Design and Simulation study of fire-resistant biodegradable shoe

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Abstract: Today’s generation is run over by fashion and its acts as a symbol of class and prestige. Due to which people tend to buy things without thinking and then the old ones are dumped. The same trend is followed in the footwear industry where the user tends to buy things and then throw it. This has led to the huge pile of footwear which are waste to them and these tend to end up in landfill and harm the environment and affect the health of the humans. Improper shape and material used in shoes tend to affect our ankle, gluteal calf muscles and in the longer run, it forms small ripples of vibration which slowly but surely affect our lower back. This is an essential commodity in today’s world and its reliability I not that great in run according to research and various surveys. So, considering that there was a need to find an alternative design and material. Nowadays, the industry is moving toward environment inspired biodegradable, biocomposite materials and design, as it is easy to work with them and are inexpensive at the time. There are many biocomposites in India to choose from ranging from sisal, banana leaf, hemp, jute, bamboo etc. There is a desire to make this shoe available to the last person without compromising on its compressive strength, tensile strength, modal, nonlinear, life and wear. So, it was concluded to go back to our roots to find a material and design to do an amalgamation of science and Vedas. So, the traditions we are performing on the selected material and some parts of design are inspired by our Vedic knowledge backed by virtual testing and some modern techniques.

1. INTRODUCTION

The footwear industry is a diverse manufacturing sector having 19 billion shoes produced every year, it is ranked 2nd in the fashion industry [1,2]. In today’s fast phase life, there is a demand for shoes according to their respective work or personal life, there are shoes from home slippers to sports shoes to customize ones. There is a competition to produce shoes. There is a new design of shoes coming every month and people buy a new pair of shoes for every 3 to 4 months and discard the old ones [2,4]. The disposal of old shoes becomes a problem as current materials are not easily decomposed due to which there is global warming causing and other major effects on the environment. Also, there is a tremendous increase in cost due to the variety of shoe available. [2,3]

Due to all mentioned points, there is a need to produce shoes that are less in cost, environment friendly mainly that is eco-friendly. As the world is moving towards an environment-friendly alternative for everything, there are experiments being performed even is footwear industry in the field of the biodegradable shoe, some of the experiments are using mushroom species, plans, woods etc that are

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easily procured, decomposed quickly and cost less as compared to above materials.

2. MATERIAL SELECTION

Presently the shoes are made of leather, plastic and rubber all these materials have major disadvantages, as in the case of leather it heats up in summer and makes us feel chills in winter, it at times tends to become stiffer and layers of leather or laterite come out [7]. On the same time, it is banned by PETA. On the other hand, plastic is flammable, not easily decomposable and has many health hazards. When both materials are burnt it produces carbon monoxide that is harmful to the environment as well as us as our haemoglobin has an affinity to react with Carbon monoxide over oxygen [8]. Therefore, there is a need of a material that is easily decomposable, non-flammable, environmental and cost-friendly. Detailed literature survey observed some biodegradable materials which are bamboo [4], mushroom species [5,11] such as King Oyster, Reishi, Yellow oyster, Mahogany fruit bark with Neem leaves [6], natural rubber, wool, silk with lyocell and lavender used as fragrance [9,10,16]. The detailed study of all the materials on the basis of their properties helped us to identify wood, natural rubber and eucalyptus. We have used taking into consideration the material stated in Table 1 for testing purpose.

| Material       | Young’s modulus (GPa) | Tensile strength (MPa) | Flexural strength (MPa) |
|----------------|-----------------------|------------------------|------------------------|
| Abaca          | 41                    | 500-700                | 40.24                  |
| Pineapple leaf | 127                   | 6.51                   | 21                     |
| Steam of corn  | 95.8                  | 74                     | 17.4                   |
| Bamboo         | 5-25                  | 100-800                | 76.5                   |
| Coconut shell  | 856                   | 30.6                   | 46.5                   |
| Flax           | 60                    | 345-1035               | 4.3                    |
| Hemp           | 30-60                 | 400-938                | 54                     |

3. MANUFACTURING PROCESS

In this process for manufacturing, 6 different shapes and types of wood were chosen and were tested as per SATRA TP3 standards. In this type of testing all the shoes are subjected to compressive testing, impact testing etc for getting a clear picture about its comfort to the user and how much does it reduce any shock absorption, Cushioning assessment, Resistance to compression set, Flexibility, Ground insulation, Friction of in socks and linings[17]. Whole shoe thermal insulation (cold rating) and Water vapour permeability and absorption. And finally, this layer was submerged in mustard oil for 3 days and then left to dry for 96 hours after which a layer of artificially prepared rabbit teeth composition was applied on it and finally a special gel made after analysis composition of the lotus leaf is applied on to make it waterproof.

3.1. Biodegradable Shoe

In this, the shoe divided into two main parts sole and upper covering. Here the upper covering is a combination of vape, vane, welds footbeds etc. as shown in Figure 1.
4. Problem statement

Use of coatings on the shoe to make it more efficient by reducing the effect of structural loads as well as the thermal load on it under various conditions and at the same time make it biodegradable

5. Methodology

A step by step procedure was carried out from design to simulation using tools like Catia V5 and ANSYS 18.2 version.

6. Virtual analysis of the material

Here we have done the nonlinear, static structural analysis, modal analysis, on the shoe considering the wood and rubber as a material for shoe sole and eucalyptus fibre material for vape, vane and toes of the shoe and tried to find at what level does it.

The analysis is done through Ansys 18.2, considering the following conditions

- Force = 840N
- Velocity = 18m/s
- Temperature = 446°C
- Thermal conduction at top = 100°C
- Convection = 35°C
- Conduction at base = 85°C
- Convection at base = 20°C

**Figure 1.** Body of shoe
Boundary conditions
The pressure is applied to the inner sole (that comes in contact with the human skin). And the lower part of the sole is fixed (where the sole comes in contact with the ground) as shown in Figure 2 and its characteristics in Table 2.

6.1 Mesh Model

![Mesh Body](image)

**Figure 2. Mesh Body**

| Model Name     | Nodes   | Elements  |
|----------------|---------|-----------|
| Shoe (Coarse)  | 7964    | 3394      |
| Shoe (Fine)    | 6328826 | 4179545   |

To improve and check the convergence of the results, two methods were used:

a) H-type: This technique involves altering the global size of the element set during the meshing process either with raising or lowering the size of an element without changing the type of mesh being used in simulations. Which results may not always converge [12,13].

b) P-type: This approach focuses on the form of mesh used in the analysis, keeping the size of the element constant. Which means the order of the elements is changed Higher-order means more reliable results, but it needs more computational time, noticeably [13,14,15].

6.2. Linear static structural
During the analysis, we have fixed the bottom of the shoe sole and applied the pressure of 840N on the upper part of the shoe.
The results we have got during the analysis are as shown in Figure 3, Figure 4, Figure 5 and Figure 6:-
6.2.1 Considering only sole

a) In case of rubber

Figure 3. (a)- a) Equivalent total strain b)Total deformation c) Maximum principal stress

b) In case of wood

Figure 4. - a) Equivalent total strain b) Total deformation c) Equivalent stress

Table 3. Characteristics in linear analysis of sole only

| Material / Parameters | Total deformation (mm) | Equivalent total strain (mm) | Equivalent stress (MPa) |
|-----------------------|------------------------|------------------------------|-------------------------|
| Wood                  | 9.78e-12               | 5.5327e-12                   | 0.0044                  |
| Rubber                | 3.8774e-10             | 4.5975e-8                    | 0.0043                  |

Table 3 summaries the effect on sole under linear analysis
6.2.2 Considering whole shoe

A) In case of rubber

Figure 5. a) Equivalent total strain b) Total deformation c) Maximum principle stress

B) In case of wood

Figure 6. a) Equivalent total strain b) Equivalent principle stress c) Total deformation

Table 4. Comparative study for Shoe as a whole

| Material / Parameters | Total deformation (mm) | Equivalent total strain (mm) | Equivalent stress (MPa) |
|-----------------------|------------------------|------------------------------|-------------------------|
| Wood                  | 4.035e-12              | 4.029e-12                    | 0.0034                  |
| Rubber                | 3.7844e-10             | 1.577e-8                     | 0.04                    |

Table 4 summarises the effect on shoe as a whole
6.3 Modal analysis
During the analysis we have fixed the cover of the shoe the results are shown in Figure 7 and results concluded in Table 5

![Figure 7. a) Directional deformation b) Total deformation c) d)](image)

| Material / parameter | Total deformation (in mm) | Directional deformation (in mm) |
|----------------------|---------------------------|-------------------------------|
| Wood                 | 3.6624                    | 3.6622                        |
| Rubber               | 7.653                     | 7.543                         |

In case of modal analysis, it can be seen that after we replace rubber sole by wood, the deformation tends to reduce by a factor of 2 and thus the structure becomes more rigid giving more support to our leg and feet[16,17]. This, in turn, leads to less pressure getting applied to our lower back and calf muscles. Thus, in the longer run, it will lead to fewer alignments as told by medical experts and also in the Holy book of Indian culture. As more load leads to the strengthening of leg muscles and this material is biodegradable so it leads to less carbon footprint[18,19] and thus safer and better for the environment[20]. The results are summarised in Table 4

6.4 Linear static structural (whole body)

![Figure 8. a) Total deformation b) equivalent total strain c) maximum principle stress](image)

During the analysis, we have fixed at the bottom of the shoe sole and applied the pressure of 0.0533 MPa on the upper part of the sole as shown in Figure 8. The results we got during the analysis are as follows in Table 6 and Table 7:

6.4.1 Consider sole only
Table 6. Characteristic of sole under linear static structural analysis

| Material / parameter | Total deformation (in mm) | Equivalent total strain (in mm) | Equivalent stress (in MPa) |
|----------------------|---------------------------|---------------------------------|---------------------------|
| Wood                 | 9.19                      | 9.029                           | 0.084                     |
| Rubber               | 1.0012                    | 0.069                           | 0.012                     |

6.4.2 Considering whole shoe

Table 7. Characteristic of Whole Sole under linear static structural analysis

| Material/ Parameter | Total deformation (in mm) | Equivalent total strain (in mm) | Equivalent stress (MPa) |
|---------------------|---------------------------|---------------------------------|-------------------------|
| Wood                | 1.277                     | 9.029                           | 0.084                   |
| Rubber              | 1.0733                    | 0.0688                          | 2.5881                  |

6.5 Thermal analysis

As the shoe undergoes friction so we go through the thermal analysis on both the shoe and its base to make the shoe thermally stable we have added powdered rabbit teeth. And the analysis is taken wrt to rabbit teeth (composition)

During the analysis, we have divided the shoe into two parts the upper shoe and the sole

6.5.1 Thermal Load applied on shoe

![Figure 9. a) Temperature b) Total heat flux](image)

We have added the temperature at the top and we have taken the other side as the convection and also taken the film coefficient as shown in Figure 9 and concluded in Table 8

Table 8. Results with respect to Rabbit Teeth

| Rabbit teeth | Temperature (Degree °C) | Total heat flux (W/m^2) |
|--------------|--------------------------|-------------------------|
| minimum      | 99.998                   | 9.689e-5                |
| maximum      | 100                      | 87.003                  |
6.5.2 Thermal applied on sole

![Figure 10](image)

For the base part during analysis we have added the temperature inside and convection at the other side. And considering all the essential value we got the result as shown in Figure 10 and concluded in Table 9.

| Rabbit teeth | Temperature (Degree ºC) | Total heat flux (W/m²) |
|--------------|-------------------------|------------------------|
| Minimum      | 39.998                  | 1.688e-10              |
| Maximum      | 40                      | 14.642                 |

7. CONCLUSION

- From virtual simulations, we can conclude that:
- The sole of the shoe manufactured using wood as the material has less total deformation compared to that of Rubber.
- The manufacturing cost of the shoe is drastically reduced by the usage of wood as the material compared to other materials as it available for us in the form of waste, thus results in us in low cost for the shoe.
- As the shoe made of wood will not harm our body like lower back, calf etc and acts as a good insulating material.

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