Rebound Effect Evaluation of Commonly Used Footbeds under Repeated Foot Pressure

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Abstract—Comfort is one of the most important factors for the footwear wearer. Underfoot cushion provides a great extent of comfort. Several materials have been developed to meet this purpose. But some of those do not sustain under repeated compression. In this study several commonly used footbed materials i.e. EVA foam, latex foam, memory foam and fabricated memory foam were taken for investigation. Several tests were carried out for all the cushion materials to identify the best-suited material that exposed rebound effect under recurrent compression. The tests included density test, hardness test, tensile strength test, tear strength test, wear trial, abrasion resistance test and water absorption test. Wear trial was carried out by making two pairs of sandals and wearing them daily almost 2 hours continued up to 16 weeks with every 4 weeks regular thickness observation. The results showed that the thickness sustainability of fabricated memory foam was the most. Moreover, the performance of fabricated memory foam was found the best in almost all related tests. As the memory foam with backing provides the greatest cushioning effect over prolonged usage, it can be used widely in all types of footwear production to relief from the difficulty of discomfort of the foot.

Index Terms— Footwear, Footbed materials, Comfort, Cushioning property, Rebound effect.

1 Introduction

Footwear development with maximum comfort and performance is very vital for footwear manufacturers in all over the world to remain competitive. The introduction of cushioning underfoot is a common method of improving the comfort property of a shoe. Some investigations have shown when the cushioned insoles are introduced in a shoe, the pressure at the painful area is reduced to a large extent [1][2][3]. In walking or running stage, loads which is almost equal to 1.5 to 5 times of body weight are absorbed recurrently through each foot [4]. Studies showed that this repeated loads and related impact forces cause microtrauma to the foot tissues and as a result, it may cause severe damage to the foot [5]. It is proved from some previous studies that, several injuries to the foot can be reduced by using shock absorbing or cushioned insole [6].

Besides cushioned insole, the footbed also plays a vital role to provide comfort to the feet [7][8]. But there is a common scenario of lower resistance of footbed cushioning materials to repeated compression. Due to the recurrent compression underfoot, the cushioning materials do not show rebound effect like that of the initial stage. Therefore, the cushioning materials that compress fast underfoot pressure are not suitable for use in a shoe. The earlier studies made comparisons among different cushioned insole materials and suggested the most durable & comfortable insole materials by several tests [9][10][11]. But any research has not been carried out to justify the best footbed cushioning material that provides comfort for a long period of time.

Thus determining the comfort durability of different types of footbed materials (EVA foam, latex foam, memory foam and fabricated memory foam) through several required tests was the main aspect of this study. Several tests were carried out for the sample materials to get the best compatible footbed cushioning materials. These tests are— density test, hardness test, tensile strength test, tear strength test, wear trial with every 4 weeks regular observation, abrasion resistance test and water absorption test. Depending on this research work, the best suited cushioning material which provides maximum comfort to the feet for a long footwear wear life has been recommended.

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2 Materials

2.1 Ethylene Vinyl Acetate Foam

Ethylene vinyl acetate or EVA is commonly used as footbed in footwear because of its comfort, durability, flexibility, lightweight and waterproofing properties. It is also used as outsole, midsole and even for complete footwear making. It is the copolymer of ethylene and vinyl acetate and a blowing agent is used during the molding operation to expand the material. This expansion gives EVA foam very good cushioning property and that is the main reason for using EVA foam as footwear bottom components.[12]

2.2 Latex Foam

Latex foam can be made form both natural and synthetic sources. Synthetic latex footbed was taken as the sample for the experiment. Synthetic latex, also known as Styrene-Butadiene-Rubber (SBR), is developed from petrochemicals. Due to its better shock absorption property, excellent breathability, insensibility to heat, it is widely used as footbed materials [13].

2.3 Memory Foam

Memory foam is the most widely used footbed materials and it is also referred to as viscoelastic polyurethane foam. Different types of basic ingredients (water, isocyanates and polyols) are involved in the mixture and blowing agents used for the foaming process. High density memory foam footbeds of better quality are used in medicated footwear due to its cushioning property [14]. But it softens in reaction to body heat which makes the foam less durable.

2.4 Fabricated Memory Foam

As Memory foam is heat sensitive and softens due to body temperature, a nylon mesh fabric coated memory foam was also taken as a sample material. Nylon mesh fabric has the high-temperature resistance, excellent strength and low elongation properties [15]. This features of Nylon mesh makes the fabricated memory foam footbed more durable.

3 METHODOLOGY

3.1 Density Test

SATRA TM 12 test method was used to determine the density of footbed cushioning materials. Firstly, the volume of a test specimen was calculated by measuring the dimensions (length × width × thickness) of the specimen. All the dimensions were measured in millimetre unit by using thickness gauge. All the dimensions were taken from three different places of the specimen and the mean was calculated. Secondly, the mass of the test specimen was measured in mg unit using a balance and finally, the average density of the test specimen in g/cm^3 unit up to two decimal places was calculated by using the formula:

$$\text{Density (g/cm}^3) = \frac{\text{Mass of the specimen}}{\text{Volume of the specimen}}$$

3.2 Hardness Test

To find out the hardness of the footbed cushion materials SATRA TM 205 test method was followed. Hardness value expresses the cushioning effect and flexibility of sole, insole, midsole and footbed. Shore OO type was used for evaluating hardness characteristics of foaming materials. In this method, the thickness of the test specimen was adjusted to 10 mm and both surfaces were smooth and flat. The test specimen was pressed by the indentor of the durometer in a specific load. The indentor penetrated into the specimen and the specimen's resistance to the penetration of indentor indicated hardness which was shown on a dial gauge in shore OO hardness unit.

3.3 Tensile Strength Test

SATRA TM 2 method was followed to determine the tensile strength properties of footbed cushion materials. To determine tensile strength, the materials were cut into dumpbell shape with the dimensions shown in fig 1. Each material was cut into two test specimens which were parallel and perpendicular to the direction of the longer edges of each material. The area of cross section was measured. The machine having a uniform speed of jaw separation 100±10 mm/min was used. The two ends of the specimen were clamped in between two jaws of the machine and the machine was set 100 mm apart. The machine was run until the specimen ruptured and the breaking load was noted. Finally, the tensile strength was determined by using this formula:

$$\text{Tensile strength (N/mm}^2) = \frac{\text{Breaking load}}{\text{Area of cross section}}$$

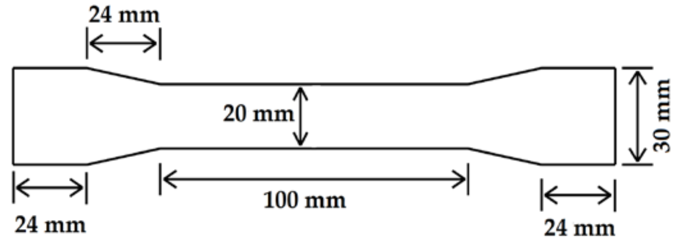

Fig. 1. Specimen for tensile strength test

3.4 Tear Strength Test

Tear strength of insole materials was determined by the test method SATRA TM 30. Two test specimens for each sample material were cut according to the dimensions shown in fig 2, where the first specimen was in the lengthwise and second one was in width direction of the sample material. The thickness of the test specimens was measured. Each specimen was given a long narrow cut to generate two legs and two legs were clamped in the two jaws of a tensile testing machine. 15 mm of each leg was clamped inside jaw and the distance between the jaws was kept 30 mm. At a speed of 100±10 mm/min, the jaws were separated until the specimen was torn apart. The maximum load required during tearing was recorded as the tearing load. Eventually, the tearing strength of the test specimens was obtained by using the formula:

$$\text{Tear strength (N/mm)} = \frac{\text{Tearing load}}{\text{Thickness of the specimen}}$$

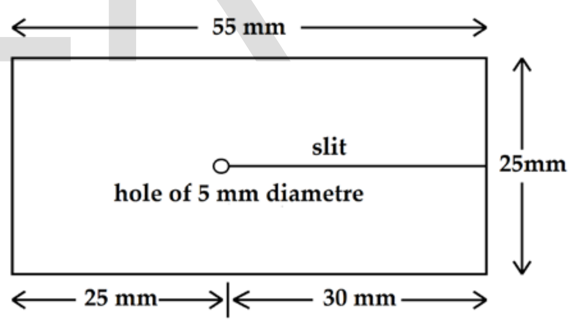

Fig. 2. Specimen for tear strength test

3.5 Wear Trial

Wear trial is one of the most important tests for testing rebound sustainability of footbed cushioning materials. This test was carried out based on British Standard BS5131: section 6.2: Code of Practice for Footwear Wear Trials. The sample materials were cut similar to the fig 3 to use them as footbed in sandals. Two pairs of thong sandals were made & four footbed materials were used in four different sandals. Two adult males were selected for wearing the sandals. Age of those people was approximately same (about 20 years) and also they had the same weight (about 60 kg). The size of two pair sandals were 39 and 42 (Paris point). Everyday the sandals were worn by them for 2 hrs±15 mins carefully. After wearing first four weeks the covers of footbed cushioning materials were removed and the thickness of the cushioning materials was measured. Percentage of thickness reduction of every material was calculated. After that, the sandals were reconstructed to wear and the similar process was carried out three times more in every four weeks. Finally, the percentage of thickness reduction with their initial thickness was compared.

Fig. 3. Sample footbeds (i. EVA foam, ii. Latex foam, iii. Memory foam, iv. Fabricated memory foam) for wear test

3.6 Abrasion Resistance Test

Martindale method SATRA TM 31 was used to determine abrasion resistance of the footbed cushioning materials. Separate tests were carried out for both dry and wet specimens to speculate the effect of perspiration on footbed materials. Each of four specimens was cut in 38 mm diametre similar to the fig 4 and clamped horizontally in the four separate test stations to abrade four test pieces simultaneously. Under a constant pressure, each of the four specimens was rubbed against a standard fabric abradant. All the specimens were rubbed in the pattern of a Lissajous figure that results rubbing in all direction. The damage to specimens was examined by using thickness gauge after running the machine for 1600 number of revolutions. The percent of change in thickness of each specimen was calculated by using the initial and final values.

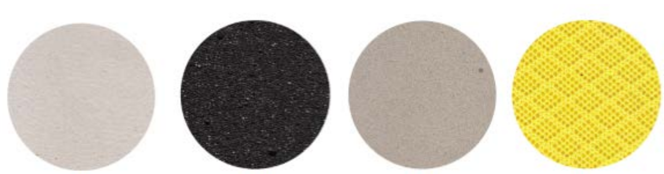

Fig. 4. Sample materials (i. EVA foam, ii. Latex foam, iii. Memory foam, iv. Fabricated memory foam) for abrasion resistance test

3.7 Water Absorption Test

The water absorption property of footbed cushioning materials was determined according to the test method SATRA TM 6. Water absorption is related with material capacity to absorb water. This property is important to remove humidity from foot skin surface and promote a higher comfort. An analytical balance was used to measure the mass of the test specimen with sealed edges and the initial mass was recorded in mg. A beaker was filled with adequate water at a temperature of 20 ± 2^0 C and the test specimen was put in the beaker so that it was fully submerged in. The test specimen was removed from the water after 8.0±0.1 hours. By using the balance the final mass of the specimen was measured in mg and the value was recorded. The water absorption by the test specimen was determined in percentage by using the formula:

$$\text{Water absorption (\%)} = \frac{\text{Final mass - Initial mass}}{\text{Initial mass}} \times 100$$

4 Results and Discussion

4.1 Density Test

Different densities were found for different footbed cushioning materials. Memory foam and fabricated memory foam had the almost similar density of 0.108 g/cm^3 and 0.103 g/cm^3 respectively, whereas EVA foam had the highest density 0.132 g/cm^3 and latex foam had the lowest density 0.058 g/cm^3. Neither the extreme nor the insignificant density foam can provide extreme comfort to the foot. The densities of all the sample materials obtained by the test were moderate to use as footbed in a footwear.

4.2 Hardness Test

A relationship was observed between density and hardness of the specimens. The hardness of the specimens was increased with the increment of density. Hardness value was minimum for Latex foam (03) and the maximum hardness (24) was found for EVA foam which are described in table 1. On the other hand, memory foam and fabricated memory foam showed the medium hardness value which was 9 and 8 respectively. The footbed having excessive low hardness value does not meet the requirement for the application in a comfortable footwear. Extreme soft foaming footbeds are more comfortable initially but it compresses gradually and alternatively, footbed of higher hardness value provides less comfort. All the sample materials exhibited proper hardness values which indicate that they can be used in footwear for cushioning effect.

TABLE 1
DENSITY & HARDNESS PROPERTIES OF FOOTBED MATERIALS

Sample No.	Sample Name	Initial Thickness (mm)	Density (g/cm^3)	Hardness Shore OO
1	EVA foam	3.8	0.132	24
2	Latex foam	3.5	0.058	3
3	Memory foam	3.3	0.108	9
4	Fabricated memory foam	4.3	0.103	8

4.3 Tensile Strength Test

Fabricated memory foam showed the highest tensile strength (1.08 N/mm^2) and EVA foam exhibited the tensile strength (0.322 N/mm^2) which are given in table 2. In contrast, memory foam and latex foam showed very nominal value for tensile strength. Fabricated memory foam exhibited better strength only because of its fabricated backing. Materials that have more tensile strength are more suitable for using in the footbed of a footwear. As the fabricated memory foam has the highest tensile strength, it can be said that fabricated memory foam is more durable than the other foaming materials.

TABLE 2
TENSILE STRENGTH PROPERTIES OF FOOTBED MATERIALS

Sample No.	Sample Name	Average Load (N)	Tensile Strength (N/mm^2)
1	EVA foam	24.5	0.322
2	Latex foam	2.94	0.042
3	Memory foam	7.76	0.012
4	Fabricated memory foam	93.1	1.08

4.4 Tear Strength Test

In tear strength test different results were obtained for different materials. According to table 3, EVA foam, Latex foam and memory foam showed tear strength 0.515 N/mm, 0.28 N/mm and 0.44 N/mm which are not sufficient to use in a shoe whereas fabricated memory foam showed the maximum tear strength (11.39 N/mm). The footbed materials having more tear strength are more viable in wear. So, fabricated memory foam is preferable than others.

TABLE 3
TEAR STRENGTH PROPERTIES OF FOOTBED MATERIALS

Sample No.	Sample Name	Average Load (N)	Tear Strength (N/mm)
1	EVA foam	1.96	0.515
2	Latex foam	0.98	0.28
3	Memory foam	1.47	0.44
4	Fabricated memory foam	49	11.39

4.5 Wear Trial

The thickness of the footbed materials was reduced to a great extent after first 4 weeks and gradually thickness reduction was continued up to 16 weeks. The thickness of EVA foam decayed about 59.21% which was the highest reduction and the thickness of fabricated memory foam was reduced only 4.65% that was the lowest reduction. The thickness of latex foam was reduced almost 50% and the memory foam was reduced 9.09% of the initial thickness. As memory foam and fabricated memory foam exhibited a very slight decrease in thickness which is shown is fig 5 over prolonged walking session, it can be said that they showed the best performance in thickness sustainability under repeated foot pressure and can be considered as the suitable footbed materials which may expose better rebound effect.

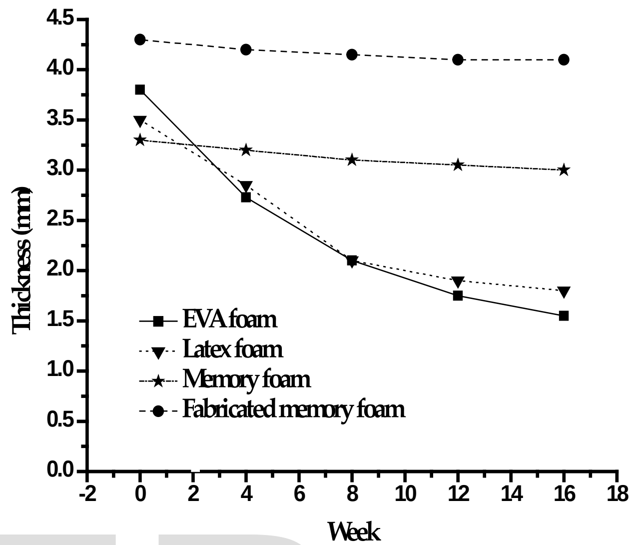

Fig. 5. Thickness reduction through wear trial

4.6 Abrasion Resistance Test

To determine abrasion resistance properties the dry and wet tests were carried out for all the foam materials. The maximum thickness reduction was found for memory foam in both dry and wet test methods which were 30.3% and 69.69% respectively but in case of fabricated memory foam, minimum thickness reduction was found in both dry and wet test methods which were 1.16% and 2.32% respectively shown in fig 6. The thickness of EVA foam and latex foam was also decreased to a smaller extent due to abrasion. Fabricated memory foam showed the highest resistance to abrasion and it can be considered as the most suitable material for footbed cushion.

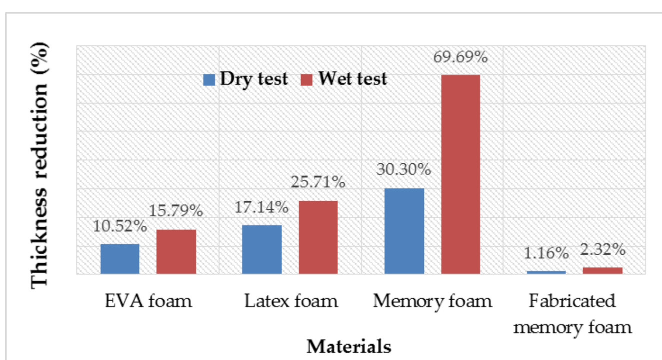

Fig. 6. Thickness reduction through dry and wet abrasion tests

4.7 Water Absorption Test

In water absorption test, latex foam absorbed more water (187.56%) because of its large number of porosity whereas EVA foam absorbed the minimum amount of water (23.9%) due to its higher density. The material that has more water absorption property is avoidable for use as footbed in a footwear. As latex foam exhibited the high amount of water absorption property than others so it is not suitable and as EVA foam had the less water absorption property so it is more suitable than other sample materials. According to the table 4, Memory foam and fabricated memory foam absorbed a large quantity of water which was the drawback of using memory foams as footbed in a footwear.

TABLE 4
WATER ABSORPTION PROPERTIES OF FOOTBED MATERIALS

Sample No.	Sample Name	Initial Weight (gm)	Final Weight (gm)	Water Absorption (%)
1	EVA foam	2	2.478	23.9
2	Latex foam	2	5.751	187.56
3	Memory foam	2	3.785	89.25
4	Fabricated memory foam	2	3.919	95.93

Memory foam showed the best performance in cushion sustainability among EVA foam, latex foam, and memory foam but it did not sustain in the tensile test, tear test, wear trial and abrasion resistance test. The same material with fabrication was able to show the best performance in all the tests. Although the fabricated memory foam absorbed more water compared to EVA foam, it showed the best result in all other tests.

5 CONCLUSION

All the foams taken for this experiment provide comfort to the feet. But determining the durability of the comfort was the main aspect of the study. After analyzing the values of different tests it can be said that EVA foam, latex foam and memory foam are less suitable than fabricated memory foam. Because fabricated memory foam showed better properties in almost all the different tests. After the research work, it can be suggested that fabricated memory foam is the most suitable as footbed cushioning material than others. This study would enable shoe manufacturers to design and produce footwear with memory foam with fabric backing which provides optimum & long-lasting comfort.

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