ADDITIVE MANUFACTURING TECHNOLOGY AND CARBON FIBER REINFORCED FILAMENT POTENTIAL USE FOR TRANSTIBIAL AMPUTEE SOCKET FABRICATION

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SCOPE

This study examines the potential of additive manufacturing technology to be used in the fabrication of transtibial prosthetic sockets; initially by looking at the material properties of filaments with appropriate for the application characteristics, then by simulating the prosthetic socket under load and finally by constructing a prototype socket.

For the material characterization is investigated how material properties (tensile strength, Young's modulus) are affected by the chopped carbon fiber reinforcement content and the selected raster angle during the printing process.

For the socket is investigated the stresses that are present during simulated loading.

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MATERIALS AND METHODS

Fused Deposition Modeling (FDM) Flashforge creator 3
ASTM 368 Type IV

Table 1. Selected Materials

Company	Product Name	CF
Matter Hackers	Nylon X Carbon Fiber	20
Fillamentum	Nylon CF15	15
DSM Novamid	Novamid ID 1030-CF10	10
Taulman	Nylon Bridge	0

Table 2. Printing Parameters

Outline direction	Outside-In
Infill percentage	100%
Outline	2
Layer Height	0.2
Infill pattern	Rectilinear
Infill angle	0°, 90°,45°
Speed	3500mm/min
Extrusion width	0.40mm
Printing Temperature	20: 257, 15,10: 275, 0: 255

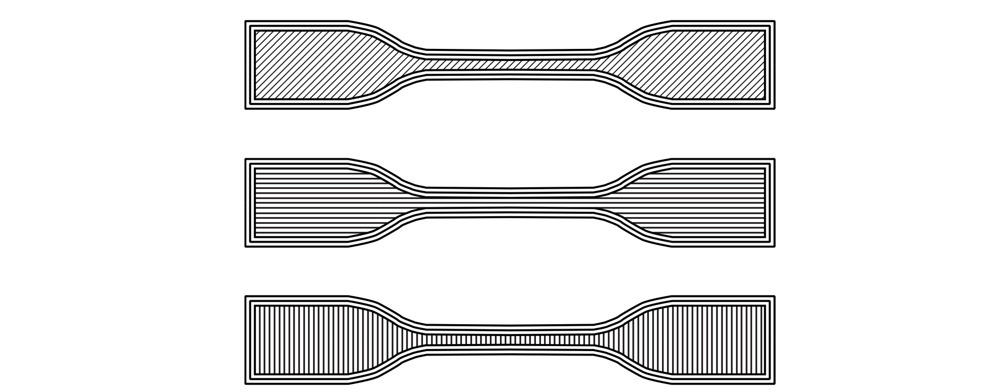

Fig.1. Raster angles 45°, 0° and 90°

Fig. 2. Printing specimens

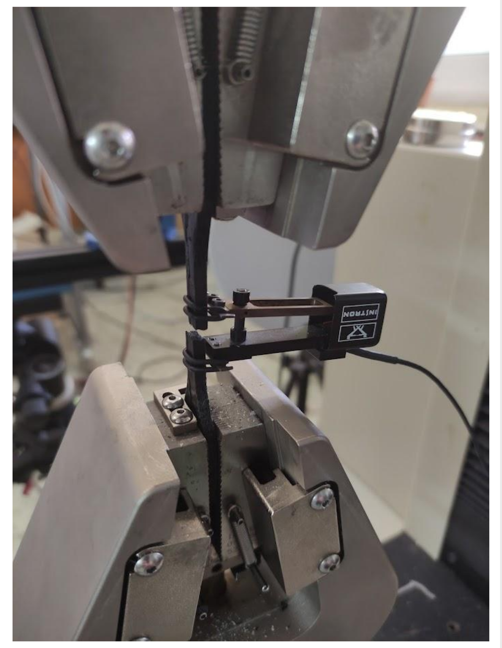

Fig. 3. Tensile testing

MATERIAL CHARACTERIZATION

- The material with 10% CF reinforcement outperformed the rest
  - The tensile strength was increased compared to the unreinforced Nylon by 2 times and the Young's modulus by 5.25,
  - The average tensile strength for all raster angles was 49.37 MPa and the Young's modulus was 2.28 GPa,
  - The highest tensile strength and Young's modulus were measured for the 0° raster angle, namely 67.75MPa and 4 GPa.
- It was observed that increasing CF reinforcement content, the void content in the specimens also increased.

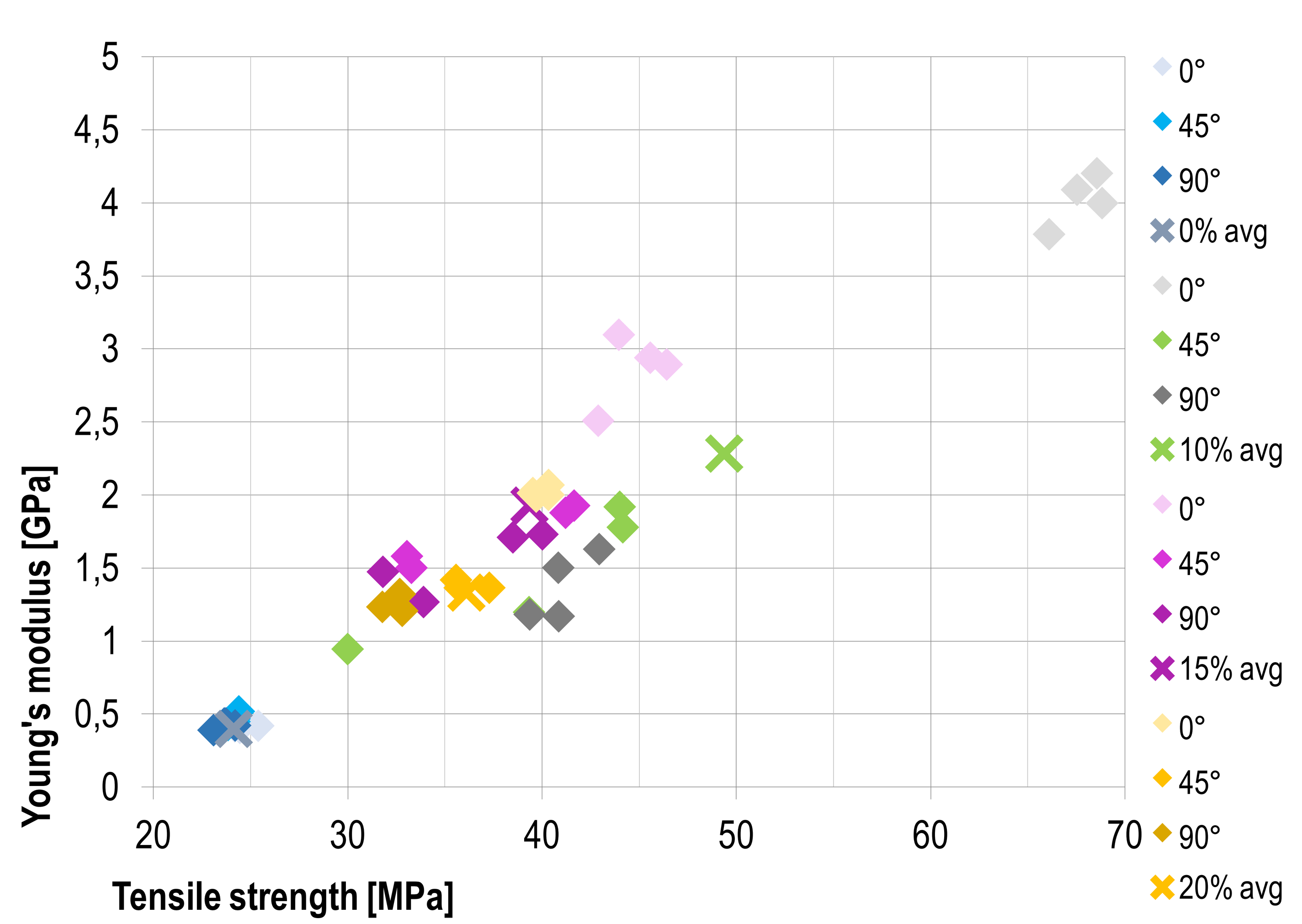

Chart 1. Young's modulus vs. tensile strength map for 0% (blue), 10%(green), 15%(purple) and 20%(orange) CF content

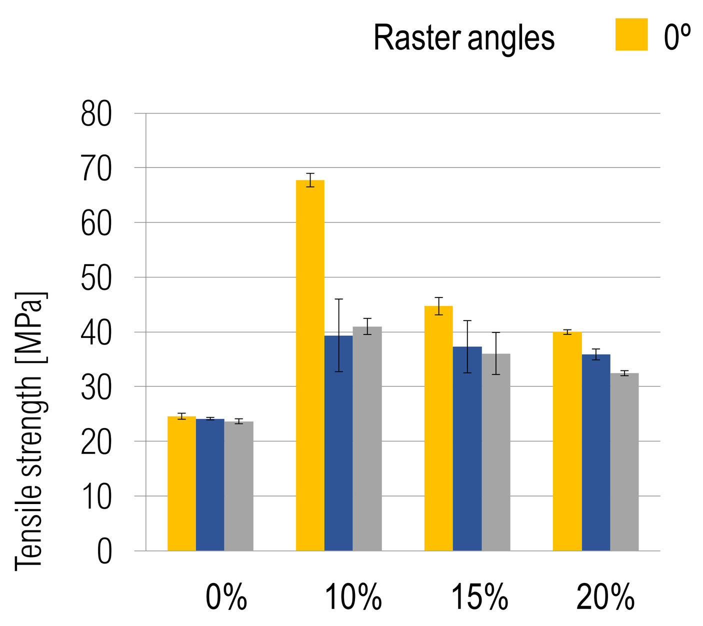

Chart 2. Tensile strength for different CF content and raster angles

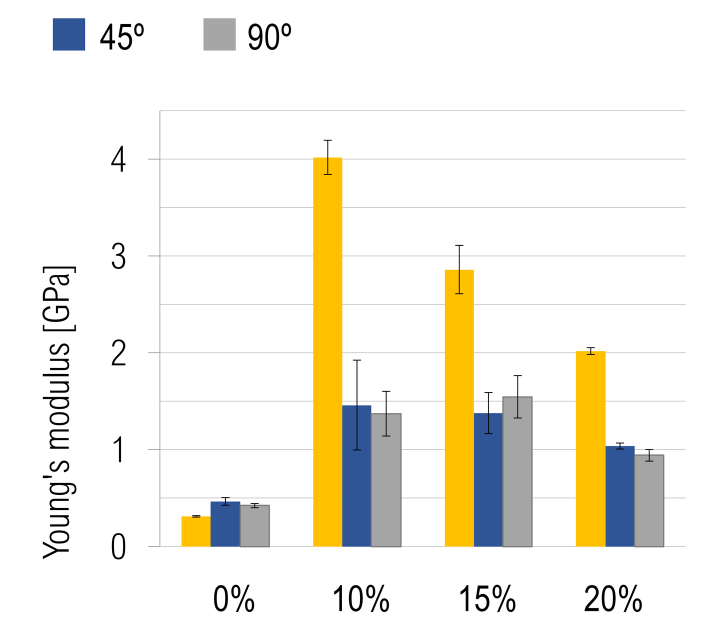

Chart 3. Young's modulus for different CF content and raster angles

SOCKET SIMULATION

As the 10% CF reinforcement content presented results comparable to other plastics used in the industry of orthotics and prosthetics and had properties fit for this specific application it was selected for further investigation.

A thin walled (2mm) transtibial socket model was created after obtaining the stump geometry using a scanner. The model was printed as a prototype to explore physical restrictions of the product, using an Ultimaker printer and PLA filament..

Fig. 4. Stump mould

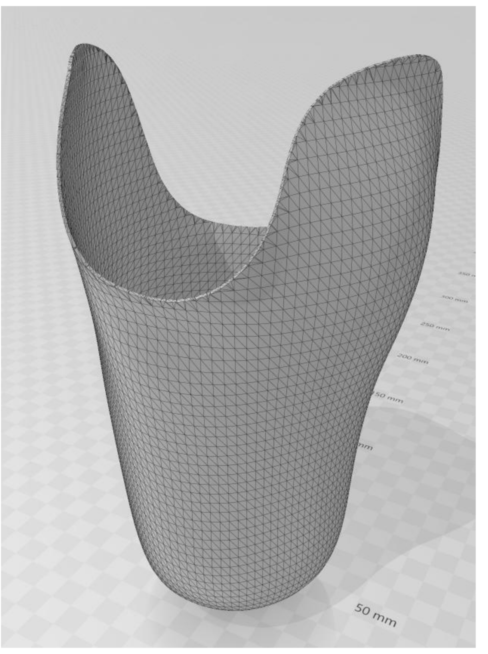

Fig. 5. Socket model

Fig. 6. Printed prototype

The experimental data of the material characterization as well as the socket model were fed to a FEA program and a basic computational analysis was carried out that considered only the maximum ground reaction force observed during walking (900N).
The mesh had 39078 nodes and 19348 elements. The analysis was static structural. The bottom face of the socket was considered a fixed constraint.

It resulted into 15MPa maximum stress, corresponding to the literature, that could easily be rectified by increasing the wall thickness considering the thickness of a conventional plastic socket wall is about 10mm.

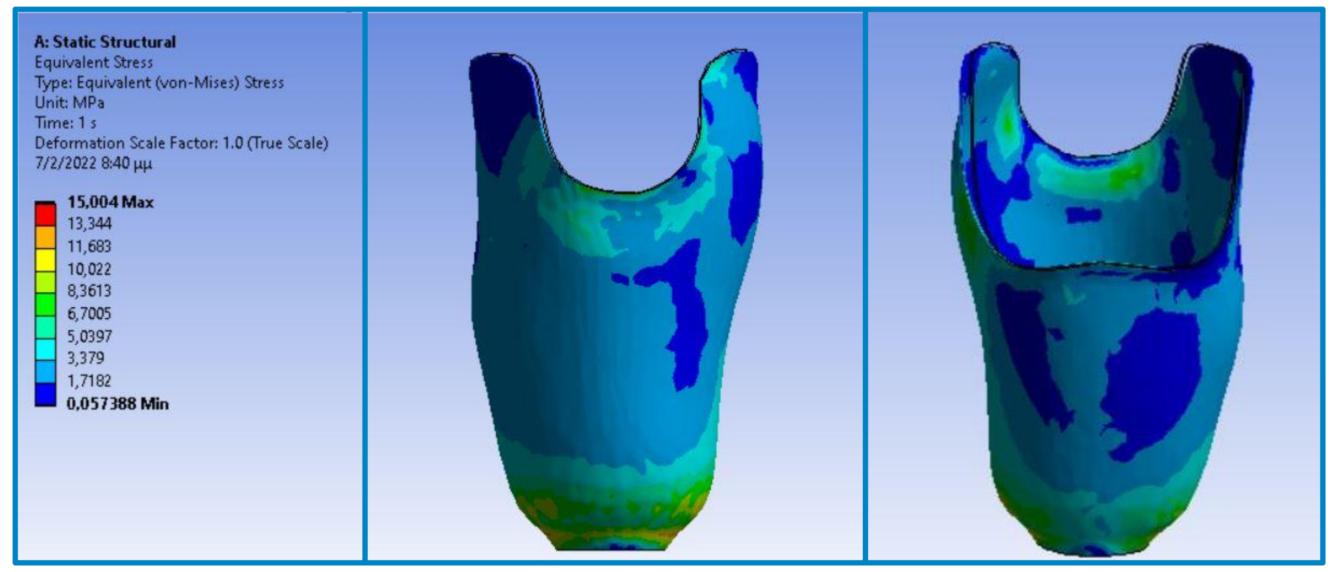

Fig. 7. Socket FEA - Von Misses Stresses in compression of 900N

CONCLUSIONS AND DISCUSSION

The results indicate that printing a prosthetic socket is indeed feasible and the commercial materials available are more than sufficient for this application.

It is apparent that the anatomy is easily replicated, providing a secure and comfortable fit for the stump.

The materials are able to perform well during loading. It is important going forward to investigate further the fatigue of the material as well as the fatigue of the designed socket.

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