OPEN ACCESS

Special Issue

Journal of Medical Materials and Technologies

Proceedings of 4th Euro BioMAT

4th Euro
BioMAT 2017

European Symposium and Exhibition on Biomaterials and Related Areas

09. - 10. May 2017
Weimar, Germany

Editors
Klaus D. Jandt
Thomas F. Keller

ISSN 2366-9136

OPEN ACCESS
Journal of Medical Materials and Technologies
Vol 1, No 2, Special Issue Proceedings of 4th Euro BioMAT, Page No. 8-10 (2017)
http://journal.medmat.online
ISSN: 2366-9136

Mechanical properties of 3D printed water-soluble polyvinyl alcohol for maxillofacial prostheses prototypes

[1]*Jochen Kuttig, [1]Phan Hai-Binh Bui, [2]Alexey Unkovskiy, [1]Christine Schille, [1]Jürgen Geis-Gerstorfer and [1]Sebastian Spintzyk

[1]Section Medical Materials Science & Technology, University Hospital Tübingen, Osianderstr. 2-8, Tübingen 72076, Germany
[2]Department of Prosthodontics, University Hospital Tübingen, Germany
*Corresponding author: sebastian.spintzyk@med.uni-tuebingen.de

Abstract – A digital workflow to produce maxillofacial prostheses could improve reproducibility and aesthetic outcomes. The possibility to 3D scan patients' limbs is given, but there is no method established to produce the prostheses from this data. In this study, printtests were performed and a protocol developed to print 3D objects from water-soluble polyvinyl alcohol (PVA) in consistent quality. Prototypes of maxillofacial prosthesis were fabricated. Those could be used to create molds for the casting of prostheses and therefore close the gap in the digital workflow. To proof the stability of 3D printed objects made from PVA, their flexural strength and flexural modulus were determined. The outcome suggests the typical anisotropic mechanical properties of 3D printed objects.

Keywords – 3D printing, additive manufacturing, maxillofacial prosthetics, mechanical properties, polyvinyl alcohol, rapid prototyping

1. INTRODUCTION

Additive manufacturing is gaining impact in the field of maxillofacial prosthetics due to the possibility to fabricate cost-reduced, personalized and geometrically complex objects [1-3]. 3D-printed PVA could have a significant impact on the creation of molds for production of maxillofacial prostheses. The 3D scanned limb is printed as a prosthesis prototype for final matching by the anaplastologist to the patient. A prototype of a left ear prosthesis is shown in Figure 1.

FIGURE 1
PROTOTYPE OF MAXILLOFACIAL PROSTHESIS MADE FROM PVA WITH A REPRAP INDUSTRIAL 3D PRINTER. THE OBJECT IS A LEFT EAR, THE 3D DATA WAS GAINED USING A STRUCTURED LIGHT SCANNER (ARTEC SPIDER, ARTEC GROUP, LUXEMBOURGH).

The adjusted prototype is used to produce a mold for the conventional casting of definitive prosthesis. The main advantage of this process is the fact that the adjusted prototype made of PVA can be easily dissolved in water within the mold. However, little information is provided about mechanical stability and quality of 3D printed PVA objects.

Aim of the study: The aim of this work is to ascertain the mechanical properties of PVA objects printed with a RepRap industrial 3D printer (Kühling&Kühling, Kiel, Germany) and establish a protocol to print with consistent quality.

2. MATERIAL AND METHODS

A protocol was developed to print PVA in layer thickness of 0.1 mm and rectangular infill patterns at 45° angles with 50% density. Best print results were achieved with a nozzle diameter of 0.35 mm. Print temperature was set to 215 °C and the printbed to 50 °C. The print chamber was kept at room temperature. Print speed was 4 mm/s, although first layer speed was reduced to 2 mm/s and the first layer thickness enhanced to 0.2 mm to ensure the attachment of the first layer to the printbed. Prosthetic prototypes were produced to proof the concept (Figure 1). Cantilevers in size 5 mm x 5 mm x 30 mm were printed as samples. Flexural strength and Flexural modulus was determined according to print direction (X, Y, Z), testing 15 samples per direction. Furthermore, influences of the object's positions on the printbed were examined by testing three samples of five print positions on the printbed. These objects were all printed in X-direction. The positions on the printbed are shown in Figure 2.

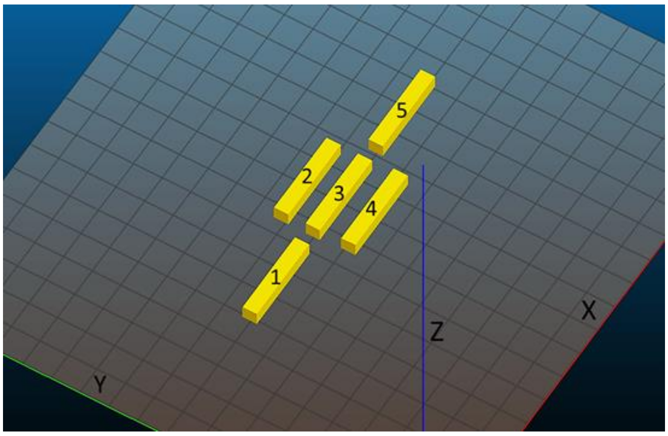

FIGURE 2
OBJECTS' POSITION ON THE PRINTBED OF THE REPRAP INDUSTRIAL 3D PRINTER **(A)**. MAIN PRINT DIRECTION IS ALONG THE X-AXIS (RED LINE) OF THE PRINTER.

Axial loads at fracture points and deflections were determined by three-point flexural tests with a universal testing machine Z010 (ZWICK, Ulm, Germany), based on DIN EN ISO 4049 (Figure 3). Dimensions of the cantilevers were measured with a micrometer.

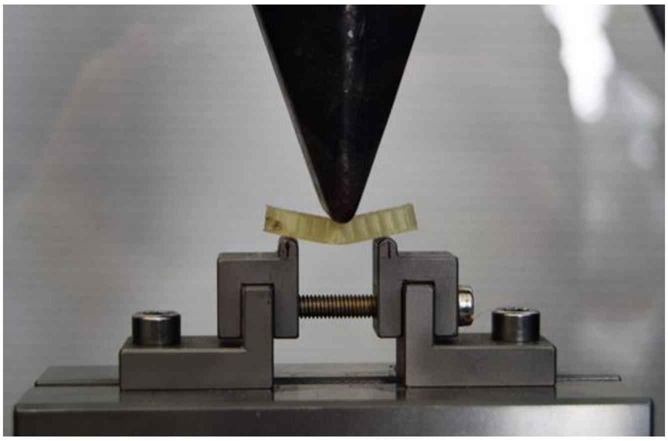

FIGURE 3
THREE-POINT FLEXURAL TEST PERFORMED ON CANTILEVER IN THE UNIVERSAL TESTING MACHINE ZWICK (B), BASED ON DIN EN ISO 4049. CANTILEVERS WERE MADE FROM PVA.

3. RESULTS

Flexural strength of 15 samples printed in each print direction was determined. The mean values are shown in following figure 4.

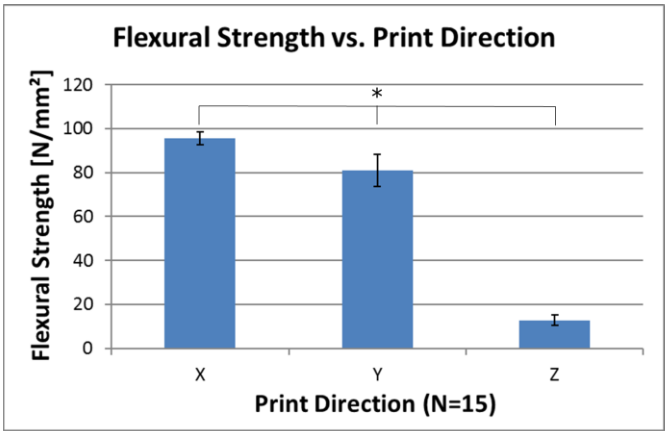

FIGURE 4
MEAN VALUES OF FLEXURAL STRENGTH OF PVA CANTILEVERS PRINTED IN X-, Y- AND Z-DIRECTION OF THE PRINTER.

Flexural modulus of the same samples are shown in the graph of following Figure 5.

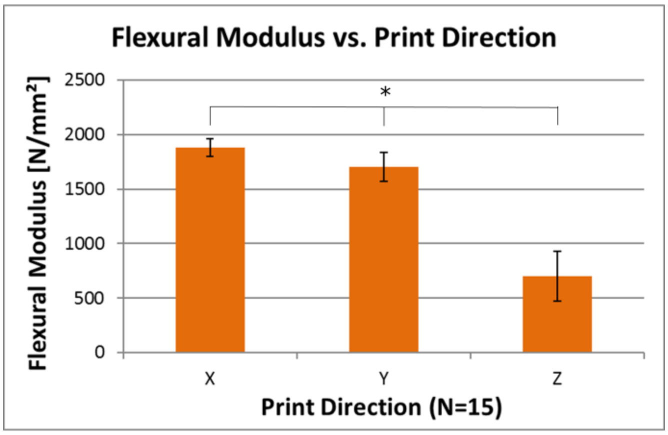

FIGURE 5
MEAN VALUES OF FLEXURAL MODULUS OF PVA CANTILEVERS PRINTED IN X-, Y- AND Z-DIRECTION OF THE PRINTER.

Average results of objects printed in the X-direction were 95.62 N/mm² ± 2.95 N/mm² in flexural strength and 1879.77 N/mm² ± 83.83 N/mm² for flexural modulus. Lower values were measured in the Y-direction: flexural strength was 80.98 N/mm² ± 7.43 N/mm² and flexural modulus was 1702.48 N/mm² ± 134.19 N/mm². In the Z-direction values were as low as 12.85 N/mm² ± 2.46 N/mm² for flexural strength and 701.32 N/mm² ± 228.57 N/mm² flexural modulus. Mean values were statistically different on a $p=0.05$ level (ANOVA, Post Hoc Tukey HSD).

The influence of the objects' position on the printbed was tested by printing objects in X-direction (Figure 6).

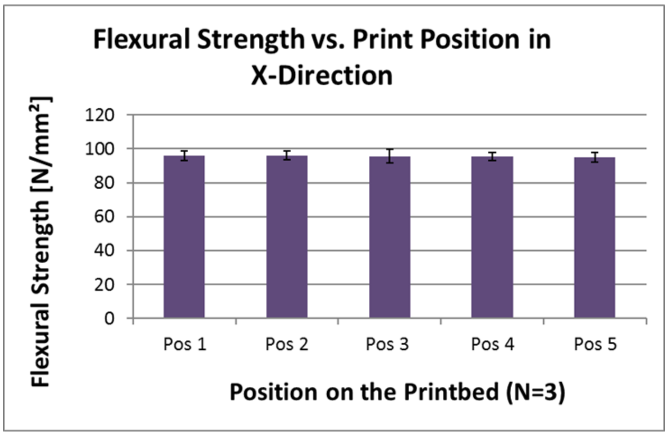

FIGURE 6
MEAN VALUES OF FLEXURAL STRENGTH OF PVA CANTILEVERS PRINTED AT VARIOUS POSITIONS ON THE PRINTBED.

Resultant mean flexural strength of all print positions: Position 1: 99.45 N/mm² ± 2.79 N/mm²; Position 2: 98.39 N/mm² ± 2.46 N/mm²; Position 3: 100.40 N/mm² ± 3.94 N/mm²; Position 4: 98.42 N/mm² ± 2.41 N/mm² and Position 5: 96.85 N/mm² ± 2.76 N/mm². No statistical differences were found according to the objects' position on the printbed.

The results show that flexural strength of 3D printed objects made from PVA meets the values of polylactic acid (80 N/mm²) in X- and Y-direction. However, poor layer-to-layer adhesion is indicated by low values in Z-direction. There is no influence of the objects' position to the mechanical properties. These outcomes must be kept in mind at the orientation of prosthesis prototypes on the printbed. As the outcome of this study might be promising, there are some uncertainties about: the achievable and required surface quality of the prototypes, the accuracy of the 3D printed objects compared to the scanned data and the original limb, and the mold creation from the PVA master forms.

4. CONCLUSIONS

PVA objects fabricated by fused deposition modelling show anisotropic characteristics regarding their mechanical properties which are common for this 3D printing technology. Nevertheless, the mechanical strength in X- and Y-direction is comparable to 3D printed PLA. For the usage of PVA prototypes as a master form to create molds, further studies must be done, investigating the accuracy and aesthetic of the final prostheses.

5. REFERENCES

[1] De Crescenzio, F., et al., "Design and manufacturing of ear prosthesis by means of rapid prototyping technology", *Proc Inst Mech Eng H*, 2011. 225(3): p. 296-302.

[2] Flugge, T.V., et al., "Three-dimensional plotting and printing of an implant drilling guide: simplifying guided implant surgery", *J Oral Maxillofac Surg*, 2013. 71(8): p. 1340-6.

[3] He, Y., G.H. Xue, and J.Z. Fu, "Fabrication of low cost soft tissue prostheses with the desktop 3D printer", *Sci Rep*, 2014. 4: p. 6973.