Development of 3D Printed Socket for Transtibial Prosthetic Leg

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https://doi.org/10.15017/2552929

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 5, pp.44-46, 2019-10-24. 九州大学大学院総合理工学府
バージョン：

Development of 3D Printed Socket for Transtibial Prosthetic Leg

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Abstract: *The high cost to fabricate a good quality prosthetic leg became a burden to patients especially those with financial constraint. Experienced and specific skills are required to build a customized prosthetic leg and therefore also contribute to time consuming. The socket of the limb prosthesis requires adjustment and modification to accommodate the changes occurred in the residual limb over time. Development of 3D printed of lower limb socket as proposed in this study is expected to be an alternative in the near future. The objectives of this project are to (i) design a lower limb socket for below knee amputees according to size and shape of residual stump, (ii) analyze the performance of the socket at different infill density and (iii) fabricate the lower limb socket using 3D printing technology. The design stage of the project involved four main phases which are data collection and processing, product design, finite element analysis and fabrication of the socket using 3D printing. The analysis findings were discussed based on the resulting von mises stress, shear stress and total displacement. It was suggested that the socket is sufficient to be printed at 60% infill density. In comparable with other infill density percentage, the 60% model experienced only 0.413 MPa of von Mises stress and 0.0067mm of displacement.*

Keywords: Amputation, Lower Limb Socket, Prosthetic Leg, 3D printing, Infill Density

1. INTRODUCTION

Diabetes Mellitus patient usually undergo lower limb amputation due to leg necrosis. There are few types of lower limb amputations for instance hip, knee, ankle and foot amputations. The most common type of lower limb amputation are transtibial amputation, transfemoral and hemipelvic [1]. The risk of serious post-operative complications in a below knee amputation is far less than in a transfemoral amputation. The physical therapist and doctor can work with patients to fit them with the most appropriate device to help maximize their ability to walk. [2]. They may benefit from the skilled services of a physical therapist at different points in time after their amputation. As their stump shape changes, they may require different rehabilitation to keep them strong. They may require different prosthesis from time to time if their size and shape of their stump were changing gradually. That factor also contributes in the substantial amount of constructing prosthetic leg. As the alternative solution to this problem, the Industrial Revolution 4.0 technology and can be utilized and merged with the medical field. The Additive Manufacturing technology which is 3D printing technology and 3D simulation contributed the most in fabricating prosthetic leg [3]. Our objectives will be firstly to design a lower limb socket for a below knee amputation according to shape and size of residual the residual stump. Secondly, analyze the performance of the socket at different infill density and lastly fabricate the lower limb socket using 3D Printing technology.

2. METHODOLOGY

This project involved four main phases which are (i) the data collection and processing, (ii) product design and technology implementation, (iii) analysis and parametric study and (iv) fabrication using 3D printing technology. The phases of the study will be likely the procedure to develop the customized transtibial prosthesis leg.

2.1 Data Collection and Processing

The patient has to undergo 3D scanning to obtain the stump's size and shape [4]. Next, the stump model will be imported to the CAD software to guide the design process of the limb socket. The sample of the 3D scanning process is shown in figure 2.1.

Fig. 2.1 Example of 3D scanning process for the stump [4]

2.2. Product Design and Technology Implementation

The data obtained then undergo three design process which are designing sock layer, inner layer and outer layer. The initial sketches were performed as guidance to design the socket as illustrated in figure 2.2. This process basically will promote the customized prosthesis socket for each patient.

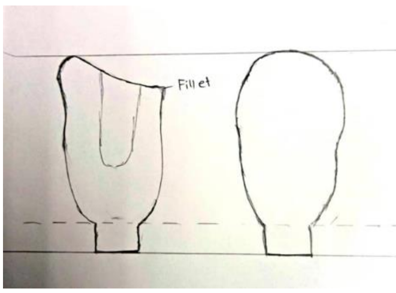

Fig. 2.2 Initial sketches of the socket

2.3. Analyses and Parametric Study

Different settings will have different results in term of energy absorption [5]. In this study, the variety of infill density were defined based on tensile modulus and flexural properties. Table 1 shows the mechanical properties of the PLA at various infill density [6]. Strength analysis was performed on final design according to their variable which is infill density to find von Mises stress, shear stress and total deformation.

Table 1 Material Properties of Polylactic Acid (PLA) at Various Infill Density

Infill Percentage (%)	Tensile Modulus (MPa)	Tensile Strength at Yield (MPa)	Flexural Strength (MPa)	Flexural Modulus (MPa)
20	469.3	9.9	20.6	630
40	938.6	19.8	41.2	1260
60	1407.9	29.7	61.8	1890
80	1877.2	39.6	82.4	2520
100	2346.5	49.5	103	3150

Analysis on infill density that had been tested were 20%, 40%, 60%, 80% and 100% by applying 600N load inside the socket and fixed support at the bottom of the socket as shown in figure 2.3.

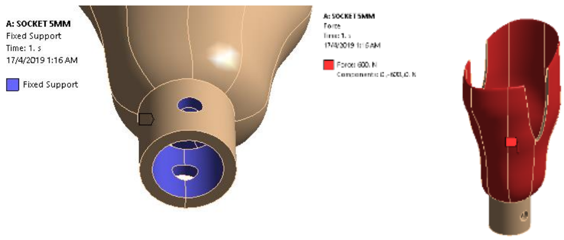

Fig. 2.3 Constraints (left) and loading (right) conditions applied in the analysis

The meshing was assigned to discretize the model into pieces which representing an element each to increase the accuracy of the analysis and to know how it would react in real life [7]. The meshed socket model is shown in figure 2.4

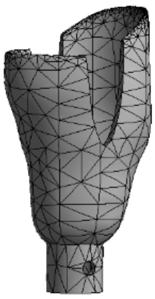

Fig. 2.4 Meshed model of the socket

2.4. Fabrication Using 3D Printing Technology

The fabrication of the model was made using 3D Printing technology by choosing the best design after performed the analysis which are PLA material with 15mm thickness and 60% infill density. The slicing process is visualized in figure 2.5.

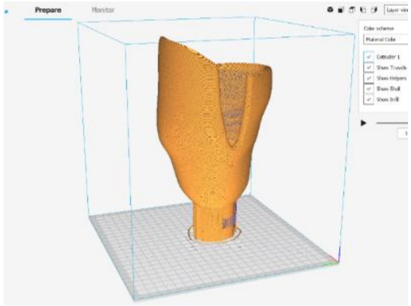

Fig. 2.5 Preparation for printing

3. RESULTS AND DISCUSSION

The infill percentages determined are 20%, 40%, 60%, 80% and 100%.

3.1 Stress Distribution of the Socket at Different Infill Density

The results show that the maximum value of von Mises stress are decreased from 20% infill and it becomes constant from 40% infill to 100% infill. The maximum von Mises stress is measured at 0.440 MPa for 20% infill while constant at the other infill density with 0.413MPa. The maximum von Mises stress in each model are compared to the yield strength of Polylactic Acid (PLA) material to evaluate their performance. All models demonstrate low value as compared to the yield strength of the materials.

For shear stress, the similar trend of von Mises stress results is evaluated. The compressive strength of samples with a 20% to 100% infill density increased significantly [8]. This is expected as the higher of the infill percentage, the greater load it can support thus, the stress is lower. The distribution of maximum Von Mises stress and maximum shear stress results are shown in figure 3.1.

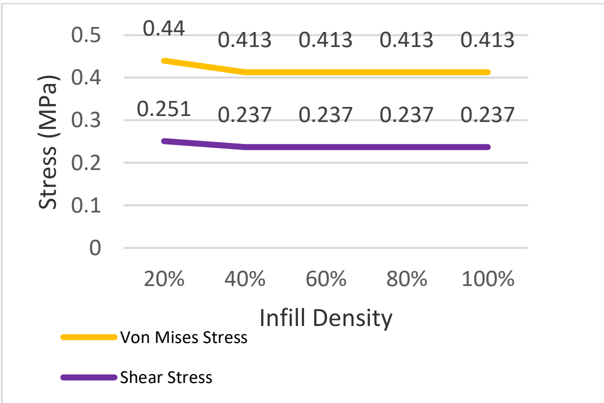

Fig. 3.1 Pattern of stress distribution at different infill density model

3.2 Total Deformation

The total deformation of 20% infill percentage is the highest while the lowest is 100%. Model with 60% infill percentage is chosen to be print as it was sufficient as the model has small value of total deformation. The graph of maximum total deformation results is shown in figure 3.2. From the graph, it shows that the higher the infill density, the greater the load it can support as the deformation decrease.

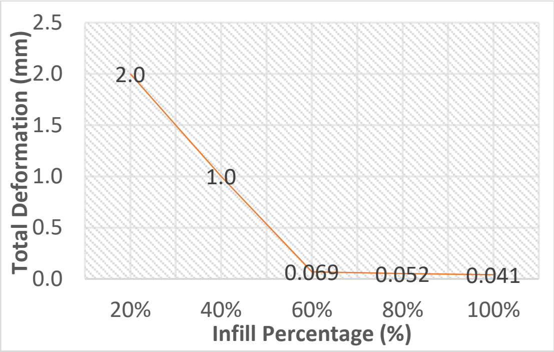

Fig. 3.2 Pattern of total deformation at different infill density

3.3 Fabrication Process

The socket was fabricated using 3D Printing technology with 60% of infill density. The material used was PLA (polylactic acid) filaments and the product is as in figure 3.3.

Fig. 3.3 The fabricated socket

4. CONCLUSION

The most suitable infill density to print the socket is PLA with 60% infill percentage as it is strong, durable and safe enough for the patient to wear it. At 60% infill density, the maximum von Mises stress and shear stress value are 0.413MPa and 0.237MPa, respectively. The higher the infill percentage, the greater load it can support. Set up printing at 60% infill is sufficient for the patient's socket to reduce time and cost consuming.

ACKNOWLEDGMENT

This research was supported by Universiti Teknologi MARA, UiTM under Grant No. 600-IRMI/PERDANA 5/3 BESTARI (103/2018).

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