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AN EMERGING APPROACH IN FOOTWEAR INDUSTRY TO INTRODUCE FINITE ELEMENT ANALYSIS METHOD FOR PHYSICAL PROPERTIES OF THE OUTSOLE

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Abstract*- Theoutsole (sole) of a shoe is an essential bottom part that comes direct contact with the ground. In footwear, varieties of outsole materials are used to attain desirable physical and mechanical properties. Thermoplastic rubber (TPR) outsole is very popular and widely used. To develop the outsole functionalities design process are examined in biomechanics laboratory over and over. The process is time consuming, expensive and test work can only be done after manufacturing of prototype. In this work, an attempt was taken to evaluate physical properties of a TPR outsole using Finite Element Analysis (FEA) to design outsole for better performance during wearing life cycle. The solid model of outsole was designed in Solidworks 2013 and imported in FEA software. After that TPR outsole material's standard values were assigned to acquire the actual physical properties of the outsole. By meshing the solid model of outsole it was simulated and analyzed. Finally, the simulated results were verified for model correctness based on comparative study with the standard requirements of the outsole. Results indicate that the outsole was suitable for cold countries up to –50°C and it will be sustained up to 5500 cycles.*

Keywords: Outsole, Finite Element Analysis, Thermoplastic Rubber, Physical Properties

1. INTRODUCTION

Wearing apparel for the foot is known as footwear. It is used as the beautification of the foot as well as to protect it from the detrimental effect of the environment[1].In basic footwear has various components such as upper, insole, midsole, outsole, toe cap, stiffener, shankpiece which have essential function to maintain the shoe shape[2]**.**However, footwear has major two parts: upper and outsole (sole). In footwear production 'outsole' is an essential bottom part of a shoe that comes in direct contact with the ground [3].

Essentially, outsole is a basic protective buffer layer of material between the foot and ground [4]. The outsole should have a variety of functional properties such as wear durability, flexibility, traction, thermal insulation, and structural stability [5].

In outsole preparation wide spectrum of materials such as Poly Vinyl Chloride (PVC), Poly Urethane (PU), Thermoplastic rubber (TPR), Nylon is used. Among these materials Thermoplastic rubber (TPR) is widely used as the outsole. The TPR outsole is very popular due to its ease molding, superior slip resistance, good flexing resistance and it could sustain at certain cold temperature (subzero condition).

The life cycle of a shoe as well as the outsole has to pass through the various mechanical operations including ground surface friction, forward-backward movement, upward-downward movement and body weight pressure etc. Besides, outsole has to face different weather conditions. During wearing the shape of outsole may be distorted which effect on the foot.

Considering those factors several prototype outsoles retested in the biomechanics laboratory over and over to obtain optimum properties for the production. The process is time consuming and costly. To reduce the cost and time consuming trial as well as error cycle a finite element analysis (FEA) based method could be used to analyze the performance test of the outsole.

Amongst various computer aided design (CAD) simulation techniques; Finite Element Method (FEM) is becoming more and more popular because of its versatile and controllable accuracy [6] in modeling irregular geometric structure, complex material properties and ease of simulating complicated boundary and loading conditions in both static and dynamic simulation [7].

The use of computer-aided engineering (CAE) approach considering comprehensive computational footwear model could be an efficient and economical alternative to allow an objective and economic evaluations as well as optimization of its performance. The numerical simulation technique such as the finite element method (FEM) could allow the realistic simulations of the foot as well as footwear interface which could offer in-depth biomechanical information including internal stress and strain distributions of modeled structure[8].The finite element analysis is a powerful tool and growing in popularity [9].It is a computerized method for predicting how a product reacts to real-world forces, vibration, heat, fluid flow, and other physical effects[10].

The computer base simulation has become an increasing important research tool in footwear science with continuous advancement driven by the numerical techniques and computer technology. The simulation is a tool that extensively used in manufacturing system design and analysis for more than 40 years [11].Computer aided engineering technique allow rapid change of input parameters to analyze their subsequent effects in virtual simulation environment without needing to conduct actual experiment [12].Moreover, the finite element analysis (FEA) provides additional insight distribution of internal loads and deformation of biological and mechanical structures or systems being modeled.

In this study, an attempt was made to evaluate the physical properties of the TPR outsole such as von misses stress, strain, buckling deformation, thermal behavior, and fatigue life using the Finite Element Analysis (FEA) to design and make a perfect outsole for the footwear construction.

2. METHODOLOGY

2.1 Creating solid geometry of TPR outsole

The solid geometry of the TPR outsole was designed by Solidworks2013 software from actual measurement of the physical outsole sample for simulation with the finite element analysis. In Fig. 1 shows the physical view of the outsole and Fig. 2 represents the solid geometry of outsole.

Fig.1: Physical view of the outsole

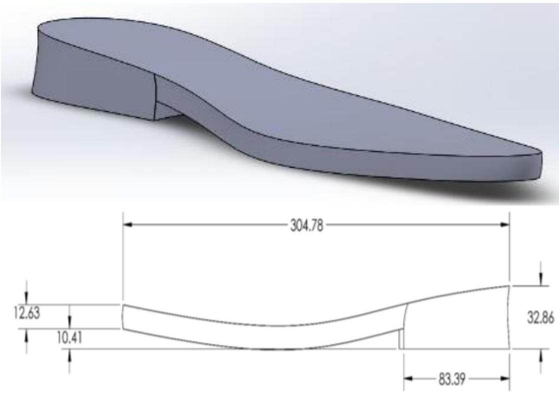

Fig.2: Solid geometry of the outsole with dimension

2.2 Assigning material properties:

The selected material (TPR) properties were assigned to evaluate the actual physical properties of outsole such as elastic modulus, Poisson's ratio, mass density, tensile strength, yield strength, thermal co-efficient. Materials properties often vary to some degree according to the direction of material in which they were measured. Material properties that relate two different physical phenomena often behave linearly in a given operating range, and may then be modeled as a constant for that range. The properties of TPR outsole are given below:

Table 1:Material properties for TPR Outsole

Property	Value	Unit
Elastic Modulus	0.12×10^{9}	N/m^2
Poisson's Ration	0.49	N/A
Mass Density	900	kg/m^3
Tensile Strength	3920000	N/mm^2
Yield Strength	1330688.16	N/mm^2
Thermal co-efficient	130×10^{-6}	N/m^2

2.3 Loads and boundary condition

In case of FEA an important step is the application of load and boundary condion. The force is applied on the top surface of the outsole depending on the body weight where the heel portion of the outsole was subjected to fix geometry. In this study 588 N force was applied on the outsole surface which was equal to the 60 kg human bodyweight (Fig. 3).

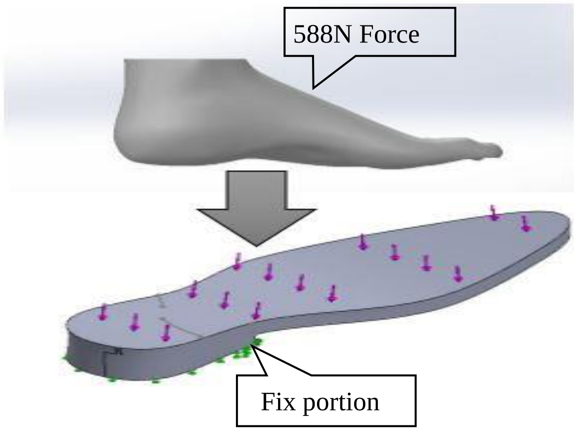

Fig.3: Loads and fix geometry

2.4Meshing the Solid Geometry of Outsole

Meshing plays an important vital role in design analysis. The automatic mesherin the software generates a mesh based on a global element size, tolerance and local mesh control specifications. Mesh controls in different sizes of element for components, faces, edges, and vertices. The size of the generated mesh depends on the geometry and dimensions of the model, element size, mesh tolerance, mesh control, and contact specifications. The accuracy of the simulation mainly depends on the meshing. The finely meshed solid model of the outsole is shown in Fig. 4.

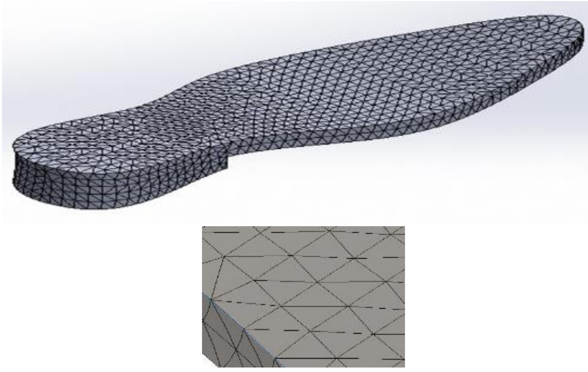

Fig.4: Meshed model of the TPR outsole

2.5 Running the simulation analysis

The simulation analysis of the outsole was carried out for static (stress, equivalent strain), thermal analysis, buckling deformation, and fatigue life.

2.5.1 Von misses stress analysis

Von misses stress is widely used by designers to check whether the design will withstand in a given load condition. It is considered to be a safe haven for design engineers. Here, the force was applied on the top surface of the outsole, then the von-misses stress was found, maximum and minimum values were noted.

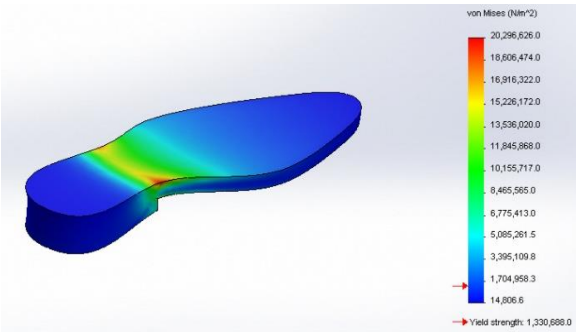

Fig.5: Von misses stress analysis

Table 2: Von Misses Stress Analysis

Analysis	Type	Min.	Max.
Static	Von Misses Stress	14806.6 N/m^2	2.02966e+007 N/m^2

2.5.2Equivalent Strain Analysis

Strain analysis was carried out to know where the strain was occurred in the outsole in case of stress. It is the relative change in shape of an object due to applied force. It is an actual physical quantity related to the change in dimensions. In most cases strain is known as equivalent of strain.

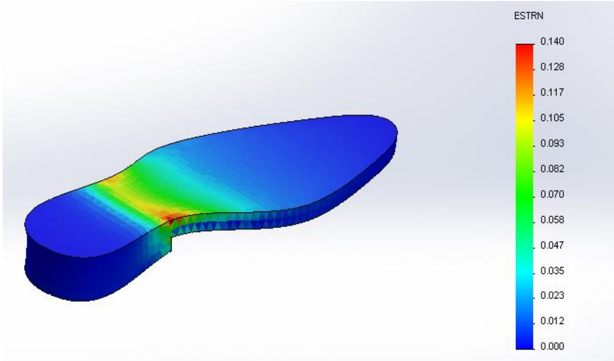

Fig.6: Equivalent strain analysis

Table 3:Equivalent Strain Analysis

Analysis	Type	Min.	Max.
Static	ESTRN: Equivalent Strain	0.000106541	0.140039

2.5.3 Buckling deformation analysis

Deformation is mainly depends on both force acting on the forefoot and material properties. Buckling produced when the structure is subjected to high compressive force. As an applied load is increased on a structure, it will ultimately become unstable and is said to have buckled. Buckling deformation analysis was carried out to know how much the outsole buckle under load in the toe portion which is very essential portion to maintain the shape of the shoe and human foot.

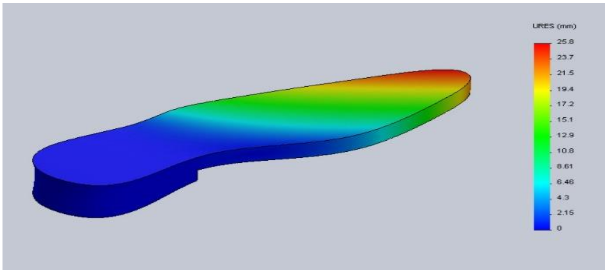

Fig.7: Buckling deformation Analysis

Table 4: Buckling Deformation Analysis

Analysis	Type	Min.	Max.
Buckling Deformation	URES: Resultant Displacement Plot for Mode Shape:1(Load Factor= -0.552555)	0 mm	25.8255 mm

2.5.4Thermalanalysis

Thermal analysis is an important part of the design process. Thermal simulation of the outsole helps to make better decisions that in which temperature of the outsole is withstand. There was no red marked in the outsole (simulated) which means there will be no crack developed in the TPR outsole.

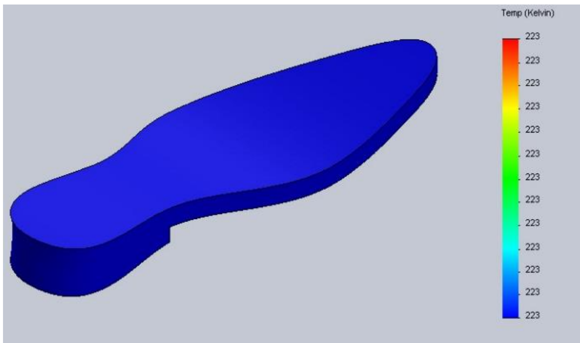

Fig.8: Thermal analysis of the TPR outsole

Table 5: Thermal Analysis

Analysis	Type	Min.	Max.
Thermal	Temp.: Temperature	223.15 Kelvin(K)	223.15 Kelvin(K)

2.5.5 Fatigue Analysis

Fatigue is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The fatigue analysis was carried out to ensure how long the outsole will be survived. To fatigue analysis the stress and strain analysis were performed. The fatigue analysis includes the percent of damage (Fig. 9) and the total life cycle (Fig.10).

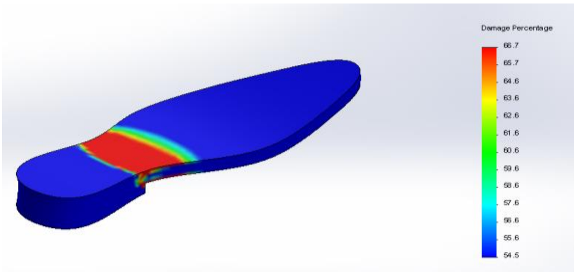

Fig.9: Percentage damage of TPR outsole

Table 6: Damage plot of outsole

Name	Type	Min.	Max.
Fatigue analysis	Damage plot	54.55	66.67

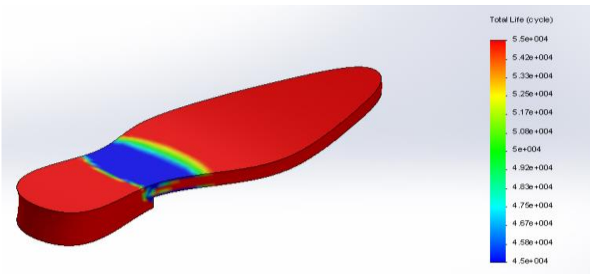

Fig.10: Total life cycle of TPRoutsole

Table 7: Life Plot of TPR outsole

Name	Type	Min.	Max.
Fatigue Analysis	Life plot	45000 cycle	55000 cycle

3. RESULTS AND DISCUSSION

3.1 Von misses stress and equivalent strain

The static von misses stress of the outsole in the heel breast portion was max. 2.02966e+007 N/m^2 and in the other portion von messes stress was min. 14806.6 N/m^2 (Fig. 5).The red marked (Fig. 5) which was located in the heel breast portion shows that the stress mainly occurs in this portion and blue portion shows that there was no stress. Von misses stress is considered to be safe for designer. An engineer could state or understand his/her design will fail if the if the max. value of von misses stress brought in the material is more than strength of the material [13]. In Fig. 6 the strains in heel breast portion was max. 0.140039 and other side was min. 0.000106541 (Table 3).It was clear from the stress and strain analysis that the max. stress and strain were occurred in the heel breast portion. Therefore, material density should be given more in this portion to prevent crack development.

3.2 Buckling deformation

In Fig. 7 it was clear that the buckling deformation of the outsole was max. about 25 mm at the toe portion and there was no buckling at the heel portion. The buckling load factor (BLF) was -0.55 (acceptable range, -1<BLF<0). Due to body weight of the human body, the outsole generally buckles on the toe portion and the shape of the shoe may be changed.

3.3 Thermal analysis

It was noticed that there will be no crack in the outsole even at -50°C. It could be varied up to –120°C depending on the variable amount of mass density and tensile strength of the TPR. The outsole was suitable for cold countries up to –50°C. Generally, crack is developed in the outsole in lowering temperature, but it could be easily forecast by the FEA up to which cold temperature the outsole will be sustained.

3.4 Fatigue analysis

In Fig. 9 shows the fatigue analysis, implies max. damage will be occur in the outsole at heel breast portion and it was 66.67%; on the other side of the outsole min. damage was 54.55%. The TPR outsole will be sustained (Fig. 10) max. 5500 and min. 4500 cycles, respectively. Designer/manufacturer should know how long the outsole will be stable and it could be predicted by the finite element analysis. The outsole life cycle can be easily extended by increasing the elastic modulus, mass density, tensile strength, yield strength.

The simulated results reveal that on which portion of the outsole should give more attention to make a perfect outsole for the footwear construction. The more attention should be given are toe and heel breast portions. In these portions of the outsole the materials properties should be maintained accurately to prevent crack development.

The validation of the finite element analysis results mainly depends on selection of accurate material property and finely meshing. Noticeably both the factors were maintained properly. Evidently, evaluation of the physical performance of the outsole was very essential before using them in footwear construction which can easily identify by the Finite Element Analysis. It could be conclude that Finite Element Analysis could be used in the footwear construction to save time and money.

4. CONCLUSION

In this paper complete solution of virtual prototype of outsole and physical performance evaluation was presented. In industry, vast production of a product mainly depends on prototype model that has to pass through time consuming trial and error cycle for its performance testing. The behavior of outsole and effectiveness under various physical conditions during walking could be easily predicted by finite element analysis. The simulated result from the finite element analysis easily help to decide in which physical property more attention to be given for making stable outsole for using. Besides CAD provide extra criteria to footwear industry for product design, product development and its sustainability in the environment. Also CAD and FEA reduce the prototype cost at a great extent.

5. REFERENCES

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