DESIGN A TESTING EQUIPMENT FOR FATIGUE RESISTANCE OF FOOTWEAR INSOLE MATERIALS

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ABSTRACT

Modern footwear is a ell-designed engineering product made using advanced fabrication machines as well as highly skilled artisans to provide optimum comfort and safety to the user. It consists upper, outsole, insole, fasteners and a number of invisible components that include metal shank. Insole is an important invisible bottom part of the footwear that is generally made up of from cellulose and/or nonwoven cellulose sheet. This provides a rigid shape to the bottom sole apart from other wear properties like water absorption and desorption properties. But insole fails to bear the body weight of the user and tend to become weak at waist part of the footwear resulting breaking of insole and loss of shape of the footwear and make instability while walking. Hence a strip of metal reinforcement known as steel shank is provided between heel and forepart of the insole and insole that acts as a cantilever beam to offer rigid support while walking. Steel shanks used in footwear are one of the main stressed components and are regarded as the spine of shoes as they are used to connect the heel and forefoot in such a way prevent excessive bending of the plantar arch. The quality of shanks affects human health, safety and the stability of footwear. A simple steel strip can not withstand the continuous stress applied on it and causes bending and breaking. Therefore specially designed moderate hard steel shanks are used. Hardness, flexural rigidity and fatigue resistance are considered some of the essential properties of steel shanks. In this study a testing machine is designed to evaluate the fatigue resistance property of steel shank provided insole by simulating repeated bending action at the bottom part of the footwear for repeated bending cycles. Repeatability, validation and statistical analysis of test results were conducted using this testing machine to exhibit that the testing machine is suitable for evaluation of fatigue resistance of steel shanks as well as whole footwear flexing.

Keywords*: *Fatigue resistance, Insole back parts, steel shanks, footwear.

INTRODUCTION

FOOTWEAR

Modern footwear is a well designed engineering product that meets almost all the demands of the customer. Footwear can conveniently be divided into two parts (1) upper and (2) outsole. The upper is either leather or manmade materials like textiles or polymer coated materials. Bottom part of the footwear mainly consists of outer sole and insole. Outer sole is made of natural rubber or flexible polymeric material such as poly urethane (PU), poly vinyl chloride (PVC), thermoplastic rubber (TPR), micro cellular rubber (MCR), styrene butadiene rubber (SBR), ethyl vinyl chloride (EVA) etc., while insole is made up of leather, cellulose or nonwoven material or combination of cellulose and non-woven material.

INSOLE

In shoe construction, insole forms as a foundation on which the upper and bottom of the shoe are attached. This is sandwiched between the bottom outer sole and top in-sock material. These insole material are semi rigid and flexible sheet material generally made from leather, leather board, cellulose and synthetic materials and intended to retain the shape of the bottom profile of the footwear and to provide maximum comfort by absorption and desorption of water, permeation of foot sweat, resistance to shrinking upon heat and moisture and also firmly holding the heel. But this material is vulnerable to fatigue upon repeated flexing and therefore flexing resistance of insole is considered one of the primary properties. Footwear insole can be divided in to three parts (1) forepart, (2) waist and (3) heel. Forepart of the insole is often made by cellulose materials to ensure good flexing resistance while heel part is made with non woven material to with hold the heel attached on it. The waist part that comes in between the heel and forepart is not making much contact with the floor and form a bridge between the heel and forepart. While walking with footwear, heel strike on the floor initiates the load transfer to the forepart through the waist causing more stress and strain on the waist part. This repeated load transfer action initiates cracks on the insole and produces horizontal cut across the insole and destabilizes the rigidity of footwear between the heel and forepart so that walking is impaired.

STEEL SHANKS

In order to overcome the fatigue at waist a specially designed rigid steel strip material known as shank is reinforced on the insole at the weak waist area making as a supportive structure between heel and waist regions of the insole. The presence of a shank is highly essential to the functionality of ladies high heel shoes, industrial and mountaineering boots. Contemporary shanks are also made up of less heat conductive but equally rigid options such as fiberglass and Kevlar materials. This steel shank is the most severely stressed component in the shoe, suitably designed with a flout in the middle. Hardness, flexural rigidity and fatigue resistance are considered important properties. One end of the steel shank is attached with the heel with a nail and buried in between the layers of insole. Intact steel shank is one of the most vital hidden components in shoes. It provides essential support to the arch of the shoe by acting as a cantilever beam between the heel and waist. It has to withstand heavy bending and tensional stresses while maintaining accurate alignment of the fore part and heel throughout all the stresses of the shoe life. Inspite of modern technological developments and awareness of quality of materials used, steel shanks requires more attention by the manufacturer and customer for design, material and quality. Steel shanks cannot be taken lightly while manufacture with steel. Steel shanks should be manufactured from the hard carbon steel usually containing less than 2 % non metallic components. Steel shanks are cut from the steel strips and then hardened and tempered to 46 – 53 Rockwell “C” hardness (HRC).

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Steel thickness 1.00 to 1.20 mm is commonly used in the manufacture of steel shanks and the width of the shanks being either 9.5 mm or 12.7 mm with flute height 1.27 mm or 1.90 mm. After pressing the steel strips on the mould of the shank to have a desired flute height and length, the shank is oil hardened and tempered or austempered. In austempering process steel shanks are heated to 865^{o}C in a high temperature shaker hearth furnace and then quenched in a molten salt bath at 310^{o}C. The shanks are then washed with warm water to remove the salt present in the surface and dried in hot air to give clean, bright blue finish. The austempered product is accurate in shape, consistent in strength and tougher than oil hardened steel shanks.In general shoes with heel height less than 25 mm do not require steel shank. However in high heeled women shoes with knock-on heels a strong stiff steel shank is required to form and maintain the waist shape and to give heel stability by preventing backward or forward heel movement due to waist flexion and also to give torsional stability between the heel and forepart. Now moulded plastic shanks, composite fiber shanks are also used to protect the shoe from damage through waist and heel. But for ladies bump toe shoes steel shanks are the only option.

HARDNESS- ROCKWELL "C" SCALE (HRC)

Hardness is a measure of the resistance to localized plastic deformation induced by mechanical indentation. Macroscopic hardness is generally characterized by strong intermolecular bonds. The behavior of solid materials under force is complex and there are different methods to measure hardness known as scratch hardness, indentation hardness and rebound hardness. Of this indentation hardness method is commonly employed for measuring steel shank hardness in which the resistance of a sample to material deformation due to a constant compression load from a sharp object is measured and reported in terms of Rockwell "C" hardness scale. The determination of the Rockwell hardness of a material involves the application of a minor load (98N) followed by a major load (1470N) and return to original minor load (98N). The depth of penetration from the zero is measured from a dial reading of Rockwell hardness testing machine. Penetration depth and hardness are inversely proportional and harder material shows higher number. The chief advantage of Rockwell hardness is its ability to display hardness values directly, thus obviating tedious calculations involved in other hardness measurement techniques.

FATIGUE RESISTANCE OR FLEXING RESISTANCE

One of the main problems encountered with a shank in wear is premature fracture leading to subsequent breakage. This kind of fatigue results from progressive weakening of the shank associated with the very slight bending on every step of walking. Fatigue is weakening of a material caused by repeatedly applied loads. It is a progressive and localized structural damage that occurs when a material is subjected to cyclic loading. When the material fails to withstand the load above a specified threshold, microscopic cracks will begin to form at the stress concentrators and grain interfaces of the metal that develops to a critical size and propagates suddenly to fracture. Therefore fatigue resistance is defined as the highest stress that a material can withstand for a given number of cycles without breaking. This type of resistance also called endurance strength.

FATIGUE RESISTANCE TEST

ISO 18895:2006 specifies a test method for assessing the fatigue resistance of steel shanks of at least 100 mm in length used for the reinforcement of the waist region of women's shoes and of some men's and children's shoes. In this method one end of the steel shank sample is fixed on a clamp and other ender is fixed to a piston. The piston is operated to give a to and fro motion at 5 kgf force towards forward and backward directions so that the steel shank is bent and released repeatedly until break. Number of cycles to make fatigue is measured.

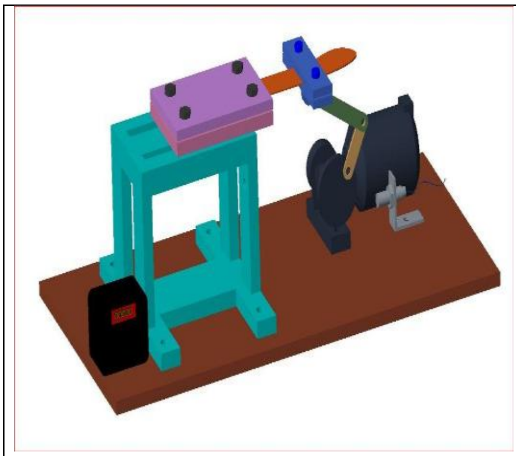
NEW TESTING EQUIPMENT

Using the above test procedure fatigue resistance of steel shanks alone can be tested. But insoles reinforced with shanks and whole shoes cannot be tested. Further the test equipment is operated with pneumatic pressure and therefore pneumatic pressure application facility is essential. Hence a new motor operated testing machine to test the steel shanks as well as insoles with shanks and whole shoe is designed making use of Pro/Engineer software.

PRINCIPLE

The rear end of insole with steel shank is clamped horizontally through to the fixed clamp and the forepart is fixed with the loading arm of flexing mechanism and flexed to a specified angle 30^0 by an alternating force applied. The number of loading cycles required to damage the steel shank is termed as the fatigue life.

DESIGN



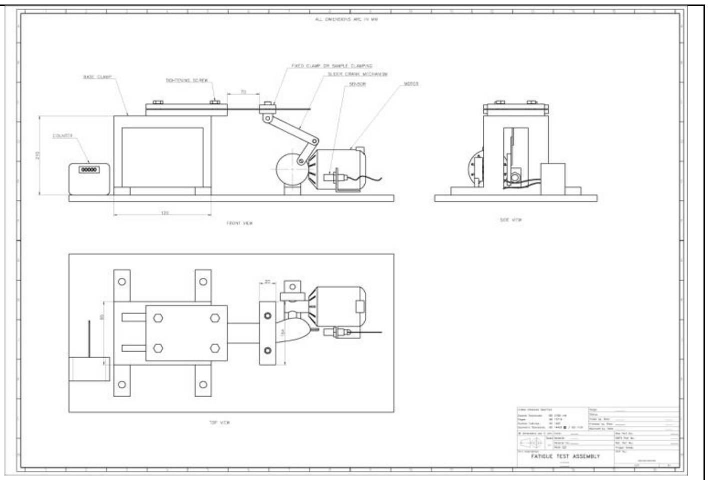


Fig-1 3D model

Fig-2 3D model assembly diagram

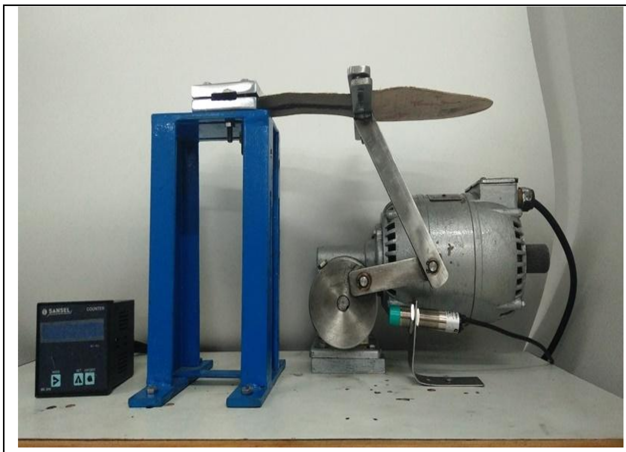


Fig-3 Fabrication of fatigue test equipment

Fig-4 Sample before testing and after testing

TESTING MACHINE

1. This test equipment consists of a rectangular solid metal platform (85 mm x 65 mm) to accommodate different parts of the equipment
2. A vertical solid iron bench having arrangements to fix the test shanks as shown in the figure.
3. The sample holding part is made up of two plates with sufficient room to accommodate the heel end of an insole or a shoe. One plate is fixed on the bench end and the other plate can be aligned and tightened on the fixed plate with screw mechanism.
4. An electric motor is fixed on the base palate in such a way that the test sample can be secured into the arm of the lever arrangement.
5. A two part sliding lever arrangement attached with the pulley of the motor so that it makes forward and backward movements and bending the test specimen during test.
6. A counter to measure the flexing cycles.
7. Electrical connection with 220 ± 20 volts AC power supply
8. Safety guard

TEST PROCEDURE

Heel side of the insole board is fixed at the stationary clamp such that the rear end of the steel shank is tightly secured in between the clamp. The other end of the steel shank part is secured into the loading arm clamp mechanism such that the test sample is in horizontal position. The distance between the inner edges of the clamps is adjusted to 70 mm. The screws of the both the clamps are tightened with a torque wrench regulated to 5 N.M, so that the steel shank are secured without over tightening. After setting the number of test cycles in the preset counter, testing is conduced continuously with periodic inspection for damage to the shank. If failure occurred before the prescribed number of test cycles, the counter stops automatically so that only the number of cycles at which the failure occurred is recorded. Fatigue resistance is calculated as fatigue index by taking Logarithmic value to base 10.

EXPERIMENT

One sample of 40 HRC steel shank reinforced insole was selected from a batch and secured horizontally in between the clamps of the testing machine. The testing machine was set for and test conducted following the test procedure described above. After completion of the 10000 cycles, the insole sample was examined for any failure to the steel shank. Test was continued for 20000, 30000, 40000, 50000, 100000, 200000, and 1000000 and so on until the failure occurred. Four more samples having 40 HRD were tested and the test results were given in Table 1 and represented in Fig. 5,6,7,8, 9 and 10.

TABLE 1 : FATIGUE RESISTANCE FOR HARDNESS (HRC) 40 STEEL SHANK

S.No.	Sample Hardness (HRC) 40	Number of fatigue cycles	Fatigue index (log value of fatigue cycles)
1	Sample 1	870000	5.9395
2	Sample 2	870000	5.9395
3	Sample 3	850000	5.9294
4	Sample 4	860000	5.9344
5	Sample 5	830000	5.9190
Mean		856000	5.9323
Standard deviation		16733.2005	0.0085

FIG.5. FATIGUE INDEX FOR STEEL SHANK HARDNESS 40 HRC

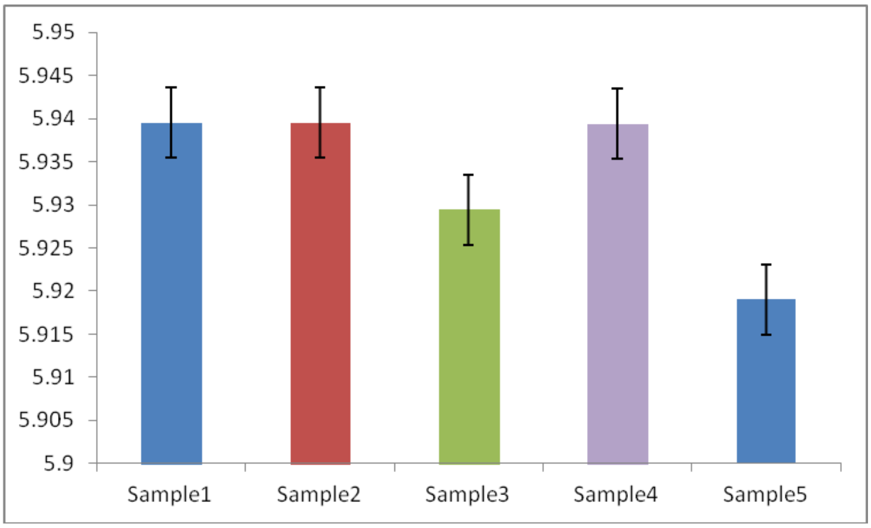


FIG.6. FATIGUE INDEX FOR STEEL SHANK HARDNESS 42 HRC

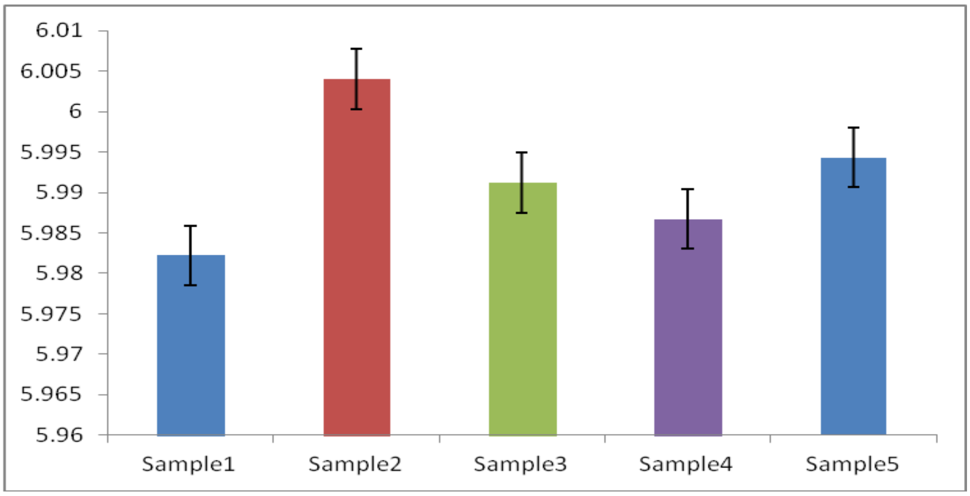


FIG.7. FATIGUE INDEX FOR STEEL SHANK HARDNESS 44 HRC

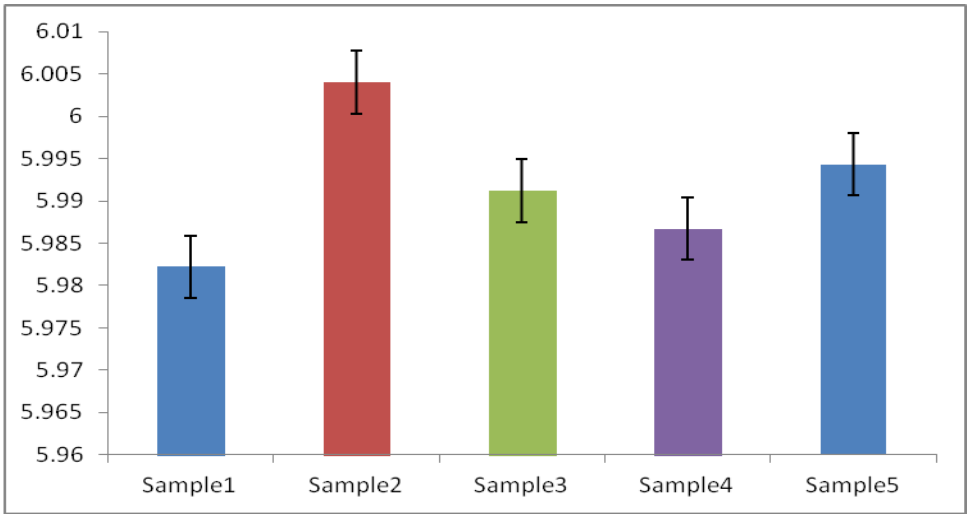


FIG.8. FATIGUE INDEX FOR STEEL SHANK HARDNESS 46 HRC

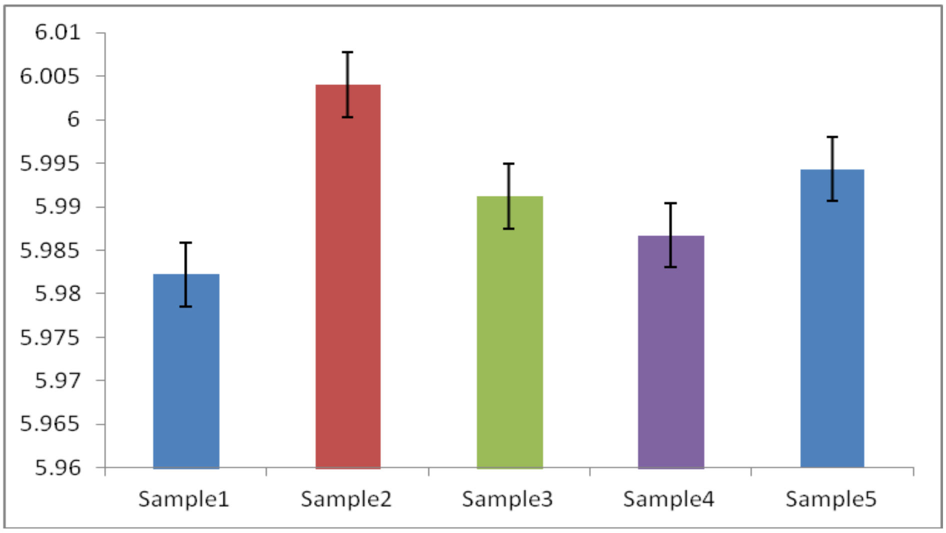


FIG.9. FATIGUE INDEX VERSES HARDNESS (HRC)

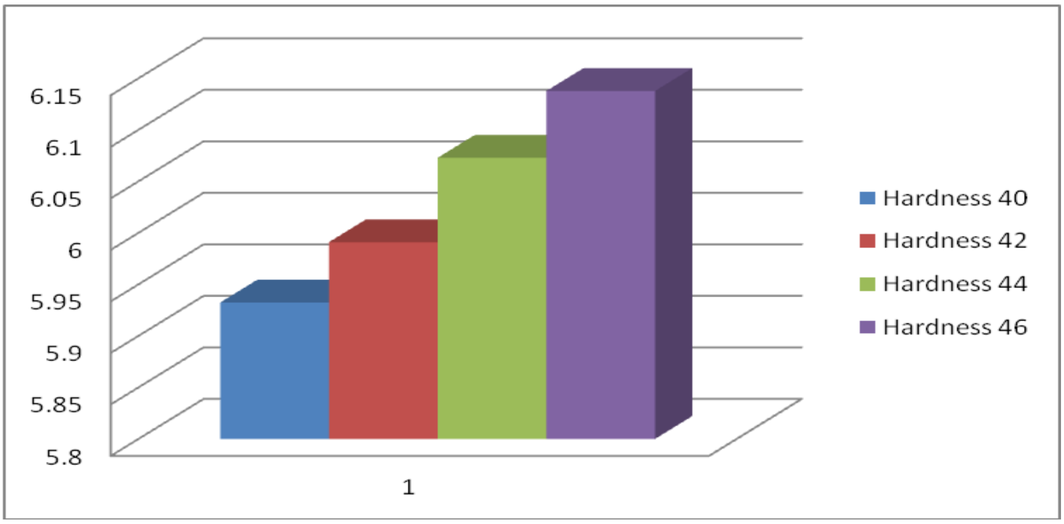


FIG.10. COMPARISON BETWEEN REPEATABILITY OF SAMPLE

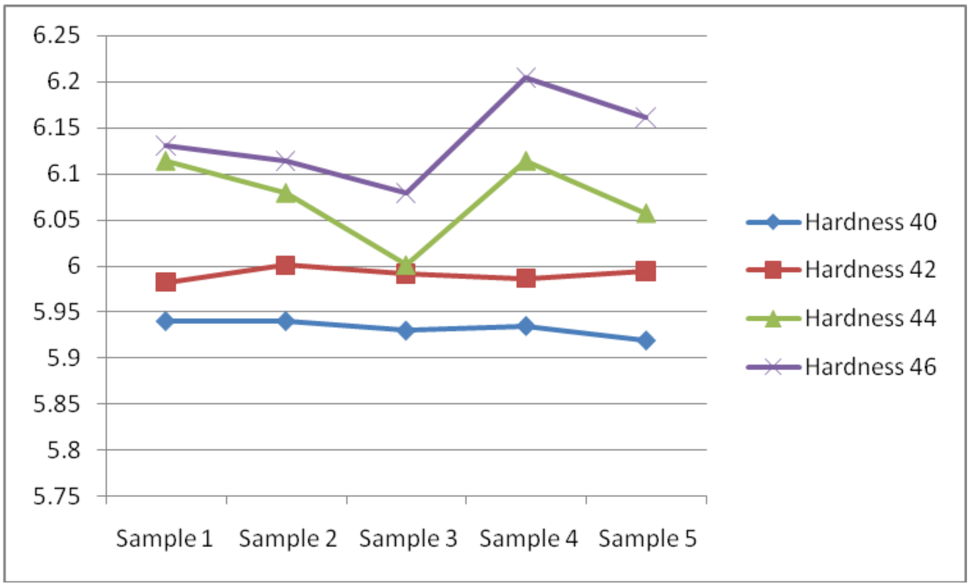
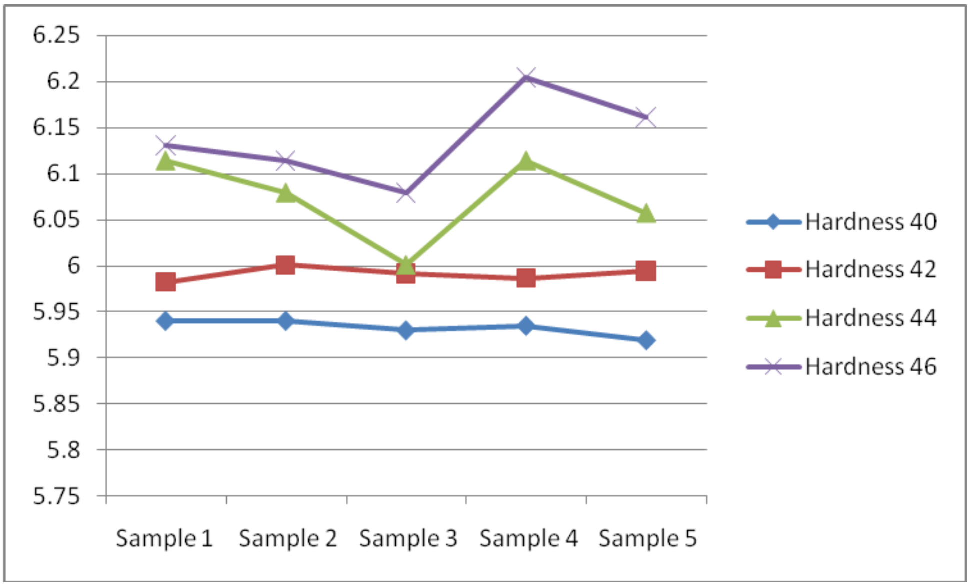


FIG.11. COMPARISON BETWEEN TECHNICIANS VALIDATION EXERCISE



REPEATABILITY AND REPRODUCIBILITY

Repeatability and reproducibility are the two components of precision in a measurement system. It is the variation that is observed when same operator or different operators conduct the same tests many times, using the same machine, under the same conditions. Hence repeatability and reproducibility test was conducted using further insole samples having hardness 42 HRC, 44 HRC and 46 HRC were tested and the test results were reported in Table 2,3,4 and 5

TABLE 2 : FATIGUE RESISTANCE FOR HARDNESS (HRC) 42 STEEL SHANK

S.No.	Sample Hardness (HRC) 42	Number of fatigue cycles	Fatigue index (log value of fatigue cycles)
1	Sample 1	960000	5.9822
2	Sample 2	1001000	6.0004
3	Sample 3	980000	5.9912
4	Sample 4	970000	5.9867
5	Sample 5	987000	5.9943
Mean		979600	5.9909
Standard deviation		15725.7750	0.0069

TABLE 3 : FATIGUE RESISTANCE FOR HARDNESS (HRC) 44 STEEL SHANK

S.No.	Sample Hardness (HRC) 44	Number of fatigue cycles	Fatigue index (log value of fatigue cycles)
1	Sample 1	1300000	6.1139
2	Sample 2	1200000	6.0791
3	Sample 3	1001000	6.0004
4	Sample 4	1300000	6.1139
5	Sample 5	1140000	6.0569
Mean		1188200	6.0728
Standard deviation		125004.7999	0.04720

TABLE 4 : FATIGUE RESISTANCE FOR HARDNESS (HRC) 46 STEEL SHANK

S.No.	Sample Hardness (HRC) 46	Number of fatigue cycles	Fatigue index (log value of fatigue cycles)
1	Sample 1	1350000	6.1303
2	Sample 2	1300000	6.1139
3	Sample 3	1200000	6.0791
4	Sample 4	1600000	6.2041
5	Sample 5	1450000	6.1613
Mean		1380000	6.1377
Standard deviation		152479.5068	0.04720

TABLE 5 : FATIGUE INDEX FOR STEEL SHANKS WITH DIFFERENT HARDNESS

S.No.	Hardness (HRC)	Fatigue index (mean of five samples)
1	40	5.9323
2	42	5.9909
3	44	6.0728
4	46	6.1377

VALIDATION EXERCISE

The definition used for validation in the ISO standard 8402 is confirmation be examination and provision of objective evidence that the particular requirement for a specific intended use are fulfilled. Therefore test method validation is the documented process of ensuring a test method is suitable for its intended use. An attempt is made in this study to validate the test procedure and test equipment. Three highly skilled technicians from different laboratories were selected and assigned to test fatigue resistance test following the test procedure described above using the newly developed testing machine. Four samples of steel shank reinforced insoles having hardness 40 HRC,42 HRC,44 HRC and 46 HRC were tested by each individual technician, test results were compiled and reported in Table 5 and in Fig. 10

TABLE 6 : VALIDATION EXERCISE ON NEW TEST EQUIPMENT AND TEST PROCEDURE

S.No	Sample	Fatigue index			Standard deviation	Measurement of the uncertainty
		Technician 1	Technician 2	Technician 3		
1	Hardness 40 HRC	5.9302	5.9344	5.9328	0.00212	0.0024
2	Hardness 42 HRC	5.9876	5.9894	5.9889	0.00093	0.0011
3	Hardness 44 HRC	6.0720	6.0729	6.0743	0.00116	0.0013
4	Hardness 46 HRC	6.1403	6.1407	6.1413	0.0005	0.00058

RESULTS AND DISCUSSION

The aim of this study is to evaluate the function of the newly developed mechanical test equipment designed for determining the fatigue resistance of steel shanks reinforced on insoles. In this study steel shanks with four different hardness (Hardness 40 HRC, 42 HRC, 44 HEC and 46 HRC) containing five samples for each hardness level were selected and tested so that a total number of 20 test results were generated. In general it is observed that there is no abnormality of test results between the samples of same hardness and between the different hardness Table 1,2,3,4 and Fig. 5,6,6,8. This trend of uniformity in test results indicates that the function of test equipment is considered reliable and satisfactory. The fatigue resistance cycles and fatigue index for 40 HRC and 42 HRC test samples are found to be consistent without much of difference between the samples. But very slight variation is observed for HRC 44 and 46 HRC test samples Fig.10 and this variation also not to a greater extent. This trend of consistency and repeatability between test samples can be ensured by very minimal values of standard deviation 0.0065 - 0.0089 for 40 HRC and 42 HRC and 0.047 for 44 HRC and 46 HRC.

After ensuring the consistency and repeatability tests, another approach is made further to study the suitability of the test equipment for R & D and regular testing purposes. Validation is one of the methods followed to standardize the test method so as to the equipment. Three skilled technicians from three different laboratories were selected and assigned to conduct the fatigue resistance test with four different hardness test samples. The test results were given in Table 6 and Fig. 11. There is no significant difference between the test results arrived by three technicians and also noticed uniform increase in fatigue resistance with increase in hardness. This is due to more plastic deformation caused by more indentation on less hardness material tend to initiate crack at lower fatigue cycles. The increase in fatigue resistance cycles for increase in hardness and thereby fatigue index arrived, indicated that the function of the test equipment is working without giving any unreliable test results.

CONCLUSION

Footwear is provided a specially designed metal strip called steel shanks in the waist region that acts as a cantilever beam to firmly unite and protect the forepart and heel part of the footwear. This material is also with stand the tensional rotation of the footwear during walking. When the quality of material is bad it causes fatigue and make failure of the product. In ensure the quality of the shanks fatigue resistance test is conducted. In this study a simple and mechanical testing machine is designed, fabricated and tested for fatigue resistance test. Operation, maintenance and testing of materials are not complicate. Motor operated flexing arm of the testing machine flex the fore part of the steel shank to an angle of 30 degree so that a simulation of walking is produced. Steel shanks with different Rockwell “C” hardness (40 HRC, 42 HRC, 44 HRC, 46 HRC) were tested. The fatigue cycles are reported in the form of ‘fatigue index’ (Log value to base 10). The test method (conducted using this new test equipment) has also been validated for reliability and repeatability of test results with three different technicians. The linear increase in fatigue cycles with increase in hardness of the steel shanks and the consistence in test results obtained by three different technicians is made to conclude that the newly designed simple mechanical motor driven fatigue resistance testing machine is ensuring repeatability and reliability of the testing machine.

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