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Design and Development of Ankle Foot Orthosis for Foot Amputated Person by Using Carbon Fibre

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Abstract

Ankle and foot orthotics play a pivotal role in the rehabilitation of individuals who have suffered a stroke, aiding in the restoration of their gait and overall mobility. However, optimizing the effectiveness of these orthoses requires a personalized approach that takes into account each patient's unique biomechanical characteristics. This study delves into the innovative use of carbon fiber combined with cost-effective 3-D printing technology to craft custom foot plate orthoses for individuals with partial foot amputations. The core of this investigation revolves around the development, testing, and validation of a novel prosthetic foot plate. To ensure precision in design and performance, the study begins by modeling the human foot as a finite element (FE) model, replicating the dimensions of a UK7-sized foot with a 2 mm thickness. This FE model serves as the foundation for the creation of the foot plate, enabling theoretical predictions and empirical assessments to be conducted with scientific rigor. One of the most significant findings of this research is the remarkable efficiency of carbon fiber in extending the length of the legs and mitigating strain on the delicate distal ends of the feet. By redistributing the weight to other areas of the foot or leg, the carbon fiber foot plate offers a breakthrough solution for enhancing balance, stability, and comfort for individuals with partial foot amputations. In summary, this study showcases the transformative potential of carbon fiber and 3-D printing in the realm of ankle and foot orthotics, with a particular focus on individuals with partial foot amputations. Through meticulous design, testing, and validation, the research underscores the importance of tailored orthotic solutions and offers a promising pathway towards optimizing gait rehabilitation and overall mobility for a diverse patient population.

Keywords: 3D printing, ankle foot amputation, carbon fibre, and orthoses.

INTRODUCTION

An amputation, whether resulting from illness or a traumatic accident, can have a profound impact on an individual's mobility and overall quality of life. In many cases, preserving as much of the natural limb as possible is a primary objective to maintain functional capabilities. Partial foot amputations, in particular, offer a potential advantage over more extensive amputations, as they allow for the retention of a portion of the foot. This preference arises from the observed functional benefits, which include mitigating issues like "toe drag during swing phase" and "foot slam during heel contact" that often occur with more extensive amputations [1].

Advancements in prosthetic technology have provided individuals with innovative solutions to replace missing body parts, such as limbs, thereby enhancing mobility and restoring some degree of normalcy. Prosthetic limbs are engineered to closely mimic the function and comfort of natural

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human limbs, offering hope and improved functionality to amputees. In the context of partial foot amputation, carbon fiber footplates and prosthetic sockets, produced using techniques like standard or stereolithography, have been instrumental in optimizing the gait cycle [2].

The surgical approach to amputation is a critical factor in preserving normal foot and ankle function. Retaining as much length as possible in the residual foot is a central objective in this regard. This study delves into the importance of maintaining the length of the residual foot to support normal foot and ankle function during walking. To achieve this, the study considers load conditions, taking into account ankle mobility and the concept of floor response force. By emphasizing the significance of preserving the length of the residual foot, this research contributes to the ongoing efforts to enhance the functional outcomes and overall well-being of individuals who have undergone partial foot amputations [3].

MATERIALS AND METHODS

Manufacturing of Insole using Carbon fiber using 3D Printing

The manufacturing process of insoles using carbon fiber and 3D printing represents a significant leap in orthotic technology, offering a precise and customizable solution for individuals with partial foot amputations. To achieve this cutting-edge approach, we follow a meticulously planned procedure that combines traditional and modern techniques, resulting in a superior product that enhances comfort and functionality.

First and foremost, the foundation of the insole is created through the traditional method of 3D template production. A UK7-sized template is used to ensure accurate foot measurements. To construct the insole, layers of carbon fiber, precisely cut to UK7 specifications, are strategically combined with epoxy adhesive [4], [5]. This meticulous layering process forms the core structure of the insole. To further enhance its durability and cohesion, an 80 kg weight is applied, exerting pressure to consolidate the carbon fiber layers into a unified piece while refining the surface finish.

Before transitioning to the actual manufacturing phase, we integrate state-of-the-art 3D printing technology to create a model. This model serves as a critical tool for cutting the carbon fiber to the exact shape and size required for the insole, ensuring a seamless fit and optimal functionality (as depicted in Figure 1). This 3D-printed model essentially acts as a mold in the subsequent stages of production, contributing to the precision and customization of the final product.

The journey towards the creation of the carbon fiber insole continues with the digital realm. The stereolithography CAD file (.stl) is generated following the meticulous 3-D modeling of the AFO foot plate within UG-NX software (Figure 2). This digital representation of the footplate is then imported into the UP-mini 3.0 application, which facilitates the 3D printing process [6]. The choice of ABS material for 3D printing ensures a balance between durability and flexibility, key factors in providing a comfortable and supportive insole.

In summary, the manufacturing process of insoles using carbon fiber and 3D printing harmoniously merges traditional craftsmanship with cutting-edge technology. This approach results in highly customized, durable, and precisely fitted insoles that not only enhance the gait cycle but also improve the overall quality of life for individuals with partial foot amputations. This innovative technique showcases the potential of advanced materials and manufacturing methods to revolutionize orthotic solutions for a diverse range of patients.

In accordance with the flowchart depicted in Figure 3, carbon fiber sheets are employed in the manufacturing process of the orthosis.

Theoretical Calculation

The orthosis is represented as a cantilever beam in the theoretical analysis of partial foot orthoses, with one side fixed and the load applied at the other end, as depicted in Figure 4. To calculate the maximum deflection and mass moment of inertia of the orthosis, specialized formulas are employed, drawing upon established principles and equations [7], [8], [9]. These calculations are essential in understanding the structural behavior and mechanical performance of the orthosis under various loading conditions, contributing crucial insights to its design and functionality.

$$y_{max} = \frac{W\times L_1^3}{3EI} + \frac{W\times L_1^2}{2EI} \times L_2$$

Where, y_{ma}x- Total deformation in mm.
L1, L2 - Length in mm.
E- Young's modulus N/mm2.
I - Moment of inertia in mm4.

$$I = \frac{t\times b^3}{12}$$

Where, t –thickness of plate in mm.
b- Width of plate in mm.

Figure 1. 3-D printed template to manufacture carbon fiber foot plate.

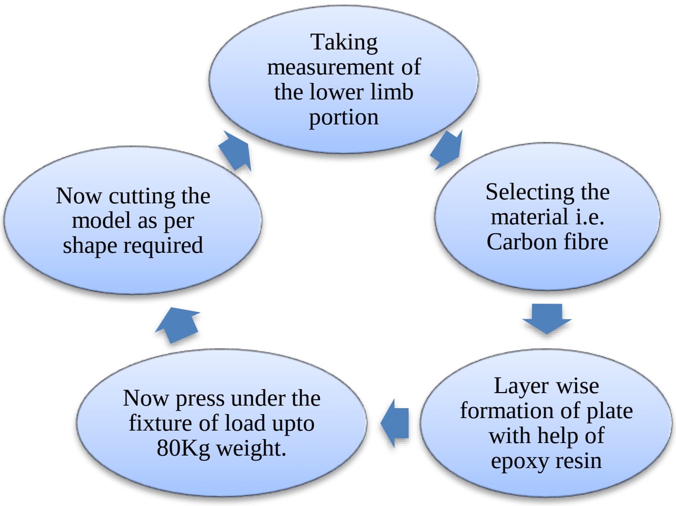


Figure 2. Flow diagram of manufacturing of AFO.

Figure 3. Carbon fiber Partial Foot Orthosis.

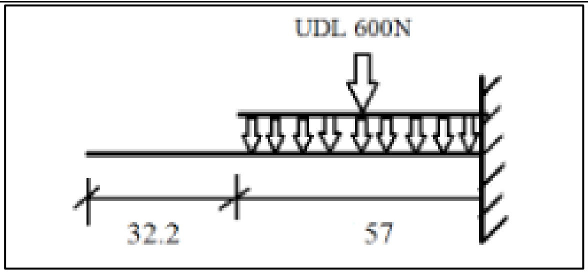
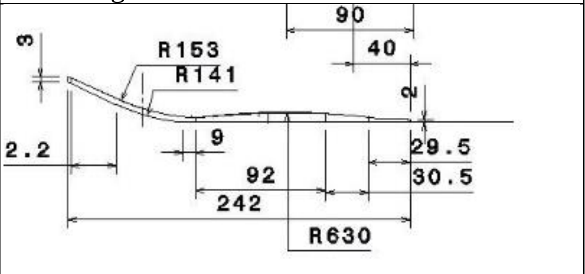
Beam and load cases	Foot Length
	

Figure 4. Foot orthosis considered as cantilever beam and the length of orthosis.

The deformation of the is calculated for 20kg, 30kg and 40kg load at heel using above formula as shown in below side Table 1.

Table 1. Theoretical calculation at Heel for different load conditions.

Load Applied	**Theoretical deformation**
20 Kg	0.729 mm
30 Kg	0.856 mm
40 Kg	0.829 mm

Theoretical Calculation at Toe for 20kg, 30kg and 40kg load is calculated using above formula as shown in below side Table 2.

Table 2. Theoretical calculation at the Toe for different load conditions.

Load Applied	**Theoretical deformation**
20 Kg	0.4120 mm
30 Kg	0.5527 mm
40 Kg	0.82419 mm

EXPERIMENTAL VALIDATION

According to the established procedure for testing the Partial foot orthosis device, the Venire caliper and load cell are installed on the experimental setup as seen in Figure 5. Clear any previous loading data from the load cell reading first. In situations 1 and 2, begin adding weights to the footplate to correct the toe and heel, respectively, following established protocols [10], [11], [12], [13]. Various stresses should be applied to the relevant areas, after which the toe and heel deformation should be measured using a digital Venire caliper and the findings should be recorded meticulously [14] [15]. These precise measurements are vital for evaluating the orthosis's performance and ensuring its effectiveness in real-world scenarios.

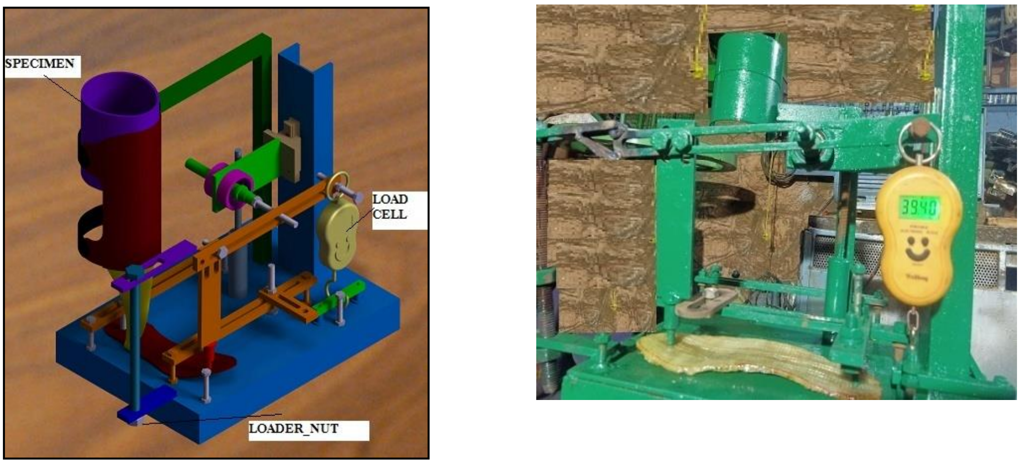


Figure 5. Foot orthosis considered as cantilever beam and the length of orthosis.

EXPERIMENTAL RESULTS

The experimental results show that 20 kg, 30 kg, and 40 kg of weight are applied to the toe and heel, respectively. We steadily increased the weight on the toe until it reached 40 kg while maintaining the heel in place. Experimental study conducted by [16] examines the tensile and flexural behavior of epoxy and SiO_2 composite, while another article focuses on the design and development of a carbon fiber-based Ankle Foot Orthosis for foot amputated individuals. [17] Highlight the experimental investigation of a composite material's hardness and tribology behavior, as well as the design and development of an innovative Ankle Foot Orthosis using carbon fiber, to assist individuals with foot amputations in regaining mobility and improving their quality of life. The toe deformation was measured using the start and end measurements of a digital Vernier caliper. To apply load to the area of the heel, a similar technique is used. In observation Tables 3 and 4, respectively, display the heel deformation.

Table 3. Observation table (Heel).

S.N.	Load applied (kg)	Initial Vernier reading (mm)	Final Vernier Reading (mm)	Deformation (mm)
01	20	5.85	5.11	0.74
02	30	5.85	4.88	0.97
03	40	5.84	4.44	1.4

The greatest distortion observed, measuring at 1.4 mm, although relatively minor, illustrates a noticeable trend where deformation in the heel area escalates proportionally with increasing applied loads. This insight highlights the orthosis's response to varying stresses.

Table 4. Observation table (Toe).

S.N.	Load applied (kg)	Initial Vernier reading (mm)	Final Vernier Reading (mm)	Deformation (mm)
01	20	14.2	13.51	0.69
02	30	14.3	13.46	0.84
03	40	14.4	13.36	1.04

Although the maximum deformation measured was just 1.04 mm, it is evident that the distortion in the toe region increases with higher applied loads. A comprehensive comparison of theoretical and experimental assessments conducted on both the heel and toe regions is presented in Tables 5 and 6, with corresponding comparative results depicted in Figure 6 and Figure 7. Remarkably, the outcomes of this comparative research indicate that the deformation estimated using all three methodologies consistently falls within acceptable limits. This consistency underscores the orthosis's reliability, as the deformation values remain practically constant across various computational approaches and load conditions.

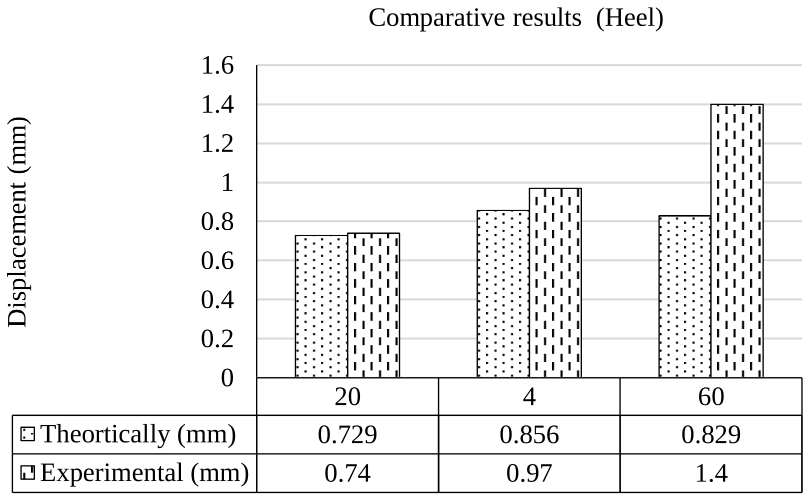
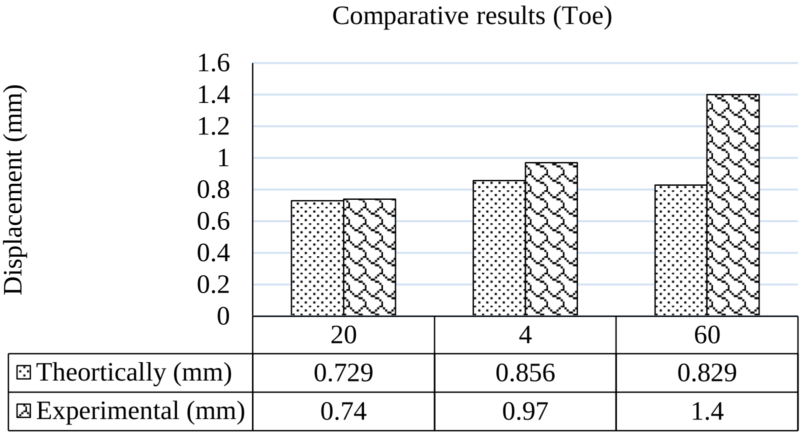


Figure 6. Comparative results (Heel).



	20	4	60
⊡ Theortically (mm)	0.729	0.856	0.829
▨ Experimental (mm)	0.74	0.97	1.4

Figure 7. Comparative results (Toe).

Table 5. Comparative results (Heel).

Load applied (kg)	**Theoretically (mm)**	**Experimental (mm)**
20	0.729 mm	0.74 mm
30	0.856 mm	0.97 mm
40	0.829 mm	1.4 mm

Table 6. Comparative results (Toe).

Load applied (kg)	**Theortically (mm)**	**Experimental (mm)**
20	0.4120 mm	0.69 mm
30	0.5527 mm	0.84 mm
40	0.82419 mm	1.04 mm

CONCLUSIONS

In conclusion, replicating the intricate design and functionality of the human foot remains a paramount challenge in the realm of prosthetic technology. The carbon fiber prosthetic foot, subjected to rigorous testing under various loads at the heel and foot, has demonstrated promising results. The data presented in Tables 5 and 6 underscore the alignment between theoretical predictions and empirical measurements of deformation at the heel and toe regions. The heel exhibits a percentage variation of 20%, while the toe demonstrates a slightly lower percentage variation of 17.5%. These findings reaffirm the feasibility of achieving functional parity with natural limbs using advanced materials like carbon fiber. As we continue to refine and innovate in this field, the potential for transformative advancements in prosthetic design and performance becomes increasingly attainable.

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REFERENCES

1. Chandrika Wagle, Dr. S.N.Padhi, Design And Analysis of Foot Plate Using Carbon Material For Partial Foot Amputation, *Trends in Biomaterials & Artificial Organs*, 35(3), page no: 273-276, (2021).
2. AnamikaSahu, Rajesh Sagar,Siddharth Sarkar, SushmaSagar, Psylogical Effect Of Amputation: A Review Of Studies From India, *Industry psycharist journal*, 25(1), pp. 4-10, (2016).
3. Sitaramamurty A.S.S.M., Krishnan V.L., Chakravarthy Y.K., Design of A Single Lower Extremity Exoskeleton System For Physiotherapy And Walking Assistance, *Journal of Advanced Research in Dynamical and Control Systems*, 73(6), pp. 444-457, (2017).
4. Chakravarthy Y.K., Vigneshwar P., Kedarnath P.V., Harish Y.S., Srinath A, Optimum Material Selection To Prosthetic Leg Through Intelligent Interface of Rsm And FEA, *Materials Today:*

Proceedings, 4(2), pp. 1998-2007, (2017).

5. Karthikeya K., Simulation And Analysis Prosthetic Leg, *International Journal of Mechanical Engineering and Technology*, 8(2), pp. 102-106, (2017).
6. Rao, An Experimental Investigation On Mechanical And Wear Properties Of Al7075/Sicp Composites: Effect of Sic Content And Particle Size, Tb, *Journal of Tribology-Transactions of The ASME*, 140(4), May (2018).
7. Polu, AR; Kumar, Preparation And Characterization Of Peg-Mg(Ch3coo)(2)-Ceo2 Composite Polymer Electrolytes For Battery Application, *Bulletin of Materials Science*,37(2), page no: 309-314, April (2014).
8. Anish; Chaubey, A; Kumar, A; Kwiatkowski, B; Barnat-Hunek, D; Widomski, MK, Bi-Axial Buckling Of Laminated Composite Plates Including Cutout And Additional Mass, Materials, 12(11), June (2019).
9. Bharat Satya Kumar Y., KalyanChakravarthy Y., Paladagu R.P., Venkatesh R., Srinath A., Development Of Force Plate For Prosthetic Applications Interfacing With Internet Of Things, *International Journal of Engineering and Technology*(UAE), 7(2.7), pp. 944-947, (2018).
10. Venkatesulu M., Rama Kotaiah K. (2019), Production And Mechanical Properties of Al 6063/B4c Composites, *Journal of Mechanical Engineering Research and Developments*, 42(1), page no:.46-49, (2019).
11. Teja K.M.V.R., Kunjunath B., Chandrasekhar K., Kunapaneni V.L.M., Siddhartha S, Comparison of The Mechanical Performance Between (Glass, Sisal, Ladies Finger, Hemp) Reinforced Polyester Composites With And Without Molybdic Acid, *International Journal of Mechanical Engineering and Technology*, 8(5), page no: 458-470, (2017).
12. Mike S, Elsam D, Dieter R, Acute and Mid term (06 Weeks), Effect of An Ankle Foot Orthosis On Biomechanical Parameters Clinical Outcomes And Physical Activity In Knee Osteoarthritis Patent With Various Misalignment, 38(6), page no: 481-91, (2014).
13. Martam, tommey, Salvb, Tom V, Carloss, Powered Ankle –Foot Orthosis: The Effects of Assistant on Healthy and Impaired User While Walking, *Journal of neuro engineering and rehabilitation*, Article no. 86, (2018).
14. Ganesh Bapat, S Sujata, Identification and Analysis of Knee-Ankle-Foot Orthosis Design Requirements Based on Feedback Survey of Orthosis Users in India, 14(1), page no: 82-90, (2017).
15. Michel P, Dillon, Stefania Faton, Andrew Hansen, Effect of Prosthetic Design on Centre of Pressure Excursion in Partial Foot Prostheses, *Journal of Rehabitation Research & Development*, 48(2), page no: 161-78, (2011).
16. Bharadwaja, K., Srinivasa Rao, S., & Babu Rao, T. (2021). Investigation of tensile and flexural behavior of epoxy and SiO2 composite: An experimental study. Materials Today: Proceedings, 45, 2649–2652. doi:10.1016/j.matpr.2020.11.514
17. Bharadwaja, K., Rao, S. S., & Rao, T. B. (2021). Investigation of hardness & tribology behavior of Epoxy and Sio2 composite: An experimental study. Materials Today: Proceedings, 45, 3343–3347. doi:10.1016/j.matpr.2020.12.653