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Development of Polyurethane (PU) Memory Foam in Sock for Diabetic Foot Ulcer Patients in Ethiopia

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Abstract

Foot ulcer is mainly developing due to diabetic disease. It is an open sore on the foot. The aim of this research is to develop polyurethane memory foam insock in Ethiopia by replacing costly material silicon surfactant and distill water by locally available and affordable input materials castor oil as surfactant and tap water instead of distilled water for the diabetic foot ulcer patients. Under this research, it was able to prove the severity of foot ulcer in Ethiopia and enhance the high demand of orthotic appliance. Three memory foam insock with different surfactant ratios were manufactured at AMAGA P.L.C foam factory, Bahir Dar Ethiopia, using standard Polyols and diisocyanates. The in sock was prepared by using materials used in the factory to prepare PU memory foam mattress with 5 g, 9.5 g and 10.36 g of castor oil surfactant amount as a new replaced material instead of costly silicon surfactant from the three, the first castor oil (5 g) is not form a foam and hence no further investigation is conducted on it. Physical properties such as thickness, density, Hardness, Compression set, water absorption and abrasion resistance of developed in sock were tested. Further the new developed in sock was compared with that of existed commercial polyurethane in sock and the SATRA standards. The new developed insock has showed an equivalent mechanical property with the standard.

Keywords: Memory foam • Foot ulcer • Diabetic • Polyurethane • Castor oil

Introduction

Foot ulcer is a term that references an open sore that forms on or near one or both of our feet. It may form on the bottom of the foot, the toes, and the top of the foot or even the lower region of the leg mainly caused by diabetic disease [1]. According to research result shows about 15% of diabetic patients develop foot ulcers in their lifetime enhancement [2]. Diabetic foot ulcer is becoming major concern of diabetic patients. People with a Diabetic Foot Ulcer (DFU) have a 40% greater 10-year death rate than people with diabetes alone. Foot ulcer problems with diabetic patients account for up to 15% of healthcare resources in developed countries and 40% in developing countries and one in every six people with diabetes will develop ulcer [3].

Poverty and unhygienic conditions associated with foot ulceration are major factors contributing to development of the diabetic foot in developing countries like Ethiopia. For diabetic patients living at or below poverty line, the purchase of appropriate footwear (orthopedic footwear) might not be affordable, feasible or of high priority. For diabetic foot ulcer patients and people who are overweight, extra pressure may be the cause of ongoing foot pain/ulcer but by using/wearing orthopedic footwear appliance can be redistribute evenly and the development of ongoing foot pain/ulceration development retards.

The, knees, and back are just some of the body parts that can be adversely affected by improper posture or gait. Orthotics address this by spreading the pressure evenly around our feet, and making sure that they hit the ground at the right angle, which is why it is so important that cushion memory foam in sock is a need in redistribute our pressure by absorbing shock. Inappropriate footwear and inappropriate insert can have a large share in contributing factor to the development of foot ulceration [4]. In the research of diabetic patient's foot ulcer diagnosis, footwear with cushion in sock has been implemented to reduce pressure on the foot of diabetic patients, and then its pain status and its result showed very good progress of pain reduction.

Today Memory foam shoe inserts is available commercially at high cost and its source for foot ulcer purpose is imported from developed Countries at high cost. This leads low access, and unable to be used by the low-income patients due to higher cost and consumption of expensive raw materials for production of PU insock [5]. Hence replacement of castor oil surfactant and tap water in the place of silicon surfactant and distilled water respectively is an

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optional cost effective way of (PU) Memory in sock production.

Polymer elastomers and foams are widely used to meet the material properties of insole and in sock. Among various polymers, Ethylene Vinyl Acetate (EVA), Polyurethane (PU) and rubber based materials are widely used in footwear. PU foams and elastomers are proved as the most effective materials for shock absorption in footwear while most are effective when new; the softer foam materials tend to deteriorate rapidly with use. Different types of foam are available commercially at high cost [6]. But the available materials are not scientifically characterized and optimized for composition of PU for application as insole for treating foot abnormalities. PU viscoelastic cushion in sock will reduce the foot plantar pressure and give additional cushion support to the foot arches.

Therefore, new PU memory foams were developed for application as insoke in therapeutic footwear for patients with diabetes. The developed materials were characterized for physical and mechanical properties and PU foam composition was also optimized for application as cushion insock [7]. The purpose of this study was developing Polyurethane (PU) Memory Foam In sock and the developed materials were characterized for physical and mechanical property and PU foam composition was also optimized for application as cushion in sock.

Materials and Methods

In this study the Polyurethane (PU) Memory Foam In sock was prepared by using standard Polyols, HT, and Isocyanates-Toluene di Isocyante (TDI) castor oil, methyl chloride was obtained from research grad textile and leather laboratory. Other additive and auxiliary such as Tin, Thertialy, cross linker, Catalyst, Inorganic filler and cell opener which are physicochemical and environmentally safe were used. The following chemicals specification were derived from AMAGA, P.L.C. Bahir Dar bed foam manufacturing used for Polyurethane (PU) Memory Foam formation at different concentration of castor oil (Figure 1).

Component		Sample-1	Sample-2	Sample-3
No.	Ingredients used	Weight added in (g)	Weight added in (g)	Weight (g)
1	Polyols HT, 762	93.3	93.3	93.3
2	Tap water	2 × 2.6	2 × 2.6	2 × 2.6
3	Castor oïl surfactant	5	9.5	10.36
4	Tertiary amine catalyst	1.7	1.7	1.7
5	Tin catalyst	1.37	1.37	1.37
6	Cross linkers	8.4	8.4	8.4
7	Isocynates, TDI	75.5	75.5	75.5
8	Auxiliary blowing agents	4.7	4.7	4.7
Total consumption	-	199.67 g	199.67 g	200.5 g

Table 1. Bill of raw materials for three pair of in sock sample production.

Experimental procedure for foam manufacturing

Polyols, reacting agents and tap water were mixed, and stirrer at 30°C temperature for 14 seconds. Isocyanates-toluene Di Isocyante (TDI) was added and again stirrer for 15 seconds to make sure the reactant was well reacted to their perspective bond. After all, the product was whipped into froth and poured into a mold (test box). An exothermic reaction was resulted which caused the mixture to bubble up and produce foam. The final product foam was cured and takes to store for 8 hours. After curing, memory foam was inert (no longer reactive) and for in sock application, the foam was cut by die for next application.

Physiochemical characterization

Type of foams with varying density and cushion ability were developed by varying the concentration of surfactant (castor oil). The developed foams were characterized for thickness (mm), density (g/cc) hardness (mg/L), water absorption (%) compression set (%) abrasion resistance and pressure redistributing properties of the in sock were required by the material for application as cushion in sock in therapeutic footwear for patients with diabetics.

Plantar pressure distribution test

The plantar pressure reduction and distribution properties of the developed in sock, foam was measured using carbon copy pressure measurement system, and then related with that of Ethyl Vinyl Acetate (EVA) in sock which was conducted at Leather Industry Development Institute (LIDI) and Ethiopian institute of Textile and Fashion Technology (EiTEX) research laboratory with ELETTROTECNIC A.B.C machine at 7 bar pressure and analyzed the effect due to the material changes.

Results and Discussion

The physico mechanical properties of PU memory foam are presented. It has shown that the initial formulation of PU memory foam in sample 1 is not foam but as a thick liquid this is due to very low amount (5 g) of castor oil as a surfactant is used due to this no further study is done on it and sample 2 is not suitable for application as cushion insock for Diabetic foot ulcer due to low hardness, density and low compassion but sample 3 shows a very good properties.

Density

During measuring density, by taking similar thickness of PU memory foam in sock and size. The density test resulted of samples are presented. The test result value for sample 2 was 0.194 g/cm^3 and 0.22 g/cm^3 for sample 3. Hence, sample 3 found between 0.2 g/cm^3-0.3 g/cm^3 which is in between SATRA density standards requirements as results show density of PU memory foam in sock which is the newly developed sample 2 is slightly lower than that ofexisted in sock but approximately confirms the standard, in case of Sample 3 it is much harder than that of sample one but it is still within the range of standard. If the density is below standard requirements the insock will compressed and sticky during use and if it is too high, itconsumemore material

and become costly and less comfort. Material with higher density the higher the load bearing capacity, this implies that the sample 3 has remarkable load bearing capacity and support. Therefore, the replacement of materials silicon surfactant by castor oil surfactant and distilled water by tap water shows a positive effect in this particular property (Table 2).

No.	Properties	Obtained value			
		Sample 2	Sample 3	Commercial insole	SATRA sandaled
1	Density (g/cc)	0.194	0.22	0.253	0.2-0.3
2	Hardness (mg/L)	19.25	21.09	44747	17-22
3	Thickness (mm)	11	11.5	8	13-14
4	Abrasion resistance (%)	2.98	2.62	6.9	-
5	Compression (%)	3.82	4.2	6.1	5
6	Water absorption (%)	63	52.5	39	30

Table 2. Physical test results of PU memory foams.

Hardness

The mean value of hardness was shown is 19.25% of the new developed Polyurethane (PU) memory foam insock of sample 2 and 21.09 for sample 3 is obtained within the standard range in SATRA test method, and greater than that of existed PU foam in sock. The failing of the test result below standard requirement leads the product strength somewhat poor. In contrary, if this property is above standard it will be less flexible and comfort so, it should be between standard requirements. The only difference between in sample 2 and 3 is due to using of different amount of surfactant (castor oil). Therefore, the new product in this research shows the product have fulfilled the standard requirement and are acceptable

Thickness

The recipe of the chemicals/materials including the new surfactant material, castor oil and tap water is formulated based on SATRA standards and Amaga foam factory in Ethiopia materials to produce 11 mm foam insock thickness and then manufactured it [8]. After developing the products sample 2 and 3 the mean value of both sample thickness showed uniformity of the developed insock. Therefore, as the new research result shows it is possible to manufacture these products with uniform thickness.

Compression set

Elastic properties of the in sock was conducted for both sample 2 and 3 each and all of the test resulted for sample 2 in average is 3.82%, which is within standard requirement. In case of sample 2 are 4.2% which is also between the standard and it value is greater than that of sample 1. The commercial/existed normal foam insock valueis 6.1, which is not fit with standard requirements, this shows that just commercial in sock is not good for diabetic foot ulcer patients foot ulcer treatment due to lower elastic property than that of standards [9-12]. This leads the product to have lower comfort particularly in this property because orthopedic shoe appliance need to be more flexible and comfort for foot ulcer patients and Products with good compression set has good comfort.

Abrasion test

The purpose of testing of this property is to know its resistance to abrasion because during wearing the insock will rub between our feet and the shoe sole/insole, so it needs to have very good Abrasion resistance. To know this property of the insock experimental test in abrasion resistance of normal PU Foam and that of the new developed foam insock were conducted. From these as result shown the PU memory foam insock abrasion resistance resulted is very good than that commercial foam value because it has less amount of weight loses due to abrasion than that of normal PU foam [13]. This implies that the newly developed memory foam insock will resist any forces that rub it by that it will have longer life span than commercial PU foam/insock however; sample 3 is lower than that of sample 2 because in sample one is low density due to lower amount of surfactant (castor oil) use.

Pressure redistribution test of the in sock

After the pressure reduction and distribution properties of the developed in sock was measured at Leather Industry Development Institute (LIDI) Addis Ababa, Ethiopia. The Ethyl Vinyl Acetate (EVA) and the new developed memory foam in sock carbon test results are presented in Figure 1.

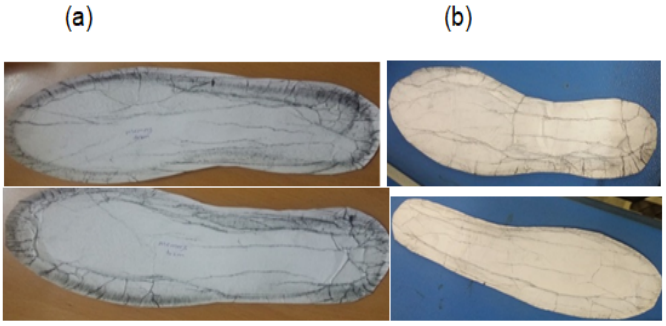

Figure 1. Comparison of (a) carbon copy test result of EVA; (b) Memory foam in sock.

The contact area (points) of carbon on in sock were almost the same but, the picture of test results of memory foam in sock slightly greater than that of EVA in sock, this implies that, our foot contact to in sock during wear is also higher. Therefore, if the contact area is higher it reduces our body pressure and redistribute it to the ground by this it reduces foot ulcer pain. Pressure from walking can make an infection worse and an ulcer expand [14]. For people who are overweight, extra pressure may be the cause of ongoing foot pain but by using/wearing orthopedic footwear with memory foam cushion in sock/insert our body pressure during walking can be redistribute evenly and the development of ongoing foot pain plus its ulceration development retards because in socks can increase contact areas of our feet and then decrease our pressure.

Conclusion

Foot ulcer is an open sore mainly on the bottom of our feet caused by diabetic disease. Therapeutic shoe with appliance (in socks) like Polyurethane (PU) memory foam in sock plays a great role in retarding foot ulcer. The in sock which was prepared by using materials used for preparing PU memory foam mattress with 5 g, 9.5 g and 10.36 g of castor oil surfactant, the third one was showed better comfort properties and the first one was unable to be foam but it remains as a thick liquid. In this research the new in sock was developed, at low cost by including less cost and locally available surfactant materials (castor oil) instead of costly silicon surfactant and tap water instead of distilled water. In the field test at Adina's hospital, Bahir Dar Ethiopia implies a very good comfort, and very good pressure reduction ability Therefore, from this study the newly developed in sock showed good futurity for foot ulcer patients and solve limited access problem by affordable price through manufacturing it locally.

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Conflict of Interest

The author declared that they have not conflict of interest.

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