Sports shoe design using simulation and finite element analysis

Accepted 16th October, 2022

ABSTRACT

The main purpose of the present study is to calculate the impact force of shoe landing on the ground and making contact with the floor. The developed FE model is used to predict the mechanical interaction between the foot and various types of athletic shoes. A 3D solid model of the insole of a sports shoe was created using Solid Works Surface Modeling. Finite element (FE) analysis of the 3D mesh was performed on the imported solid model using Hypermesh software. Foot impact analysis was performed to determine peak force using an insole that was different from the final design. Sports shoes play a major role in sports when it comes to injuries. Injuries commonly occur in the knees, shins, ankles, and feet. Most of these injuries are primarily related to bone or connective tissue, and their main function is to transmit force from the muscles to move them. FEA analysis is basically a numerical calculation method involving the use of computer. It provides piecewise (mesh) analysis under specific boundary conditions. It is used to design new products and modify existing products. Also, it is commonly used to solve structural, mechanical, heat transfer, and hydrodynamic problems.

Key words: Finite element analysis, Hypermesh, peak force, solid-works, sports shoes, simulations.

INTRODUCTION

Athletic shoes have been in use since the mid-1950s and were originally designed for the specific purpose of maximizing functionality, comfort, and athletic performance. Athletic shoes are categorized into running, training, walking, field sports, winter sports and other types of specialty shoes. The development of shoes has been done for many years to protect the feet from the rugged terrain. Egyptians have been wearing shoes for a very long time, even during war. They went barefoot during the war. Later, in the mid-1850s, styling was more important than utility,
especially for women. The old sports shoes did not have this distinction, they all copied the same style. Skating boots were considered the only shoe to use a high ankle design with some cleats. Leather strips were sometimes machined on the soles of soccer shoes to improve grip. In the mid-20th century, soccer and baseball players wore the same type of shoes. Previously, the enthusiasm for sports was limited to the wealthy upper class, but then everyone in every class began to enjoy it.

People’s interest in sports later led to the establishment of the Olympic Association. Vulcanized rubber was later used by the shoe people and eventually became a term such as sneakers and canvas shoes. In all sports, the use of athletic shoes has started to increase significantly. The general public started mass production of shoes in the latter half of 2000 in response to the needs of the people. As the enthusiasm for sports shoes has increased, the competition between people has also intensified, and sports shoes of various designs have been chosen as achievements by athletes who depend on sports shoes. To meet people’s demands, the main focus was on shoe protection and functionality. Over time, mountaineering shoes have also been developed to reduce accidents during mountaineering, and different types of shoes have been developed for hunting, so as not to hurt the feet of poachers (Knapik et al., 2016).

As competitive behavior began on the Olympic fields and basketball courts, followed by World War II, shoes with better performance and better athletic results were considered. Canvas sneaker in basketball dominated the American footwear market while immediately became a youth style symbol when worn with blue jeans. Later, a brand named Asics was announced that uses nylon uppers and rubber wedges and midsoles for their shoes for marathon runners.

Adidas and Puma totally dominated the footwear market in every international sports, they collaborated with all major teams in all sports and started to advertise their shoes on a large scale. Adidas sport shoes were so hyped in various universities such as UCLA and Houston, such that their players would only wear them during tournaments (Kahle et al., 2016). By the end of the 1970s, the scene of sport In the late 1970’s the sports industry scene in the US completely changed as the sheer dominance of the giants was seen there and they optimized their shoes to a further degree by adding different types of cushioning in the midsole area and along with a new lacing mechanism, which was loved by people and they decided on the changes very quickly.

The main purpose of shoes in the past was to prevent people from getting hurt, so people wore them. However, as time went on, people’s needs changed, and after a while, the main justification for wearing shoes changed and it was calculated on the basis of performance because the better the quality of the shoes, the better the player’s performance will be. A sports shoe is mainly made up of outsole, midsole, insole, upper and several reinforcements in order to support the shoe.

The shape and design differ for different sports shoes on the basis of playing condition. It is important that shoe design is always based on the type of sport. Various factors are also taken into consideration when designing shoes. Therefore, the performance of a player also depends on the type of shoes the player uses. At present, the finite element method is also used to calculate the impact force when a shoe lands or hits the ground, and all deformations can be seen. Based on this, many calculations are made to evaluate the increased performance of the shoe (Willwacher et al., 2013).

**PROBLEM DESCRIPTION**

**Landing impact and its evaluation**

The motion of the foot in every sport is completed with a landing and it is very necessary that the landing is done with proper posture, and injury should be avoided. The intensity of the impact is
always measured by the force of impact. Impact landing exerts direct force on the foot always. The essential glutinous fluid inside the human foot absorbs the shock and to some extent prevents it from being transmitted forward. However, if the person is not wearing an athletic shoe, the risk of injury is greatly maximized.

The features of the touchdown effect such as impact force, load factor and stress epicenter depend on various kinds of factors such as the material of the shoes, the person’s landing, the speed of movement, the body and ground situation. Therefore, the evaluation of such properties is very important for understanding the mechanism of action and its transmission through the human body. By using such residual limb data, you can reduce unexpected injuries and lower limb injuries. Recently, it has become an indispensable technology for shoe design, meeting the need for high-quality athletic shoes that maximize comfort and playability. However, reliable assessment of landing impact characteristics is not simple and complex, so it was usually performed by experiments with specially designed experimental equipment. On the other hand, Shoe layout, which is mainly based entirely on the evaluation of performance characteristics, requires dating between the limits of shoe layout and the overall performance of prevailing shoes. Therefore, parameter experiments associated with effect traits and shoe overall performance are important. In this regard, the reliance on experimentation to improve excessively beautiful athletic shoes, which is currently characterized by frequent version changes and short development times, may also face some obstacles in terms of value and time. The major obstacles to experimental technique may be overcome if they are verified (Joseph et al., 2017).

**Lower leg and sports shoes**

The human foot is made up of multiple bones, cartilage, tendons and ligaments rooted in the underlying tissues of a totally complicated structure. From a biomechanical point of view, the relative movements of many joints, including the ankle and subtalus, are now controlled not only by the ligaments but also by the tendons, which can be vital in explaining kinesiology of the foot skeleton. It is important because it is there. Soft tissues and skin, on the alternative hand, constitute effect absorption and cargo switch via the human body. Due to those difficulties, numerical evaluation associated with foot effect has historically been done on simplified foot fashions inclusive of easy difficult bone-hyper elastic tissue fashions, three-D skeletal fashions that do not recall gentle tissues. Sports footwear encompass an outsole, midsole, insole, top, lace, and diverse practical additives inclusive of heel counters and arch supports. The outer floor of the outsole is covered with a unique sample to enhance traction overall performance at the ground. The different soles, on the alternative hand, soak up maximum of the effect, and each the top and lace have an effect on health and the energy of the shoe-foot contact. Sport-precise capability is accomplished through putting well designed practical additives. As compared with the human foot, the sneaker additives can be easily determined by a specially designed shoe testing device. However, the construction of a 3D complete shoe version that represents person elements in elements no longer requires the simplest complicated modeling work, but also a large selection of specific elements. In addition, the connection between the base and the sneaker fashion will greatly increase the problem. Moreover, a mixed sneaker versions are vital to make reliable results (Hoogkamer et al., 2018).

**MODELLING MUSCLE DIGITAL FOOT**

Computer-aided design is increasingly being used to reduce pre-design and prototyping time and costs, and much of today’s design work is done in virtual environments. Virtual environments are
increasingly equipped to handle complex components and mechanical aspects associated with machine design, but are done to include human interactions in the early product design and testing stages. I rarely do that. Although avatars are now widely used in the film and gaming industry, they lack a physics-based method of predicting true movement and posture. They are programmed to resemble realistic movements and postures, but it is not possible to determine if the movements are really realistic. These digital humans also cannot meaningfully interact with digital design prototypes. For this reason, we will introduce the developmental stages of digital human beings that can respond to external stimuli such as strength and fatigue. The essay begins with physiology and biology related to understanding the mechanisms by which humans generate force.

3-D MODEL OF FOOT-SHOE FEM MODEL

Figure 1 shows the CAD model of the shoe created using solid-works modeling software. The geometry of shoe is created with reference to sport shoe design. The meshing will be done with element size of 8.00 and after the meshing, a load collector of force will be made and force will be applied on the heels on the shoe to calculate the impact force.

The shoe is made up of three soles and the material which is used to make the shoe is elastic, equivalent to the composite finite detail version of coat sports shoes. Each shoe component is absolutely related to adjoining components through the use of a node bonding technique. The FEM mesh for every sneaker component is built in order that the mesh distribution of the 2 adjoining components is precisely identical alongside the not unusual place area. The shoe version is built in order that its internal floor makes true touch with the outer floor of the smooth tissue-version.

Figure 2 shows the very last blended 3-D foot shoe finite detail version and the corresponding photograph illustration of its structural composition. The principal function of this contemporary version is that it knows the decrease limbs that aid the athletic footwear and is absolutely loose to breed any form of foot motion that could arise in an actual carrying event. This model is not only simplified and limited, but also highly exemplary as compared with traditional simulation models that rely on experimental data to explain the effects of foot-shoe interactions. In the initial phase, the Solid Works shoe model is imported into Hypermesh, after importing the model model, the mid-surface of the shoe is extracted, after extraction, meshing is done in Auto-Mesh panel with element size 8, after meshing of component material is been assigned along with its properties.

In order to make the shoe, card image MAT20 is used as the material, which is also known as MAT_RIGID (Figure 3). In this whatsoever part or
Figure 3: MAT20 material is used to make the shoe in hypermesh.

Figure 4: Assigning material properties to the shoe; Rho = 1.130e^-06, E = 210.00, PR = 0.300.

Component is made up of this material is considered to belong to a rigid body. The coupling between the rigid bodies is also defined by this material. On the mass center, optional global and constraints are also defined (Figure 4).

Numerical experiments:

A mass of 45kgs is applied on the heel of the shoe and the landing impact analysis is being conducted in which different types of graphs will be plotted and the amount of pressure will also be shown in the figures so that proper results are observed (Figure 5).

Results:

• After conducting the preprocessing part in hypermesh along with its boundary condition, the file is exported to dot K extension which is the file type of Ls Dana model and then the processing is done in ls-dyna for results.
• **ITERATION No. 1:**

Figure 6: Small value of young modulus is applied as material property, that is, $E = 1.00$ in iteration 1.

**With Pressure:**

Figure 7(i) Time – 1.0995

Figure 7(ii) Time – 2.0996

Figure 7(iii) Time – 3.1994

Figure 7(iv) Time – 4.7998

Figure 7(v)

Figure 7(vi)

Figure 7(vii)
Figure 7: Results of the processing in Ls-Dyna which simulates shoe impact on the surface with the assigned material property and force. Figure (i-iv) shows different time stamp of a shoe impact. Figure (v-x) different pressure exerted on the shoe while in action. Figure (iv) and (ix) - shoe sole getting crushed in the surface and the impact pressure is very high as the young modules value is not sufficient (that is, less elastic), this will cause severe injury to foot.

GRAPHS:-

1. Rigid Body Displacement :-

Figure 8 (i): Graph showing rigid body displacement with time in the first iteration of the simulation.

2. Rigid Body Velocity :-

Figure 8 (ii): Graph showing rigid body velocity with time in the first iteration of the simulation.

3. Rigid Body Acceleration :-

Figure 8 (iii): Graph showing rigid body acceleration with time in the first iteration of the simulation.
• **ITERATION No. 2 :-**

![Table of Material Properties](image)

**Figure 9:** Larger value of young modules is applied as material property i.e. \( E = 10.00 \) in iteration 2.

![Time 1.199](image)

**Figure 9 (i) Time – 1.199**

![Time 2.599](image)

**Figure 9 (ii) Time – 2.599**

![Time 3.299](image)

**Figure 9 (iii) Time – 3.299**

![With Pressure Time 4.599](image)

**Figure 9 (iv) Time – 4.599**

**With Pressure :-**

![Time 1.199](image)

**Figure 9 (v)**

![Time 2.599](image)

**Figure 9 (vi)**

![Time 3.299](image)

**Figure 9 (vii)**
2. Rigid Body Velocity :-

Figure 10(ii): Graph showing rigid body velocity with time in the second iteration of the simulation.

3. Rigid Body Acceleration :-

Figure 10(ii): Graph showing rigid body velocity with time in the second iteration of the simulation.

RESULTS AND CONCLUSION

In the present study, force impact analysis was done for a shoe model in which RBE3 with a mass of 37.6 kg was applied on the shoe; the sole and heal thickness was 9 and 28 mm, respectively (the thicker the sole the larger amount of peak force it can sustain and reduce injury). Whole analysis was done with Ls-Dyna profile in hypermesh and the element size was 8. The material which was used for the shoe was MAT20, that is, MAT_RIGID which has properties of carbon rubber. Thus, this rubber compound uses carbon black (CB) as a filler. The functions of the Carbon black filler are to strengthen, increase the volume, improve the physical properties of rubber, and strengthen
vulcanization. The results of the rubber compound can be useful in making shoe soles. We can also increase or decrease elasticity of the material in real world by adding sulphur to it.

Young’s modulus is the measure of stiffness or rigidity of a material. The Young’s modulus is also referred to as the modulus of elasticity. The ratio of stress to the corresponding strain below the proportional limit gives the value of Young’s modulus. The Young’s modulus of the material of a wire decreases with increase in temperature. In the "Results" section, under the heading "Iteration-1", the Young’s Modulus (E) of the model is 1 N/m², which means that whenever the shoe lands on the ground, there is a higher risk of injury due to the lower stiffness. As shown in the figure in Iteration-1, at time frame of 4.7998, it is clearly visible that the sole of the shoe is totally crushed which ultimately leads to foot injury. So it is necessary that the stiffness of the sole should be more so that at the time of shoe impact on the floor, there are less chances of injury to occur, so that is why in Iteration-2 the Young’s Modulus (E) of the shoe is set to 10 N/meter square, which clearly shows in the time frame of 3.299 that the sole of the shoe is not crushed, which means the risk of injury is very low.

Since we know that the formula of force is equal to the product of mass and acceleration:

\[ F = M x A \]

In the Iteration-2 section, according to the graph, there was an acceleration of about 10 m/s², and in the above figure the mass is 37.6 kg. So, using the formula, we can calculate the force. Hence the calculated Peak Force was obtained as 376 N. This is the force that the shoe can take without causing any injury to the foot.

REFERENCES


