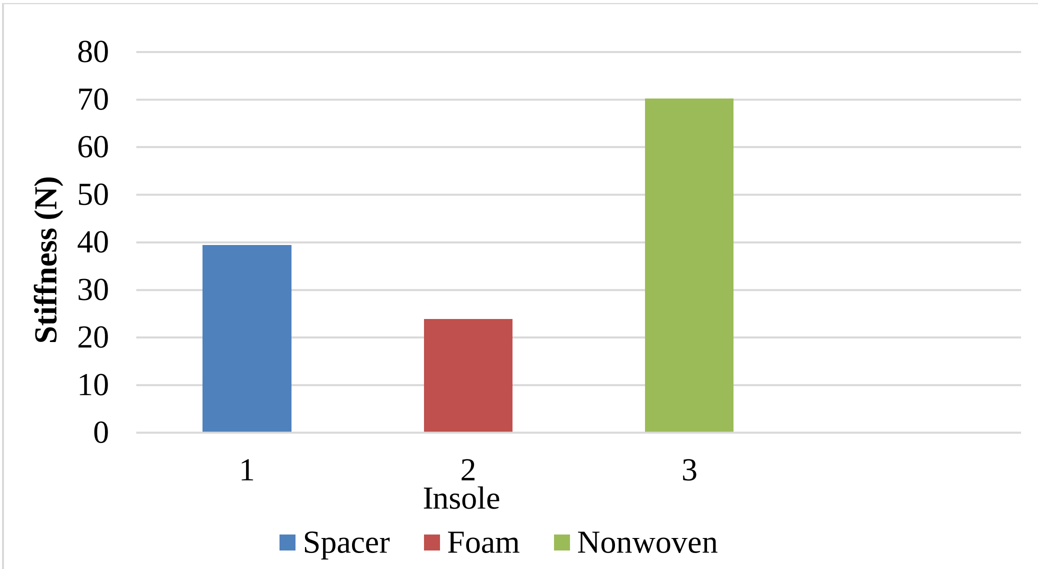

Figure 3.1 Stiffness of composite footwear insole

In ANOVA result shows that the insole combination 2 has lowest stiffness than insole combination 1 and 3. For softness purpose insole combination 2 is best but if we talk about softness as well as stability than insole combination 1 has acceptable stiffness and stability.

3.3 Water Vapour Permeability: It is observed from Table 3.3 that insole combination 1 has highest water vapour permeability and insole combination 2 has lowest water vapour permeability. It may be due tocompactness variation between the variant middle layer fabric. Spacer fabric has open structure than nonwoven and foam leads to easy passage of water vapour through insole assembly that causes higher water vapour permeability. However non-woven is comparatively more compact than spacer and open than foam hence it shows lower rate of passage of water vapour through insole assembly. Foam has close compact structure which is basically sheet of polyurethane which allows very small amount of water vapour to pass through insole assembly and leads to lowest WVP value.

Table 3.3 Data of Water Vapour Permeability test for insole combination 1, 2 and 3.

Replication	**W.V.P.[mg/(cm^2 h)]**		
	Insole 1	**Insole 2**	**Insole 3**
1	52.8	48.42	50.17
2	50.18	45.7	49.97
3	53.9	47.31	48.36
Average	52.29	47.14	49.5

In ANOVA result shows that there is significant difference (p-value 0.0148) and it is confirmed that insole combination 1 is best for water vapour permeability and significantly different from insole combination 2 and 3.

3.4 Compression Properties: It is observed from Table 3.4 that insole combination 1 has highest compression property among all insole combination. It may be due to construction parameters of 3D spacer fabric used as a middle layer material. In spacer fabric top and bottom layer are adjoined by monofilament in perpendicular orientation with respect to fabric axis that causes high recovery after removal of load. Whereas insole combination 3 has lowest compression due to construction of nonwoven fabric used in middle layer material, which has multidirectional orientation(random orientation in vertical and horizontal direction of fabric axis) of fibres in fabric structure. The Insole combination 2 has mid value of compression due to lower recovery rate of polyurethane foam after loading.

Compression(t_3-t_{50}): The change in thickness of fabric when the pressure increased from 3kpa to 50kpa.

Percentage compression recovery: The change in thickness of fabric when the pressure diminished from 50kpa to 3kpa expressed as a percentage of compression.

Numerically it is expressed as $\frac{(t_r - t_{50})}{(t_{50} - t_3)} \times 100$

Table 3.4 Compressive displacement with respect to load in static condition for 100 kg bodyweight (980N load).

Replication	**Displacement (mm)**		
	Insole 1	**Insole 2**	**Insole 3**
1	2.3	0.41	1.6
2	2.2	0.28	1.3
3	1.9	0.35	1.2
Average	2.13	0.34	1.36

Table3.5 Compressive recovery % displacement with respect to load in static condition for 100 kg bodyweight (980N load).

Replication	**Recovery %**		
	Insole 1	**Insole 2**	**Insole 3**
1	56.78	8	67.6
2	60	12	56.6
3	63.2	7	50
Average	59.9	9	58.06

In ANOVA result shows that there is significant difference (p-value 0.0473) and it shows that insole combination 1 has best compression properties than insole combination 2 and 3.

3.5 Antibacterial Activity Test:

For antibacterial activity test of fabric, the number of colony formation in treated sample agar plate and untreated sample agar plate was counted and put in equation 1

$$\% \text{ age reduction in bacterial growth} = \frac{A-B}{A} \times 100 \quad \text{……….eq1}$$

Where A is bacterial colony count in untreated fabric & B is Bacterial colony count in treated fabric

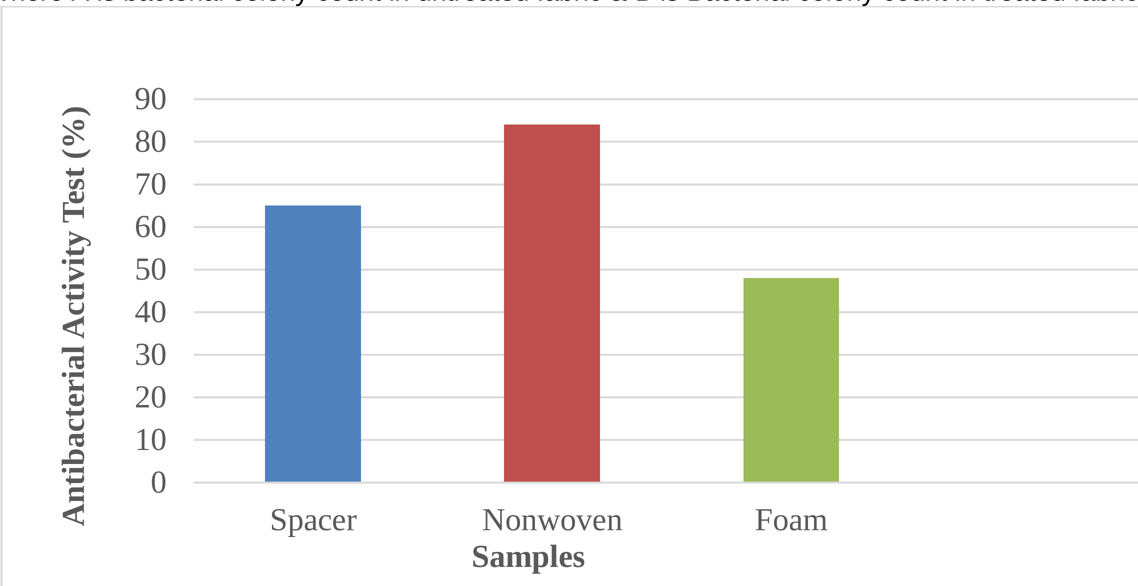

Figure 3.2 Antibacterial activity of middle layer variants.

From figure 3.2 it is seen that the percentage reduction in the bacterial growth is the maximum in nonwoven fabric. It may be due to higher surface area of the nonwoven material and more fibrous structure that allows cationic group formation on insole surface. Also the bacterial growth in the top layer which is common to all the composites is around 62%.

In ANOVA result shows that there is significant difference (p-value 0.0011) between the group which is non-woven, spacer and foam and it is confirmed that nonwoven fabric has best antibacterial properties and significantly different from spacer and foam

4. Conclusion

The comparative study of the textile composite materials used as middle layer of a three layered bioactive insole in footwear revealed-

During walking the foot(especially heel) feels an impact force that apply in reverse direction of foot movement due to ground reaction are up to 1.3 to 1.5 times of bodyweight and this exceeds up to 3 to 5 times at the time of running or sprinting. The textile or textile composite materials show better pressure distribution on whole of foot at the time of standing, walking and running.

On the basis of results it is observed that insole combination 1 has highest compression and water vapour permeability than insole combination 2 and 3, which is better for functional shoe insole.

From the results it is also observed that insole combination 3 has highest antibacterial activity in comparison to insole combination 1 and 2, which is better for bioactive footwear insole.

It is seen from the results that insole combination 2 has lowest stiffness than insole combination 1 and 3 that is better for pressure ulcers insoles.

Overall it is concluded from the study that insole combination with spacer fabric has better values for compression and water vapour permeability that are the most important property with regard to footwear along with acceptable levels of antibacterial activity and stiffness.

But for specific requirements of functional shoes the choice should be done wisely.

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