Determination of Comfort and Performance Properties of Upper Materials for Diabetic Footwear Construction

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Abstract

This work investigates comfort and performance properties of selected shoe upper materials manufactured in Nigeria for their suitability for diabetic footwear construction. The research was carried out using approved methods of analysis as per the International Union of the Society of Leather Technologies and Chemists Official Methods for Physical Analysis (1996). Key parameters studied include thickness, water vapour permeability, tensile strength etc, with recorded values of up to 2.23mm, 25.33mg/cm^2/h and 23N/mm^2 respectively. The results obtained were found to be similar to the findings of previous studies and in conformity to set standards. The research findings demonstrate that diabetic footwear made with selected upper leathers could improve foot health of the diabetic foot. The paper also highlights the need for further research using composite specimens of both upper and lining, soling materials and insoles in order to explore the best materials combination that may improve foot health of people suffering with diabetes.

Key Words: Footwear, Diabetic footwear, Diabetes, Shoe Upper Materials.

1.0 Introduction

A study on footwear materials was undertaking on the basis that clinicians and footwear manufacturers/ retailers have since agreed that the materials used to manufacture footwear are very important in regards to foot health (Venon 2007; Thornstensen 1993). Research has also shown that inappropriate footwear is a common trigger for foot ulceration, as it exposes the at-risk foot to direct effects of friction and /or irritation as well as indirect damage. Footwear designed with inappropriate upper materials could cause mechanical stress at the dorsal surface of the foot that might result to foot ulceration in patients with diabetes (Rizzo, et al. 2012; Bus, 2008). However, it has been shown that diabetic footwear should be designed with materials that would help to relieve pressure areas, reduce shock, and shear forces and be able to accommodate deformities by supporting and stabilizing them (Harrison , et al 2007; Ulbrecht, et al 2004).

There are wide ranges of materials which can be used in footwear manufacture such as leather, synthetic, fabric, etc. and each of this material has its own specific properties. They differ not only in their appearance, but also in their service life, physical properties and treatment required. Some of these materials are exceptional in the way in which they offer practical solutions to problems of foot comfort.

Physical properties give a glimpse into the potential advantages of any given material. Therefore, the material analysis was an attempt to investigate the physical properties of shoe upper leathers for their suitability for diabetic footwear manufacture or otherwise. These properties can be extrapolated or determined by subjecting the different materials to a number of tests such as tensile strength, water vapour permeability, etc (World Footwear 2013). The literature has shown that most research on designing footwear for people with foot problems or at risk of developing for problems has concentrated on comparing different shoes or materials rather than comparing the basic physical characteristics of the materials that are used (Goonetillete 2003). Therefore in this study, basic physical and foot-comfort properties of shoe upper materials were analysed.

Although currently there is a widespread replacement of leather with synthetics (man-made materials) as solings in almost all types of footwear, leather is still considered by far the most widely used upper material. However, other materials like coated fabrics and poromerics are excellent in regards to water repellency and resistance, but because foot comfort depends on absorption of foot perspiration and its transmission through the upper, some of these materials are not satisfactory (Harvey 1992).

Footwear upper materials are described as the materials forming the outer face of the footwear which covers the upper dorsal surface of the foot and attached to the sole assembly (see fig. 1). And as already known, leather is a generic term referring to a material made from hide or skin of a vertebrate through tanning processes which renders it non-putrescible under warm moist conditions (Covington 2009; Kite & Thompson 2007; British Standard, 2005). Leather is the most used natural material for footwear making because of its breathing and insulating properties and is able to adjust to an individual's foot shape. (Bata 2013; Rahimifard, et al 2007). Nonetheless, there could be wide variations of these desired properties from one type of leather to another and dissatisfaction with prescribed footwear is also thought to stem from improper fit, materials, unacceptable appearance, etc (Ferguson 2012).Therefore, in this research, comfort and performance properties of shoe upper leathers were investigated to determine their suitability for diabetic footwear construction or otherwise.

Fig. 1 Anatomy of footwear. Available from: http://gluxus.com/wp-content/uploads/2013/07/parts-of-shoe.jpg

2.0 Materials and Methods

With leather being a non-homogeneous material, performance tests have an important role to play in assessing its quality. Depending on the end-use and types of leather, a wide range of tests based on visual, physical and chemical could be carried out in a testing laboratory. In this experiment, certain comfort and physical/ performance characteristics of shoe upper leather samples were determined.

The physical properties were determined as per standard methods under specified temperature and relative humidity. Prior to testing, the samples were conditioned in a standard atmosphere of 20^{o}C, 65% R. H for 48 hours. The experiments were conducted at the Standards Organization of Nigeria Textile/ Leather Laboratory, Kaduna, from May to June, 2013. The samples of shoe upper leathers were collected from different leather Companies, Kano and standard dimensions for various physical tests were obtained as per the International Union of the Society of Leather Technologist and Chemists Official Methods of Analysis (1996).

Table 1.0 gives the different tests carried out, the methods or procedures adopted and the equipments used.

Table 1 Tests conducted and methods of analysis

S/No.	Test/ Parameter	Method of Analysis	Equipment
1	Determination of thickness of shoe upper material	IUP/4. 1996	Wallace Thickness measurement gauge; Ref:S4/9, Serial No. 82/8. Made in England.
2	Determination of Apparent Density	IULTCS/ IUP 5: 2001	1.Wallace Thickness measurement gauge; Ref:S4/9, Serial No. 82/8. Made in England. 2. Mettler Weighing balance: Type-AE 200-S. Made in Switzerland.
3	Determination of Water Vapour Permeability	IULTCS/ IUP15: 2001	MUVER-WVP equipment. Mod-5011; No. 01556; 2007.
4	Determination of Tensile Strength & Elongation at Break	BS 2576: 1986/ IULTCS/ IUP 6: 2001	SMS material tester. Model SP 2-4300, USA New Jersey.
5	Determination of grain crack & burst of shoe upper materials	IUP/9	Muver Lastometer equipment. No. 01555; Mod-5077 ET. 2007

3.0 Results and Discussion

3.1 Results

Tables 2 - 6 provide the results of the experimental analysis of different samples of shoe upper materials.

Table 2: Result of determination of thickness of shoe upper materials.

Sample		1st Position (mm)	2nd Position (mm)	3rd Position (mm)	Avg. (mm)
U_1	1a	1.26	1.10	1.10	1.15
	1b	1.19	1.12	1.17	1.15
	1c	1.70	1.12	1.15	1.32
Avg. (mm)					**1.21**
U_2	2a	1.90	1.85	1.90	1.88
	2b	1.86	1.84	1.75	1.82
	2c	1.80	1.85	1.75	1.80
Avg. (mm)					**1.83**

U_3	3a	1.90	1.92	1.90	1.90
	3b	1.85	1.90	1.90	1.88
	3c	1.90	1.90	1.87	1.89
Avg. (mm)					**1.89**
U_4	4a	1.92	1.92	1.90	1.81
	4b	1.92	1.90	1.91	1.91
	4c	1.90	1.91	1.90	1.90
Avg. (mm)					**1.87**
U_5	5a	2.15	2.12	2.10	2.12
	5b	2.35	2.50	2.45	2.40
	5c	2.16	2.27	2.12	2.18
Avg. (mm)					**2.23**

Table 3: Result of determination of apparent density

Sample	**Thickness (mm)**				**Weight (g)**				**Apparent Density (g/cm^3)**
	1	2	3	**Avg (mm)**	1	2	3	**Avg (g)**	
U_1	1.15	1.15	1.32	**1.21**	1.92	2.0	1.92	**1.95**	**0.26**
U_2	1.88	1.82	1.80	**1.83**	1.33	1.40	1.40	**1.38**	**0.14**
U_3	1.90	1.88	1.89	**1.89**	1.40	1.54	1.39	**1.44**	**0.15**
U_4	1.81	1.91	1.90	**1.87**	1.20	1.25	1.23	**1.25**	**0.13**
U_5	2.12	2.40	2.18	**2.23**	3.70	3.10	3.90	**3.57**	**0.37**

Table 4: Results of Water Vapour Permeability and Water Vapour Absorption.

Sample	**Weight loss (mg)**	**Weight gain (mg)**	**Water Vapour permeability ($mg/cm^2/h$)**	**Water Vapour Absorption (mg/cm^2)**
U_1	1.02	0.50	19.14	28.15
U_2	0.82	0.08	15.39	4.50
U_3	0.53	0.48	9.94	27.02
U_4	1.35	0.29	25.33	16.32
U_5	0.17	0.65	3.19	36.59

Table 5: Result of Determination of Tensile Strength (N/mm^2) & Elongation at Break (%).

Sample	Parallel				Perpendicular			
	Force (N)	**Displ. (mm)**	**% Elong.**	**Tensile Strength (N/mm^2)**	**Force (N)**	**Displ. (mm)**	**% Elong.**	**Tensile Strength (N/mm^2)**
U_1	188.74	33.02	46	15	161.33	34.11	65	13
U_2	95.29	14.91	57	19	67.79	16.78	48	17
U_3	223.39	25.50	61	21	160.66	30.75	81	22
U_4	189.55	30.88	50	17	145.27	19.10	32	14
U_5	488.25	40.41	76	23	459.57	40.56	29	20

Table 6: Result of measurement of distension and strength of the grain by the ball burst test.

Sample		**Crack**		**Burst**	
		Load (N)	**Displacement (mm)**	**Load (N)**	**Displacement (mm)**
U_1	1a	135.9	10.62	287.7	10.33
	1b	152.3	11.84	305.7	10.59
	1c	289.7	9.83	316.1	10.41
Av.		**192.63**	**10.76**	**303.16**	**10.44**
U_2	2a	322.7	10.99	337.4	11.15
	2b	262.4	10.75	284.0	11.04
	2c	242.3	9.56	324.8	10.37
Av.		**275.8**	**10.43**	**315.4**	**10.85**
U_3	3a	464.4	10.27	478.2	10.40
	3b	432.4	10.75	533.6	10.68
	3c	449.0	10.44	496.4	10.79
Av.		**448.6**	**10.48**	**502.3**	**10.62**
U_4	4a	249.7	8.36	419.7	9.69
	4b	242.6	8.45	391.4	9.68
	4c	167.9	7.99	360.0	9.85
Av.		**220.0**	**8.26**	**390.3**	**9.74**
U_5*					

*Ball burst test was not done on U_5 because its thickness was above the scope of this test.

3.2 Discussion

This paper provides data that give insight on how materials properties can differ significantly one from another and how a careful selection of materials based on their comfort and performance properties could have far reaching benefits in terms of foot health. Explanation of the outcome of the research and its implications are therefore outlined in this sub-section.

Table 2 shows that thickness of a piece of leather can differ significantly because it is recognized that measured thickness of leather depends upon such factors as the pressure and the time for which pressure is applied. Even though the time for the test and the pressure applied was kept constant, it was discovered that sample U_5 has the highest average value (of up to 2.23mm) and sample U_1 has the lowest average value of 1.21mm. Furthermore, it was observed that the thickness of the leather samples have appreciable influence over other determined parameters.

The apparent density of the tested materials presented in table 3 ranges from 0.13 to 0.37. Since the apparent density of a material gives an estimate of the fibres and air spaces in a material, it then means that sample U_5 have more air spaces compared with the result obtained for sample U_4. However, Clarke (2010) points out that the apparent densities of leathers vary widely. Cowhide leathers may be grouped approximately as follows: vegetable tanned sole leather range from 0.95-1.05, vegetable tanned leather other than sole leather range from 0.80 to 0.90, and unwaxed chrome-tanned leather range from 0.60 to 0.70.

Another important test carried out is the water vapour permeability (see table 4) The literature point out that moisture related tests are very useful in determining comfort of shoes made with leather, because during walking, foot temperature increases owing to rubbing between the shoe and foot. As such moment, the skin produces perspiration from sweat glands to reduce body temperature (Covington 2009). The most frequently used test to measure the comfort properties of shoe upper leathers are the water vapour permeability, water absorption, and the dynamic water penetration. In this work, water vapour permeability/absorption test was carried out to assess the comfort properties of the shoe upper leather samples.

According to SATRA Standards (1999) if the water vapour permeability of a test material is higher than 5.0mg/cm/h, then it is classed as having 'very good' permeability for footwear. In addition, Harvey (1992) points out that a permeability value of 2mg/cm^2/h is recommended for satisfactory foot comfort. Based on this, the result of sample U_4 and U_1 with values of 25.33mg/cm/h and 19.14mg/cm/h respectively are considered very excellent. Samples U_5 and U_3 have the lowest values of 3.19 and 9.94mg/cm/h respectively.

Good water vapour permeability property of shoe upper materials (also known as ventilating properties of leather) helps in the dispersal of perspiration and makes an important contribution to foot comfort and hygiene. This is an important factor of consideration because footwear has its interior in close contact with a mobile, warm and perspiring part of the human foot while its exterior may be subjected to cold, heat, rain, very dry air, snow or wet grass (Xiaosheng 2012). It can be explained as the ability of a material to transmit water from one side to the other in the form of vapour. On the other hand, water vapour absorption refers to how much of that vapour is retained by absorption within a material structure. The material holds the moisture by its molecular structure and the water cannot be physically squeezed out before its saturation with moisture. Absorption is considered a 'stand alone' moisture disposal mechanism because it is not depended upon other factors for comfort. However, once the absorption capacity of materials is reached (saturated) water will remain as a liquid and the foot will become damp and uncomfortable (Tailby, et al 2002).

It has been shown that this factor (comfort) along with the ability to shape to the foot has been the main reason for choice of leather for shoes. But comfort is a complex perception that relies on many sensations. With respect to moisture disposal, absorption by the upper materials is perhaps as important as the permeability-because this will ensure that the wearers' feet remain dry (Rose, et al. 1992; Thorstensen 1993).

Covington (2009) and Thorstensen (1993) explain that one of the most desirable properties of leather is its ability to transmit moisture. However, its properties depend on the origin of the raw material, how the pelt is prepared for chemical modification, how that modification is conferred chemically, how the leather is lubricated and how the surfaces are prepared. Previous research reported that the water vapour permeability (WVP) of coated leather (e.g with PU) decreases by 30-50% compared with uncoated or unfinished leather. To improve wear comfort and hygienic properties of shoe upper materials, leather coating with very high WVP has become very important. Researchers reveal that thinner skins of calf or split cowhides that are tanned with chrome provide upper leathers with high foot comfort properties (Yi et al. 2010).

Everyone accepts that the comfort provided by leather articles is linked to its ability to combine breathing and insulating properties. Whereas leather may pass water vapour through but resist liquid water penetration, same thing cannot be said about synthetic materials which usually give negative results in regards to water vapour permeability. The implication of this is that most synthetic materials do not allow water vapour to pass through. The good air and vapour permeability of leather is also linked to its numerous pores found both in the fibrous network and between the collagen molecules (Phebe, et al. 2010, Tagang 2010; Covington 2009). The ability of leather to transmit water vapour is one of the key properties which make it a desirable material for footwear construction. It takes out perspiration from the foot by absorption which is followed by evaporation from the footwear. This usually leads to increased comfort for the wearer. It is concluded that the higher the permeability of the upper material the better its ventilating property.

The results presented in table 5 further prove that leather has a difference in strength in the length and width direction. According to Volken (2013), leather has two directions of stretch, strong or tight along the direction of the backbone and weak or loose across the belly. The tensile strength is generally greater when it is determined in a direction parallel to the backbone because the orientation of the fibers is predominately in this direction. In addition, leather has a difference in these characteristics, depending upon the section of the hide from which it is cut. To make a pair of footwear that fits correctly, the upper patterns must therefore seek to accommodate these physical constraints and the proportions of the human foot. Furthermore, material with good stretchability has been shown to adjust to feet easily (Bata 2013).

The data from this research this indicates that the values of the tensile strength obtained by the parallel measurements were observed to be generally higher than the corresponding values for the perpendicular. This is consistent with information from the literature (Volken 2013; Marsal 2004). The highest tensile strength recorded in this experiment is 23N/mm^2 which corresponded to sample U_5 and the lowest is 15N/mm^2 (corresponding to sample U_1). Contrary to tensile strength, the highest values for percentage of elongation at break are higher in the perpendicular direction than in the parallel direction. From table 5 it is clear that the highest percentage of elongation is 81% (U_3, perpendicular) and the lowest value is recorded against sample U_5. Generally, the elongation for light upper leathers may range from 10-30% that for heavy leathers is in the range of 35-85%. Any value below this indicates poor fiber quality or degradation. This present experiment values fell between 29 to 81%.

In addition, the grain crack/ burst test was carried out by applying pressure on the leather sample until cracking of the grain occurred (see table 6). The load and distension registered gives a measure of the leather's resistance. This test is used to know the force required to break the grain of upper leather. One of the key advantages to using this test is that it gives an average value for the strength of a material in all directions. To keep grain cracking in lasting to a minimum, it is recommended that the average distension of new, unlasted leather should be at least 7 mm.

4.0 Conclusion

The choice of footwear material significantly influences foot comfort. In this study, leather samples were analysed to show how physical properties of upper leathers can differ appreciably one from another. Generally, the results obtained were found to be similar to the outcome of previous studies and in conformity to set standards. This study further shows that a thorough knowledge of the physical properties of materials used for making footwear would help to identify materials that could improve comfort and safety to the wearer.

The authors suggest that further investigations using composite specimen of both upper and lining, soling materials and insoles to establish the best material combination that may improve foot health should be investigated.

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