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Material Selection for Footwear Insole Using Analytical Hierarchal Process

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Abstract**—**Product performance depends on the type and quality of its building material. Successful product must be made using high quality material, and using the right methods. Many foot problems took place as a result of using poor insole material. Therefore, selecting a proper insole material is crucial to eliminate these problems. In this study, the analytical hierarchy process (AHP) is used to provide a systematic procedure for choosing the best material adequate for this application among three material alternatives (polyurethane, poron, and plastzote). Several comparison criteria are used to build the AHP model including: density, stiffness, durability, energy absorption, and ease of fabrication. Poron was selected as the best choice. Inconsistency testing indicates that the model is reasonable, and the materials alternative ranking is effective.

Keywords**—**Materials selection, biomedical insole, footwear insole, AHP.

I. INTRODUCTION

THE foot is an important part of human lower limbs because of its special role in weight bearing and human body mobility. The selection of appropriate material of footwear insole can help of reducing the occurrence of foot problems such as plantar ulceration (corn soreness) or heel-strike impact. Also, it provides stability for the individual during walking or running. It is desirable to include flexible materials which conform to foot arches, absorb shock, and store elastic energy. Thus, polymeric materials with high stiffness property are the best candidates for this product (footwear insole) [1]-[4].

The footwear sole materials' characteristics have been the focus of many research studies. For example, [5] presented the variation of the mechanical properties with temperature for eight of the most commonly used elastomeric foams. Sun et al. [6] conducted a compression test to investigate the deformation characteristics of thermoplastic elastomer (TPE) and silicone materials of heel cushions. Gnanasundaram et al. [7] studied the polyurethane material characteristic for controlling the microorganisms.

Even though, many research papers have been done in the past on materials' sole characteristics, a simple technique is required to enclose the best material selection among the wide variety of materials used in the foot wear sole. Reviewing the literature, no work has been done regarding the use of multi criteria decision making methods (MCDMs) for footwear insole materials selection. Therefore, this study has been done to address the lack of research in this area using AHP decision making method. In this study, the criteria that will be considered to select the appropriate footwear insole include: density, stiffness, durability, energy absorption (the ability to withstand repeated loading), and ease of fabrication.

II. LITERATURE REVIEW

A. Studies on Footwear Insole Materials

Understanding biomechanics of lower limbs is crucial to select the appropriate material of footwear insole among the wide existing alternatives. Therefore, some researchers had studied the stress distribution on the foot during gait cycle. For example, [1] investigated the effect of total contact insoles (TCI) on the foot plantar pressure with two different types of insole: The first type is TCI-1 that consists of poly plastic types (PPT) material in the top layer, microcell puff in the middle layer, and the thermo cork in the bottom layer. The second type (TCI-2) consists of two layers, the top layer is from medium plastzote material, and the other is from PPT. They generated a finite element foot model using Menat v.3.2 program (Msc.los Angeles, CA, USA). The study results showed that the peak and mean plantar pressure were significantly reduced at metatarsal region, and heel region, but they were redistributed at the middle foot region when the person used TCI-1 or TCI-2 insole.

The reaction force on the foot was the focus of many studies. For example, [2] used a combination of experimental and numerical methods to examine the ground reaction force effect on the heel tissue during the heel strike phase in a gait motion. This study was based on comparing results between the bare foot and the shod foot. The study pointed out that the mean value of a normal force for the bare foot was 0.8 BW, whereas it was 0.6 BW for the shod foot. Also, [3] developed a finite element method for foot-ankle to simulate the interaction effects between the foot and boot. It is worth to inform that all previous listed studies were performed under healthy ambulating activity conditions.

In the past, many researchers investigated the footwear insole materials characteristics; such as: water absorption, stiffness, and resilience. Some studies investigated the material characteristics under environmental and body conditions such as increasing temperature due to repetitive loading during walking, other studies concern with materials for heel cushion. For example, [5] performed quasi-static compressive and shear force material test at various temperatures using a Tinus Olsen (H1KS Model) test

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apparatus. They observed that the material mechanical properties depend significantly on temperature variations, where the temperature increase will cause the material to soften, which causes a reduction in the materials compressive and shear stress at a specific value of strain. Also, the study showed that the temperature decrease is accompanied with an increase of the energy absorption capability of the foam materials due to the reduction of foam stiffness.

Sun et al. [6] performed a compression axial test with 20 loading –unloading cycles, and found that the stored energy in thermoplastic elastomeric material (TPE) is proportional to its thickness, but it is inversely proportional to hardness. Also, it was found that the silicon material would preserve more strain energy with increasing its hardness. Moreover, the silicon was affected by changing the hardness more than TPE.

In literature, it had been documented that the polyurethane (porous viscoelastic) material can be modified by coating its surface with antimicrobial agent, which increases its water absorption characteristic [7]. In terms of density, it had been documented that poron (0.23 g/cm^3) has a higher density than plastzote (0.024 g/cm^3), while polyurethane material has a density of 1.4 g/cm^3 approximately [8]. Moreover, poron can be combined with firm and soft plastazote to significantly reduce the plantar pressure from its reported value on bare foot [9].

Cheung et al. [10] studied the influence of several design factors; including: arch type, insole, midsole thickness, insole and midsole stiffness on plantar pressure reduction based on Taguchi and finite element methods. They pointed out that insole stiffness is the second most important factor (after arch type).

Table I shows a summary of some of the previous researches that studied footwear insole material, and some of the factors that affect their properties. Therefore, Table I was used to evaluate importance of each criterion in the developed AHP model.

TABLE I
SAMPLES OF PREVIOUS RESEARCHES THAT STUDIES INSOLE MATERIALS AND SOME OF THE FACTORS THAT EFFECT ON THEIR PROPERTIES

Author/year	Key findings
Chen et al. (2003) investigated the effects of total contact insoles on the plantar stress redistribution [1].	-TCI used rather than flat insole - Both types of total contact insoles reduced the plantar pressure at metatarsal & heel region, but redistribute it at midfoot region.
Fontella et al. (2012) investigated the interaction forces occurred between foot and footwear during the heel strike phase [2].	-Diabetic poron heel pad can reduce the normal peak stress during heel strike phase efficiently.
Shariatmadari et al. (2012) studied the effect of temperature on the mechanical properties of the eight commonly used elastomeric foams [5].	-The material foams will soften and both its compressive and shear strength will be reduced with increasing temperature. -The foams' material energy absorption capability increased with decreasing temperature.
Sun et al. (2008) investigated the deformation characteristics of common heel cushions [6].	-The stored energy in thermo plastic elastomeric material (TPE) is proportional to its thickness, but it is inversely proportional to hardness -The silicon material would preserve more strain energy with increasing its hardness.
Gnanasundaram et al. (2013) developed a new insole materials based on porous viscoelastic polyurethane sheet to control foot infection and odor [7].	-The polyurethane sheet coated with antimicrobial agent has higher water absorption property than polyurethane material.
Jasper et al. (2010) investigated the amount of pressure reduction for different padding and insole materials that is commonly used in the podiatry clinic [9]	-Poron was rated as the best insole material in terms of shock absorption, and its' capability of precipitation resistant. -Composite of poron and plastazote showed desirable and good damping property. Also, it reduces the peak pressure more than a pure poron or a pure plastzote. -Plastzote is harder than poron and more resilient, so it would be ideal for durability to the shape of the foot.

B. Analytical Hierarchy Process (AHP)

The Analytical Hierarchy process is one of the most used decision making tools in problems involving the selection of the best alternative among a wide variety of existing alternatives because of its simplicity and goodness of discriminating the considered alternatives. It was developed by Saaty in early 1970's. It was used in a wide variety of applications, including materials selection. For example, Erbasi et al. [11] applied AHP for tractor body material selection. Milani et al. [12] applied the AHP on nonmetallic gear material selection. Rao [13] used AHP to compromise the ranking method for material selection of metallic bipolar plates for electric vehicles polymer electrolyte fuel cell

III. METHODOLOGY

The implementation of AHP method was done utilizing Expert choice software package in five different phases which construct the hierarchical model, criteria pair-wise comparison, alternative pair-wise comparison, inconsistency testing, and then compute the total weight of alternatives. Thus, it determines the final rank and selects the alternative with the highest weight.

A. Model Construction

Three levels hierarchical structure was built for the footwear insole materials selection problem. The top level of the hierarchy represents the goal which is choosing the most appropriate material. The second level consists of the used criteria in the selection process whereas the different alternative materials to be assessed were placed at the lowest level of the hierarchy. Fig. 1 shows the used hierarchical structure for the selection problem of the footwear insole materials.

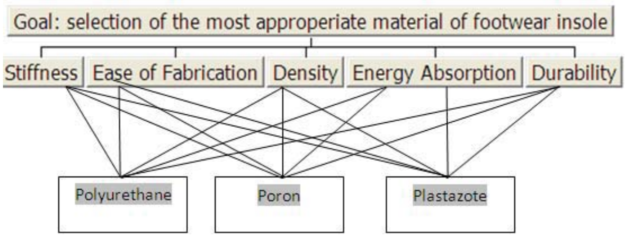

Fig. 1 AHP Hierarchy model of foot wear insole material selection

	stiffness	durability	energy abs	density	ease of fab
stiffness		3.44	2.19	1.66	5.33
durability			2.66	1.92	3.49
energy absorption				1.35	4.68
density					4.31
ease of fabrication	Incon: 0.02				

Fig. 2 Multi criteria comparison matrix

B. Criteria Pair-Wise Comparison

The five criteria were compared against each other with respect to their importance for achieving the main goal (selecting the best material for footwear insole). Saaty scale was used to show the relative importance of the criteria. Expert choice software was utilized to perform this comparison. In this respect, the descending order of the criteria is: stiffness, energy absorption, density, durability, and ease of fabrication. The comparison matrix and the criteria weight comparison bar diagram are shown in Figs. 2 and 3, respectively.

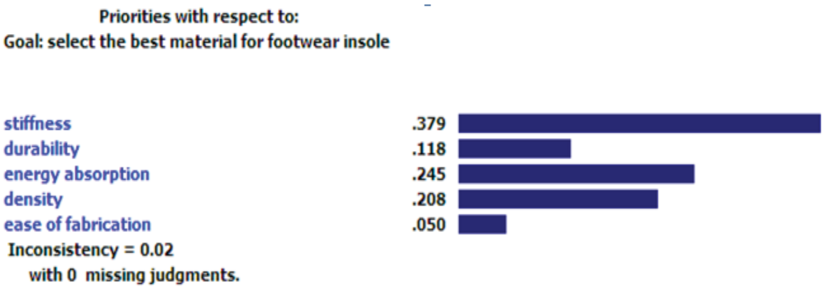

Fig. 3 Criteria weight bar comparison diagram

C. Alternative Pair-Wise Comparison

The three alternatives (polyurethane, poron, and plastoze) were pair-wise compared in terms of a favor of one alternative over another. The comparison between alternative materials was based on the information attained from the literature review and the authors' experience. The weights had been assigned based on qualitative rather than quantitative attribute. For example, the alternative with lower density has the higher priority, since low density insole is required to minimize the required energy from the body for supporting and moving the footwear. On the other hand, the alternative with higher stiffness has the priority lower since the material with the least stiffness is the most effective in terms of energy impact attenuation.

In some cases, it was necessary to compromise between some criteria in analysis. For example, the material should be stiff enough to provide a good withstanding ability, and at the same time it should be soft enough to reduce the friction between the foot and the contact area of insole.

Tables II and III show examples of the alternatives pair-wise comparison matrix with respect to the selection criteria. Figs. 4 and 5 show examples of the graphical illustration bar of the alternative priories as computed according to the assigned weight.

TABLE II
ALTERNATIVE PAIR WISE COMPARISON MATRIX WITH RESPECT TO ENERGY ABSORPTION CRITERION

	Polyurethane	Poron	Plastzote
polyurethane		1.84	1.41
poron			1.71
plastzote	Incons: 0.02		

TABLE III
ALTERNATIVE PAIR WISE COMPARISON MATRIX WITH RESPECT TO STIFFNESS CRITERION

	Polyurethane	Poron	Plastzote
polyurethane		1.33	1.11
poron			1.36
plastzote	Incons: 0.00		

D. Inconsistency Testing

The rate of consistency comparison matrix was calculated to be 0.02, which is less than 0.1. This indicates that the multi criteria matrix is reasonable, and the material alternatives ranking is effective.

E. Alternative Total Weight Computation and Final Rank Determination

After constructing the AHP comparison matrices for the criteria and material alternatives, the net weight of each one of the three alternatives had been calculated and recorded in Table IV using the criteria' assigned weight.

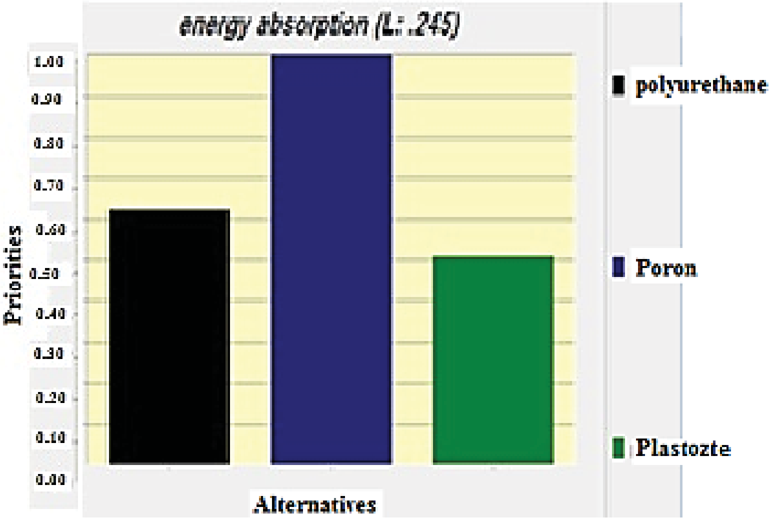

Fig. 4 Graphical bar illustration of the priorities of the three alternatives as computed according to energy absorption assigned weight

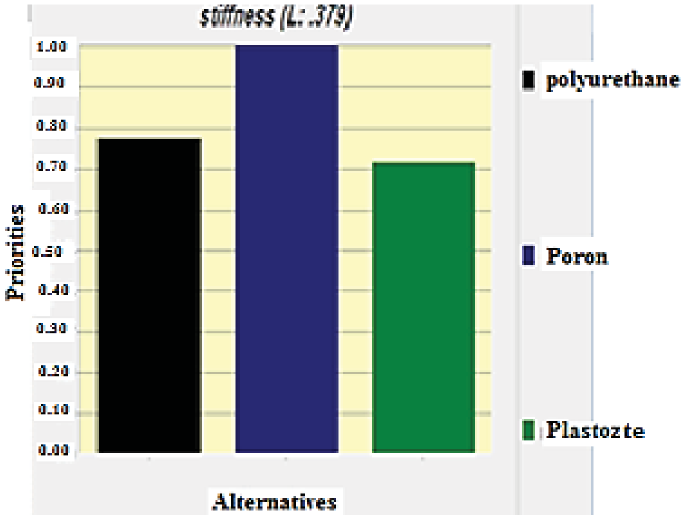

Fig. 5 Graphical bar illustration of the priorities of the three alternatives as computed according to stiffness assigned weight

Fig. 6 Final alternatives ranking

IV. Results

The final alternative ranking of footwear insole materials selection using AHP is shown in Fig. 6. The Results indicated that poron material is the best material chosen for the footwear insole application with score (0.386), follow by plastozte, and then polyuretahne. The low consistency ratio attained indicates that AHP was successfully used for the current materials selection problem, and also its goodness of discriminating between the considered alternatives.

V. Conclusions

AHP can be successfully used to select material for products within the development stage, which help to improve performance, and reduce the possibility of problem occurrence. Hence, it reduces the product development cost.

Poron is the best material chosen for the footwear insole application among the considered alternatives with overall weight (0.386).

Inconsistency testing yield value 0.02 which is less than 0.1 indicating that the AHP method is reasonable, and the material alternatives ranking is effective.

VI. Recommendations for Future Work

It is recommended that the future work should include other criteria that might affect the final decision as resilience, and hardness materials.

The use of analytical network process (ANP) is expected to produce more accurate results as it takes into consideration the criteria interdependencies in selecting the best material alternatives.

TABLE IV
SUMMARY OF WEIGHT FACTORS FOR BOTH CRITERIA AND ALTERNATIVES

Alternative	Level 1	Priority
	Percentile 32.6	
Plastzote	Stiffness (L:.379)	.118
	Durability (L:.118)	.052
	Energy Absorption (L:.245)	.054
	Density (L:.208)	.091
	Ease of Fabrication (L:.050)	.012
	Percentile 28.7	
Polyurethane	Stiffness (L:.379)	.128
	Durability (L:.118)	.024
	Energy Absorption (L:.245)	.067
	Density (L:.208)	.047
	Ease of Fabrication (L:.050)	.022
	Percentile 38.6	
Poron	Stiffness (L:.379)	.165
	Durability (L:.118)	.030
	Energy Absorption (L:.245)	.106
	Density (L:.208)	.073
	Ease of Fabrication (L:.050)	.013

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