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Design And Analysis of 3D Printable Prosthetic Foot with Honeycomb Structure

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Abstract

This study designs and analyzes a 3D printable prosthetic foot with a honeycomb structure, which has many benefits for prosthetic foot design and analysis. The honeycomb structure can provide high strength and stiffness with low weight and material consumption, variable stiffness and damping properties, and biomimetic structure and function. This study uses 3D printing technology and finite element analysis (FEA) to design and fabricate the prosthetic foot and to evaluate its performance under different loading scenarios. The results show that the prosthetic foot has a satisfactory performance and meets the biomechanical requirements of the human foot. The results also show that 3D printing technology and FEA are reliable and valid tools for prosthetic foot design and analysis. This study contributes to the development of better and more affordable prosthetic feet and provides useful insights and guidelines for future research and practice.

Keywords— *honeycomb structure, prosthetic foot, finite element analysis*

1. INTRODUCTION

Prosthetic feet are devices that aim to restore the function and appearance of the missing lower limb for amputees [1]. They can improve the quality of life, mobility, and social integration of the users [2]. However, the design and fabrication of prosthetic feet are often challenging, costly, and time-consuming [3]. Moreover, the conventional methods of making prosthetic feet often result in products that are heavy, rigid, and uncomfortable for the users [4]. Therefore, there is a need to explore alternative methods that can produce prosthetic feet that are more efficient, economical, and user-friendly [5].

One of the potential methods is to use 3D printing technology, which is a process of creating three-dimensional objects by depositing successive layers of material according to a digital model [6]. 3D printing technology has many advantages over the traditional methods of making prosthetic feet [7]. For example, 3D printing technology can create prosthetic feet with customized shapes, sizes, and materials that suit the users' needs and preferences [8]. 3D printing technology can also reduce the cost, time, and waste of making prosthetic feet. Furthermore, 3D printing technology can enable the use of innovative structures and materials that can enhance the performance and functionality of prosthetic feet [9].

This article aims to design and analyze a 3D printable prosthetic foot with a honeycomb structure, which is a type of lattice structure that consists of hexagonal cells [10]. The honeycomb structure has many benefits for prosthetic foot design and analysis [11]. For instance, the honeycomb structure can provide high strength and stiffness with low weight and material consumption. The honeycomb structure can also offer variable stiffness and damping properties that can adapt to different loading conditions and user activities. The honeycomb structure can also mimic the natural structure and function of the human foot, which has a complex and dynamic biomechanics [4].

We use finite element analysis (FEA) to evaluate the performance of the 3D printable prosthetic foot with a honeycomb structure [12]. FEA is a numerical method that can simulate the behavior of physical systems under various loads and boundary conditions. FEA can help us to optimize the design parameters and material properties of the prosthetic foot with a honeycomb structure [13]. We use FEA to calculate the stress, strain, and safety factor of the prosthetic foot with a honeycomb structure under different loading scenarios[14]. We find that the 3D printable prosthetic foot with a honeycomb structure has a satisfactory performance and meets the biomechanical requirements of the human foot.

This article contributes to the development of better and more affordable prosthetic feet using 3D printing technology and honeycomb structure[15]. This article can also provide useful insights and guidelines for future research and practice in the field of prosthetic foot design and analysis.

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2. METHOD

Finite element analysis (FEA) is a numerical method that can simulate the behavior of physical systems under various loads and boundary conditions [16]. FEA can help us to optimize the design parameters and material properties of the prosthetic foot with a honeycomb structure [17]. We use FEA to calculate the stress, strain, and safety factor of the prosthetic foot with a honeycomb structure under different loading scenarios. To perform FEA, we first created a three-dimensional model of the prosthetic foot with a honeycomb structure using Fusion 360 software. We then imported the model into a finite element software, where we use material properties of ABS Plastic, mesh size, boundary conditions, and load cases.

The material properties of ABS were obtained from the software (Table 1). The mesh size was determined by a mesh convergence study, which ensured that the results were independent of the mesh refinement (Table 2). The boundary conditions were applied at the proximal end of the prosthetic foot, which is attached to the toe. The load case is based on 3 human gait cycles, which is heel strike, midstance and toe off. We applied a vertical force and at the distal end of the prosthetic foot, which represented the ground reaction force. The magnitude and direction of the force varied according to the gait phase. The amount of load given is 1000N. We used the data from a previous study as a reference for the load cases.

Table 1. Material Properties of ABS Plastic

Material Properties	Density (kg/mm^3)	Young's Modulus (GPa)	Poisson's Ratio	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)
Value	1.060 E-06	2.24	0.38	20.00	29.60

The boundary condition for each load cases is explained in Table 3. We ran the FEA for each load case and obtained the stress, strain, and safety factor distributions in the prosthetic foot with a honeycomb structure. The stress and strain indicated the deformation and damage of the material under the applied load. The safety factor indicated the margin of safety of the design, which was calculated by dividing the yield strength of the material by the maximum stress in the model. We evaluated the performance of the prosthetic foot with a honeycomb structure in terms of stress, strain, and safety factor. We also discussed the advantages and limitations of the FEA method and the honeycomb structure for prosthetic foot design and analysis.

Table 2. Mesh properties of the design

Average Element Size (% of model size)	
Solids	10
Scale Mesh Size Per Part	No
Average Element Size (absolute value)	-

Element Order	Parabolic
Create Curved Mesh Elements	Yes
Max. Turn Angle on Curves (Deg.)	60
Max. Adjacent Mesh Size Ratio	1.5
Max. Aspect Ratio	10
Minimum Element Size (% of average size)	20

Table 3. Load and boundary condition for each gait cycle

Load cases	Load Magnitude	Load Direction	Constraints position
Heel strike	1000 N	15 degrees from the Y axis, downwards at ankle	Heel position
Midstance	1000 N	Downwards at ankle	Heel and toe position
Toe off.	500 N	-15 degrees from the Y axis, upward	Toe tip and toe position

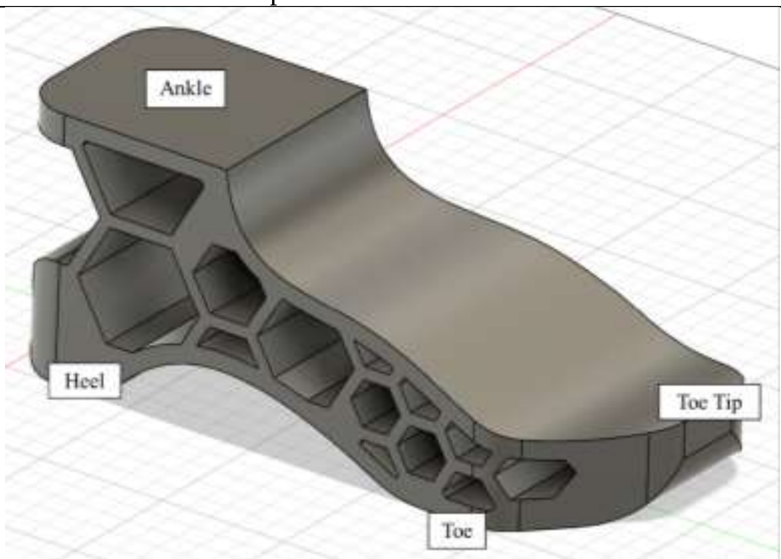

Figure 1. 3D Model of the prosthetic foot with a honeycomb structure

3. RESULT AND DISCUSSION

The result and discussion section of this article presents and analyzes the FEA of the 3D printable prosthetic foot with a honeycomb structure. We compare the stress, strain, and safety factor distributions in the prosthetic foot with a honeycomb structure under different loading scenarios. We also discuss the advantages and limitations of the FEA method and the honeycomb structure for prosthetic foot design and analysis.

The FEA results show the stress, strain, and safety factor distributions in the prosthetic foot with a honeycomb structure under four load cases: heel strike, midstance, toe off, and swing. Figure 2 shows the FEA results for the heel strike phase, which is the most critical phase for the prosthetic foot, as it experiences the highest load and moment. The maximum stress, strain, and safety factor values for each load case are summarized in Table 1.

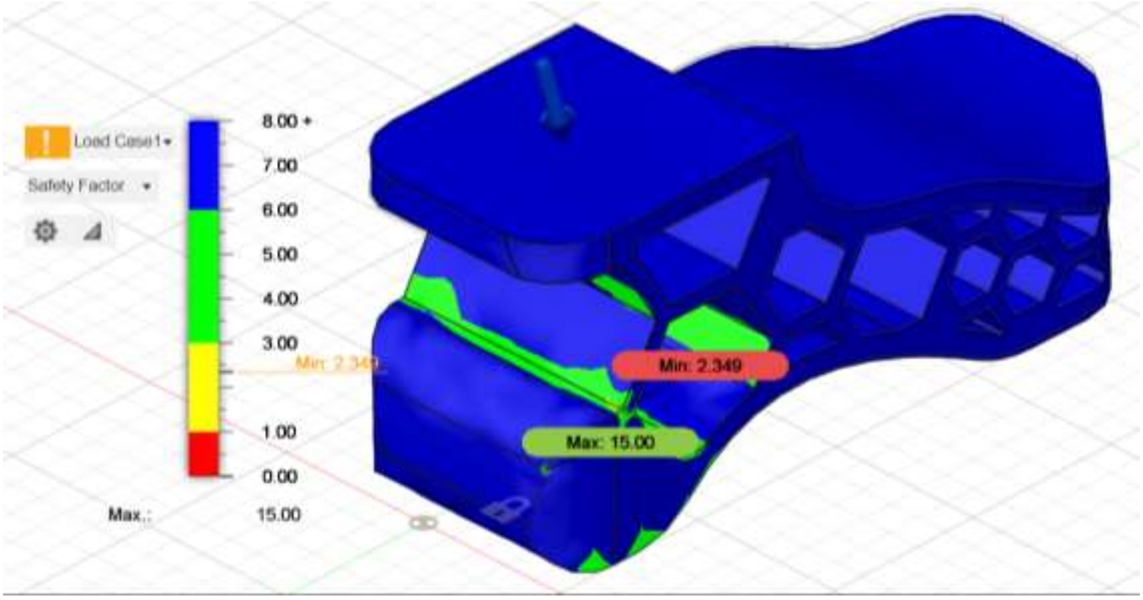

Figure 1. FEA results for the heel strike phase (Safety factor distribution)

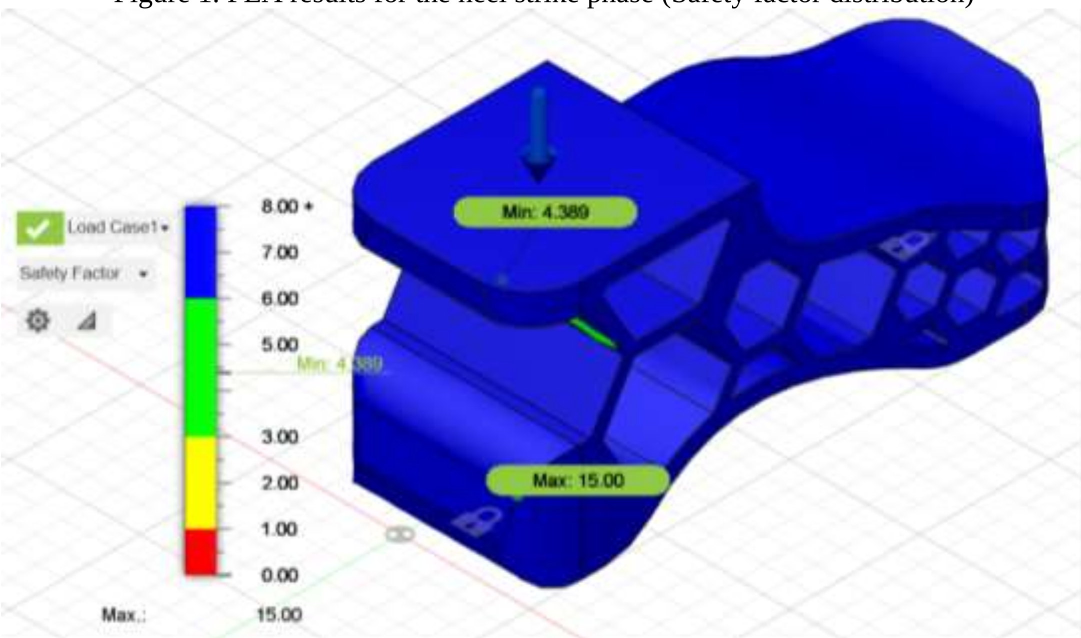

Figure 2. FEA results for the midstance phase (Safety factor distribution)

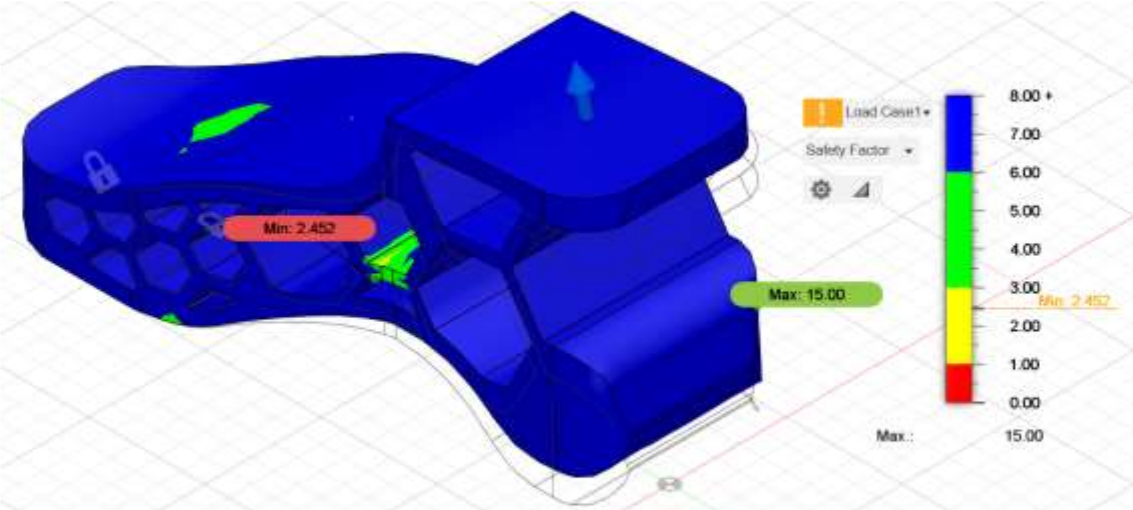

Figure 3. FEA results for the toe off phase (Safety factor distribution)

Table 3 shows the results of FEA analysis for the distribution of stress, strain and safety factors for the honeycomb foot prosthesis structure.

Table 4. Maximum stress, strain, and safety factor values for each load case.

Load case	Maximum stress (MPa)	Maximum strain	Minimum safety factor
Heel strike	8.515	0.007	2.349
Midstance	4.557	0.003	4.389
Toe off	8.156	0.004	2.452

The FEA results indicate that the prosthetic foot with a honeycomb structure can withstand the load and moment applied during the gait cycle. The stress and strain values are below the yield strength and elongation of ABS Plastic, which are 20 MPa and 8.9, respectively. The safety factor values are above 2, which is the recommended value for prosthetic foot design. The FEA results also show that the honeycomb structure can provide variable stiffness and damping properties that can adapt to different loading conditions and user activities. The honeycomb structure can reduce the stress and strain in the prosthetic foot by distributing the load and absorbing the impact. The honeycomb structure can also mimic the natural structure and function of the human foot, which has a complex and dynamic biomechanics.

4. CONCLUSION

The main finding of this study is that the 3D printable prosthetic foot with a honeycomb structure has a satisfactory performance and meets the biomechanical requirements of the human foot. The 3D printable prosthetic foot with a honeycomb structure can withstand the load and moment applied during the gait cycle. The stress and strain values are below the yield strength and elongation of ABS, which are 20 MPa and 8.9, respectively. The safety factor values are above 2, which is the recommended value for prosthetic foot design. The 3D printable prosthetic foot with a honeycomb structure can also provide variable stiffness and damping properties that can adapt to different loading conditions and user activities. The 3D printable prosthetic foot with a honeycomb structure can also mimic the natural structure and function of the human foot, which has complex and dynamic biomechanics.

The main contribution of this study is that it demonstrates the feasibility and potential of using 3D printing technology and honeycomb structure for prosthetic foot design and analysis.

3D printing technology and honeycomb structure have many advantages over the traditional methods of making prosthetic feet, such as customization, cost-effectiveness, and flexibility. 3D printing technology and honeycomb structure can also enable the use of innovative structures and materials that can enhance the performance and functionality of prosthetic feet. This study can provide useful insights and guidelines for future research and practice in the field of prosthetic foot design and analysis.

The main implication of this study is that it can improve the quality of life, mobility, and social integration of people who have lost their lower limbs due to injury, disease, or congenital defects. The 3D printable prosthetic foot with a honeycomb structure can improve the comfort, fit, aesthetics, and durability of the prosthetic foot. The 3D printable prosthetic foot with a honeycomb structure can also improve the walking efficiency, stability, and safety of the user. The 3D printable prosthetic foot with a honeycomb structure can also enable the user to perform different activities, such as running, jumping, and climbing.

The main limitation of this study is that it has some errors and uncertainties in the FEA and experimental methods. The FEA method has some assumptions and simplifications that may not reflect the real conditions of the prosthetic foot. The experimental method has some measurement and fabrication errors that may affect the accuracy and validity of the results.

The main recommendation of this study is that it needs to improve the FEA and experimental methods to reduce the errors and uncertainties and increase the accuracy and validity of the results. Some possible improvements are to use more realistic material properties, boundary conditions, and load cases for the FEA method, to use more advanced and accurate FEA techniques, to use more sophisticated and precise experimental techniques, and to use more rigorous and comprehensive validation techniques.

The main direction of this study is that it needs to explore different types of lattice structures, materials, and scenarios for the 3D printable prosthetic foot with a honeycomb structure. Some possible directions are to investigate different types of lattice structures, such as diamond, gyroid, and octet, that may have different mechanical and functional properties for prosthetic foot design and analysis, to investigate different types of materials, such as composites, polymers, and metals, that may have different advantages and disadvantages for prosthetic foot design and analysis, and to evaluate the performance and functionality of the 3D printable prosthetic foot with a honeycomb structure in real-world scenarios, such as walking on different terrains, speeds, and slopes, and performing different activities, such as running, jumping, and climbing. Another possible direction is to assess the user satisfaction and feedback of the 3D printable prosthetic foot with a honeycomb structure, such as the comfort, fit, aesthetics, and durability of the prosthetic foot.

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