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3D-PRINTABLE FOOT PROSTHESIS DESIGN FOR TRANSTIBIAL AMPUTEES

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1. Introduction

Most commercially available dynamic foot prostheses are made of either carbon or glass fiber reinforced composites which are able to store and return a sufficient amount of energy to provide propulsion [1, 2]. These prostheses are expensive, and the more affordable SACH (Solid Ankle Cushioned Heel) designed for patients with low activity level fails to return enough energy [3].

The rapid development of additive manufacturing (AM) techniques [4] makes it possible to design 3D-printable foot prostheses that have the properties of ESAR (Energy Storage and Return) feet. In this study, an ESAR foot was designed and prototyped using ABS plastic. Such products are not yet available on the market because they are still under development.

2. Methods

a. Design and geometric model

The biomimetic design was mainly based on the human foot. A number of CAD models were designed, all adjustments of the model were followed by FEA, thus optimizing its strength. The split forefoot and the heel provide a 3-point support, e.g. Fig. 1.

Fig. 1. CAD conceptions

The prototype was made for a 245 mm long foot (EU size 39). It corresponds to a woman's old child's foot.

b. Quasi - static finite element analysis

The FEA was conducted in each of the three support phases of the walking cycle. It was decided that FDM filament ABS*plus*-P430 from Stratasys would be used for the prototyping and its material properties were applied in the FEA.

c. Prototype and testing

The prototype was manufactured with a Stratasys Dimension 1200es printer using a 30% rectangular infill pattern and a 1.5 mm wall thickness to reduce mass and printing time. After the production, the prototype was tested twice using Instron 5965 (Instron, Norwood, MA, USA) tensile test machine. Quasi-static and cyclic loads were applied.

3. Results

a. FEA results

The critical phase turned out to be heel strike. The maximum stress was calculated at 17 MPa considering the auxiliary torque and the maximum lateral force besides the vertical load, e.g. Fig. 2.

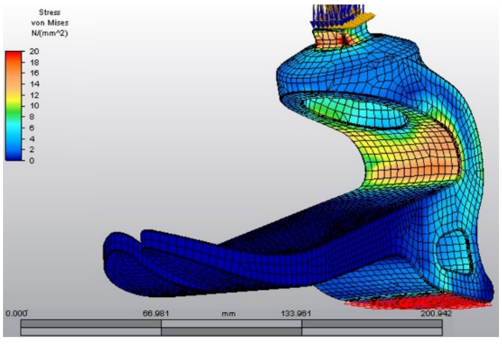

Fig. 2. FEA simulation under critical load

b. Test results

First, a maximum vertical load of 600 N was applied using different loading speeds. The curves were quasi-linear meaning that the weight is within the elastic deformation range, e.g. Fig. 3. The ankle geometry of the prosthesis generates a torque that wants to rotate it forward and will provide propulsion for the user. Because of that, the prosthesis kept slipping frequently, which resulted in non-continuous curves.

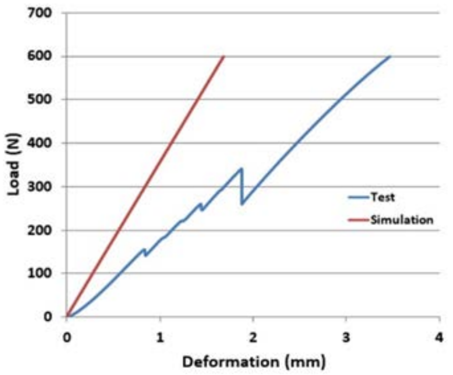

Fig. 3. 600 N vertical load (FEA and testing)

During the second test, 200 N, 400 N, 600 N, 800 N and 1000 N maximum loads were applied. The deformation axes of the graphs are adjusted by 0, 1, 2, 3 and 4 mm respectively so that all of them are visible, e.g. Fig. 5. The prototype failed at 850 N and the yield point is at approximately 750 N.

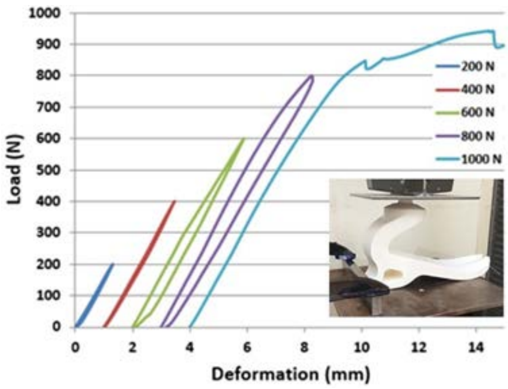

Fig. 2. Incremental cyclic loads

The area of each hysteresis loop corresponding to the dissipated energy was calculated by numerical integration. The returned energy for each load is shown in Tab. 1. The average was 88 % with a corrected standard deviation of 5 %.

Load (N)	200	400	600	800
Energy returned (%)	88,4	95,0	85,7	83,1

Tab. 1. Returned energy in each case

4. Remarks

In conclusion, the 3D-printable prosthetic foot design presented in this paper shows that such products built of ABS filament have a potential to be a low-cost solution for moderate activity level amputees. Based on the data collected during quasi-static testing, the energy return of the prosthesis is sufficient.

Considering that human feet weigh a few times more than the prototype [5], it is desirable to increase its mass in order to improve its strength and provide a more natural feeling for the user. The way to do so is adjusting printing settings such as wall thickness and structural infill percentage, as well as the geometry of the model, which is not the optimal yet.

Future work, based on this study will focus on testing the prosthesis with patients and improving its strength and lifetime.

5. Acknowledgements

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6. References

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