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Experimental Analysis on Comfort Characteristics of Polyester/Nylon Warp Knitted Spacer Fabric for Shoe Insole Application

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Abstract

The main purpose of the research is the development and analyzes the characteristics to increase the comfort for shoe insole application. Made of two separate fabric parts or layers, top and bottom and interlaced by yarns oriented in three dimensions, a warp-knitted spacer fabric is a real 3D fibrous structure. Therefore, in this research, warp knitted spacer fabrics used for shoe insole application were produced using polyester /nylon with Rachel double needle gauge of 28E, 6 guide bars. The spacer fabric characteristics were evaluated as per standard. The warp knitted spacer fabrics can replace the existing PU foam's shoe insoles, made to have comfort, recyclable, and environmentally friend. Statistical Analysis System (SAS) software was used for analysis. The spacer fabrics have significant compressibility and porosity which result in good cushioning and permeability.

Keywords: Comfort • Warp knitting • Spacer • Insoles

Introduction

Technical textile products have a great role in many applications. One of the most widely used textiles is spacer fabric products, and methods for producing spacer textile materials. Spacer textile materials naturally comprise two spaced and separated parts of fabric joined by a monofilament spacer yarns that extend within the layers of fabric. This research discusses the development and analyzes the characteristics to rise the comfort for shoe insole application [1]. Made of double layers, top and bottom and interlaced by yarns oriented in the third dimension, the spacer is a real 3D fibrous structure [2]. The fabric layers can be manufactured using various types of materials and structures. The top and bottom fabric layers are connected to each other by a monofilament yarns called spacer yarn. This type of structure with late air and water vapor transfer makes the fabric lighter and this helps to be selected for shoe insole. Mainly, spacer fabrics can be 1–15 mm thicker. Spacer fabrics are produced on double-bed Rachel machines by knitting the top and bottom layer concurrently on each needle bed [3]. The most important properties of spacer fabric lightness, flexibility, porosity, and high stiffness [4] Shoe insoles produced from warp-knitted spacer fabrics are comfortable for the wearer. They are mainly produced from polyuratine foam and other materials previously. [5,6] specially warp knitted spacer fabric applications like shoe insoles and others with the advancement of comfort ability [7-16]. The influencing factors such as thickness, density, air permeability, porosity, and thermal conductivity were measured according to the ASTM Standard for the purpose of shoe insole applications.

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Experimental

Materials and Methods

Materials

Raw materials for the study were 100% polyester, 80/20% polyester/ nylon, and 70/30 polyester/ nylon filaments. The face and back layers of the spacer fabrics are formed with 100% polyester multifilament and are connected by the central layer made of monofilament (100% polyester), 80/20% polyester/nylon multifilament and is connected by the internal layer made of monofilament 80/20% polyester/nylon) and 70/30 polyester/ nylon multifilament and is connected by the middle layer made of monofilament (70/30 polyester/ nylon) filaments (Tables 1-3).

Samples preparation

The fabric manufacturing technique and the different types of fabrics produced for the study are explained in this section. The WKSF was produced by Rachel double needle bed warp knitting machine with six guide bars, a

Table 1. Details of the 100% polyester.

Particular	Face layer	Bottom layer	Middle
Filament denier	120	80	50
No. of filaments	36	24	1
Diameter (mm)	0.125	0.085	0.063

Table 2. Details of the 80/20% polyester/nylon filaments.

Particular	Face layer	Bottom layer	Middle
Filament denier	100	70	40
No. of filaments	36	24	1
Diameter (mm)	0.115	0.075	0.055

Table 3. Details of the 70/30% polyester/nylon filaments.

Particular	Face layer	Bottom layer	Middle
Filament denier	120	70	50
No. of filaments	36	24	1
Diameter (mm)	0.125	0.085	0.063

gauge of 28E of 170 inches width. Machine speed 1500 rpm. The WKSF development consists of six samples, namely, three hexagonal structures of 100% polyester, 80/20% polyester/Nylon, 70/30% polyester/Nylon with thickness of 2, 2.5 and 3 mm respectively, and the other three were lock-knit structures of 100% polyester, rhombic mesh 80/20% polyester/Nylon, hexagonal 70/30% polyester/Nylon with constant thickness of 2.8 mm. Maintaining bottom surface layer as plain structure for all samples. Figure 1 shows the sample preparation. The structure of the face surface layers was selected as hexagonal &rhombic mesh and for the bottom surface layer the structure is maintained as a plain knit structure as shown in (Figure 8), (Figures 1 and 2).

Testing methods

The spacer fabrics are tested according to the ASTM standard. The test includes thickness, density, and air permeability; thermal conductivity and water vapor permeability properties. All tests are carried out under standard atmospheric conditions of 25 ± 2°C temperatures and 65 ± 2% relative humidity.

Figure 1. Sample preparation using Raschel machine.

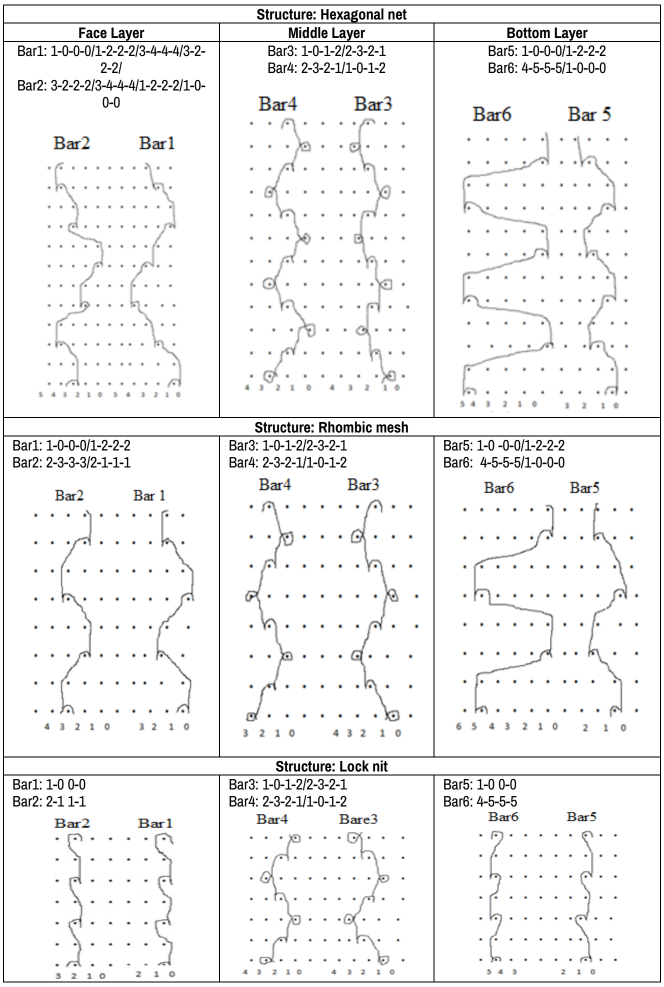

Figure 2. Stitch Notation.

Thickness

The thickness tester is a specialized equipment to determine the thickness of spacer fabrics. ASTM D 5729 standard is referred.

Areal Density

Areal density of the spacer fabric is an important factor that should be considered and the cost is also directly related to density. Mass per unit area of the spacer fabric will be measured using a weighing balance (ASTM D 3776 - 07) and the areal density of the fabric will be calculated using the following formula

Areal density (g/m^2) = (WPcm x CPcm -x-SL x 39.37x D) / (1000x 9000) (1)

Where wpcm:-wales per centimeter, cpcm: - coarse per centimeter, SL: - stitch length, and D: - denier (count).

Bulk Density

The fabric mass density or fabric bulk density (g/m^3) depends on both fabric weight and fabric thickness. The specimen with 50 cm^2 will be cut out randomly and weighted. Average of 10 observations will be taken for the sample. The bulk density of the fabric will be calculated using the following formula:

Bulk density (g/m^3)=Areal Density (g/m^2)/Thickness (m) (2)

Porosity

The number, size, and type of pores are an important factor that should be considered for shoe sole materials in a porous material. The space of course and wale increase the size of pores which in turn increases the airflow. While increasing the fabric loop length, the air permeability also increases since the fabric porosity is increased [8]. WKSF porosity was calculated by using the density of nylon (1.35 g/m^3) and polyester filament (1.38 g/m^3). The standard test ASTM E 1294-89 for Porosity determination.

Porosity (%) = [1 - Fabric Density (g/m^3) / Filament Density (g/m^3)] X 100 (3)

Air permeability

This testing method includes the measurement of the air permeability of WKSF. Air permeability is essential parameter for shoe insole application, because it remarkably influences the comfort. It is the degree of air flow passing perpendicularly through a known area under a prescribed air pressure differential between the two surfaces of a material [9]. The air permeability of the spacer fabric will be evaluated based on ASTM Test Method D 737at 10 cm water head. The unit is cc/sec/cm^2.

Thermal properties

Thermal conductivity is a property of the material that articulates the flow of heat through the material [10,11], the test will be according to Lee's disk instrument (ASTM-D 570). The average of 10 measurements was taken to minimize the possible errors.

Thermal conductivity (λ) Wm^{-1} K^{-1} = (MSR d (2h+r)) / (A (T 1-T 2) (2h+2r)) (4)

Where,

M = Mass of brass disc (C) in kgs, S = Specific heat of the material of the disc (370 JKg^{-1} K^{-1})

R = rate of fall of temperature (dT/dt), h = thickness of brass disc in mm, r = radius of the brass disc in mm, d = thickness of the sample in mm, A = area of cross section of a sample in mm^2. Thermal resistivity is also conducted accordingly.

Water vapor permeability

The water vapor permeability is the amount of vapor transfer although a unit area of a fabric in unit time [12], the following formula is used to get WVP.

WVP (g/m^2/24h) = (24xM) / (A x t) (5)

Where, M = loss of mass in gm; t = the time between weighing hrs. And A =

internal area of the dish in m². The test is conducted with BS 7209 and ISO Standard 11092.

Results and Discussion

Spacer fabric properties such as air permeability, porosity, thermal conductivity and resistivity, and water permeability of all samples were analyzed and summarized in Table 5. The effect of thickness and structure was also analyzed (Table 4).

Effect of thickness on air permeability of spacer fabrics

Air permeability is a degree of air flow through a fabric structural layer. The movement of air is of importance for a number of fabric and uses including shoe insole fabrics. Figure below shows the effect of thickness on air permeability (Figure 3).

From Figure 3, the T 1 and S 3 spacer fabrics have more open structure relatively and with the increment of porosity, the air permeability values have also increased. T 1 has good space between two surface layers, because of more void space, the air gets trapped and the middle layer restricts the flow through the fabric. As for porosity, T 3 shows the minimum space and the three layers contribute the limitation of air flow. The S 2, S 1, and S 3 outcomes show that the air permeability values increase as the spacer fabrics become looser. Lock knit structure inter loops the filament very closely and the surface of the fabric becomes tighter than the other two structures.

The influence of porosity

The porosity of a spacer fabric is the major property, which affects the air and water vapor permeability and thermal properties of spacer fabrics. Fabric porosity depends on the structure and the thickness of the fabric [13]. The T 3 has no enough space between the outer surface layers, which leads to poor porosity. T 1 has more space that the increase in fabric density leads to low porosity. The open structure causes a relative increase in its porosity. Figure 4 shows changes in the value of porosity between S 1 and S 3. The increase in porosity results in the increase of air and water vapor permeability. The same experimental result was done by [14] (Figure 4).

Table 4. Properties of warp-knitted spacer fabrics.

Samples	Porosity (%)	Air permeability (Cc /sec/cm²)	Water Permeability (%)	Thermal conductivity (λ)×10⁻³ (W/mK)	Thermal resistance (λ)×10⁻³ (Km²/W)	Thickness (mm)/structure
T1	86.78	177.52	53.21	53.31	67.26	2
T2	87.32	173.4	50.01	49.32	68.40	2.5
T3	88.41	168.2	49.15	48.56	69.21	3
S1	87.00	172.3	48.61	50.05	60.98	Lock knit
S2	86.91	170.00	51.00	49.51	68.87	Rhombic Mesh
S3	87.10	173.02	49.85	48.88	70.31	Hexagonal
PU	30.11	72.46	51.30	31.20	110.03	2

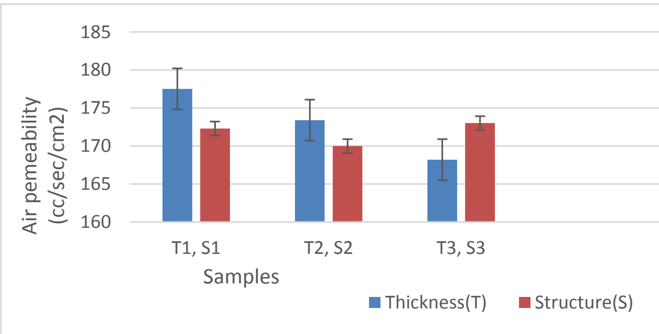

Figure 3. Air Permeability and Thickness relation.

The effect of air permeability

Air permeability designates the degree of air flowing perpendicularly onto two surfaces of a material. As the porosity of the fabric increase, the permeability increases [1-15] (Figure 5).

As it can be observed from Figure 5, S 1 sample has a more open structure than the others, and with the increment of porosity, the air permeability values have also increased. S 2 has good space between two surface layers, has more void space, so that the air gets trapped and the middle layer restricts the flow through the fabric. S 3 shows low space and all three layers contribute the restriction of air flow.

The effect of water vapor permeability (WVP)

WVP determines the rate of water vapor passage through a textile material. The water vapor permeability of polyester/nylon is higher because of the low absorbent moisture within the filament [17]. Figure 6 shows the WVP of warp-knitted polyester/ nylon spacer fabrics (Figure 6).

Water vapor transmission through largely porous structures is predominately controlled by fabric variables that determine thickness and permeability. The thickness of the fabric is a major feature and it establishes the distance through which water vapor passes through from one side of the fabric to

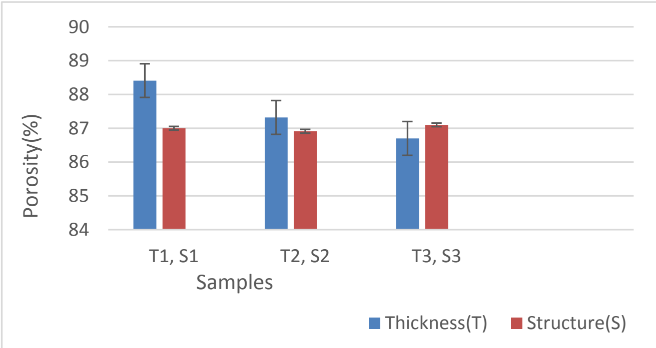

Figure 4. Porosity percentages of spacer fabrics.

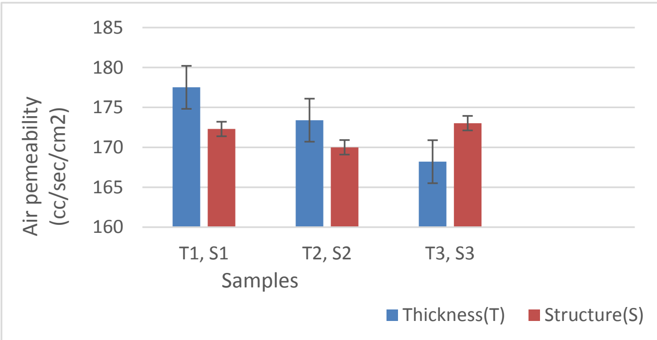

Figure 5. Air permeability of WKSF spacer fabrics.

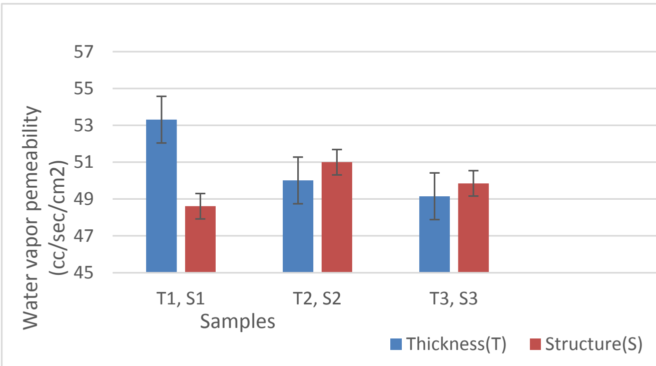

Figure 6. Shows the WVP of spacer fabrics.

the other side. As the fabric structure has more pores, it results in high porosity, good water vapor permeability. As it is seen from Figure 6, T 1 has more space and less space in T 3 holds the moisture within it, which leads to low permeability. The fabric creation also influences the moisture vapor performance. As it is seen from figure, the open structure S 2 has more water vapor diffusivity in between the surfaces and layers. The fabric structure with more pores, which results in high porosity, has good water vapor permeability. This amount of permeability indicates the property of a porous material and characterizes the passage of liquid which is forced to flow through the fabric under an applied force. The S 1 compact structure affects the water vapor permeability of the fabric significantly. The same result was also obtained in [10,18,21].

The influence of thermal properties

Thermal properties are the volume of temperature transmitted through the fabric thickness in a measured surface area. Thermal properties are affected by the fabric structure and thickness. The thermal insulation shows high response for heat conductivity and thickness of fabric [19]. Figures 7 and 8 demonstrate the influence of thickness on the thermal properties of the fabric (Figures 7 and 8).

Spacer fabric comfort property depends on the fabric thickness, and thermal conductivity was established as a vital feature leading to the thermal insulation of textiles. These results give higher fabric thickness of a spacer fabric; take more air within the middle layer which leads to higher thermal resistance. Sample T 3 has high middle layer density among the three samples; the higher sample thickness contributes more to thermal properties. Sample T 1 has low middle layer density among the three samples, less thermal resistance [19]. The samples having open skin hexagonal net structure (S 3) has comparatively lower thermal conductivity than the closed skin lock knit structure (S 1). The amount of air entrapped within the hexagonal net structure is high and it restricts the effortless conduct of heat causing minor thermal conductivity and higher thermal resistance. The same result is obtained in [20,21].

Statiscal Evaluation

The results are confirmed by Statically Analysis System (SAS) and the significant influence of the structure and thickness on fabric properties is also summarized (Table 5).

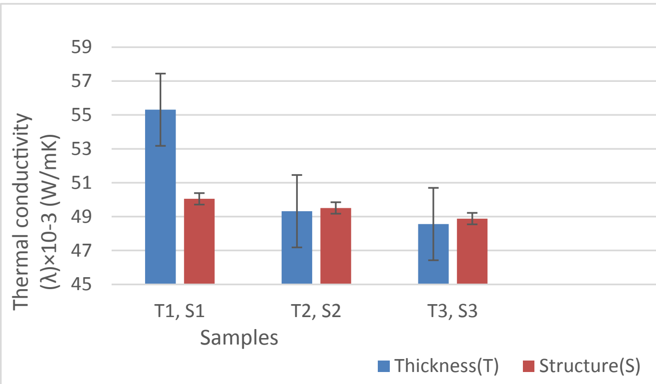

Figure 7. Thermal conductivity of spacer fabrics.

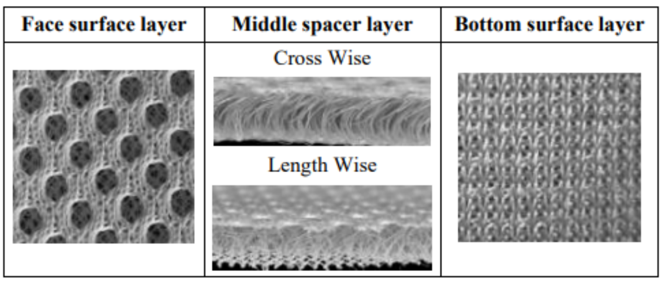

Figure 8. Nylon /polyester WKSF.

Table 5. SAS software of spacer fabric properties.

Fabric properties	Response	F_{actual}	P	DF level of significance(α)	
Porosity	T1, T2, and T3 S1, S2, and S3	127.00 199.01	<0.0001 <0.0001	6	0.05
Air permeability	T1, T2, and T3 S1, S2, and S3	594.91 1142.03	<0.0001 <0.0001	6	0.05
Water vapor permeability	T1, T2, and T3 S1, S2, and S3	13340.44 69899.87	<0.0001 <0.0001	6	0.05
Thermal conductivity	T1, T2, and T3 S1, S2, and S3	607 375.04	<0.0001 <0.0001	6	0.05
Thermal resistance	T1, T2, and T3 S1, S2, and S3	211.11 196	<0.0001 <0.0001	6 6	0.05 0.05

In statistical evaluation, SAS software is analyzed and the certain value of significance for all statistical tests in the study is 0.05 levels. The degree of freedom is 6, 14, and the $F_{critical}$ is 2.144. The outcomes of the SAS are listed in Table 6, which analyses the effect of groups of thickness and structure of spacer fabric samples with respect to porosity, thermal properties, air, and water vapor permeability. The value of $F_{critical} < F_{actual}$ proves that the change in the thickness and surface layer structure of warp-knitted spacer fabric results are highly significant to the above-mentioned fabric basic comfort properties. Even little changes in the fabric thickness have a significant impact on the fabric properties. Table 6 values confirmed that is related to thickness, the change in surface layer structure reflects a very high influence on the fabric properties. To confirm the significant range of SAS, this result shows that the warp-knitted spacer fabric samples have significant differences in porosity, air, and water vapor permeability.

Conclusion

The comfort properties of warp-knitted spacer fabrics made from polyester/nylon filaments were studied in this paper. The warp knitted spacer fabrics were applicable for shoe insoles to make comfortable than the existing PU foam. The spacer fabrics were produced from different materials with different thickness. Six samples, namely, three hexagonal structures of 100% polyester, 80/20% polyester/Nylon,70/30% polyester/Nylon with thickness of 2, 2.5, and 3mm respectively, and the other three were lock-knit structures of 100% polyester, rhombic mesh 80/20% polyester/Nylon,hexagonal 70/30% polyester/Nylon with constant thickness of 2.8 mm. Maintaining bottom surface layer as plain structure for all samples. The results discovered that the fabric thickness and porosity have a significant impact on air and water vapor permeability. Fabric porosity is the key aspect for permeability, thermal conductivity, and resistivity of warp-knitted spacer fabrics. The spacer fabric with higher thickness has higher thermal resistivity with lower thermal conductivity and lower air permeability. The fabric structure with more pores results in high porosity, good water vapor permeability. Spacer fabric with thickness 2.5 mm proves the best level of thermal conductivity with good air and water vapor permeability. Relating to the fabric face layer structure, more open or closed structures decide on the horizontal pore size of spacer fabrics. The open mesh hexagonal net structure shows good porosity than the other two structures. The results clearly demonstrate that the open structure with long loop and moderate moving number of filaments tests had good air and water vapor permeability. The SAS software shows the thickness and structure affecting the spacer fabric properties. Generally, spacer fabrics are more comfortable, recyclable, and environmentally friend when compared to the existing PU foam.

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