

3D Fabrication of Bone Structures, Based on FibreTuff

Research Group:

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FibreTuff II polymer filaments were used for the fabrication of biocompatible bone structures using material extrusion (fused filament fabrication) manufacturing technique, as illustrated in Figure 1. A multitude of process parameters were optimized with the aim to obtain strong, dimensionally accurate, and repeatable bone structures. It was experimentally observed that nozzle size, bed temperature, oven temperature, cooling rate, and print speed would significantly affect the quality as well as the performance of the fabricated bones.



Figure 1: A 3D-printed bone, composed of Polyamide, Polyolefin and Cellulose fiber (FibreTuff, Perrysburg, OH), fabricated at Marshall University's Lab for Advanced Manufacturing and Engineering Systems (LAMES).



Dr. Ross Salary with Engineering Student's at Marshall University (LAMES)



Modeling and Experimental Characterization of Biocompatible Bone Scaffolds, Fabricated Using Fused Deposition Modeling (FDM) Additive Manufacturing Process



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1. INTRODUCTION

Goal

To fabricate patient-specific, biocompatible, and biodegradable bone scaffolds for the treatment of osseous defects, fractures, and disceases.

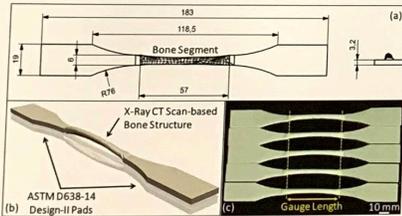
Objectives

- (i) To investigate the influence of consequential parameters of FDM process on the functional properties of fabricated femur bone structures;
- (ii) To investigate the underlying physical phenomena behind the experimental observations using a computational finite-element model.

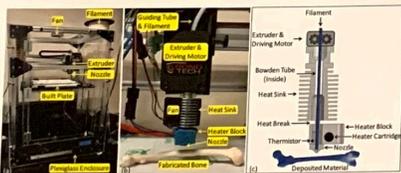


An X-ray computed tomography (CT)-based, biocompatible femur bone prototype, fabricated using FDM process at Marshall University.

2. MATERIAL & METHODS



(a) The dimensions¹⁴, and (b) an isometric view of a new test design, forwarded to characterize the mechanical properties of additively-manufactured bone structures. (c) A real picture of the fabricated bone structure. A medical-grade biocompatible polymer composite (PAPC-II, FibreTuff, Perrysburg, OH), was used for the fabrication of bone scaffolds.

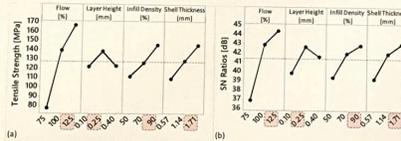


(a) The Folger Tech (FT)-5 R2 FDM 3D-printer, equipped with a Plexiglas enclosure and a 12V fan to maintain a warm oven environment for steady-state material deposition. (b) A real picture, and (c) a schematic diagram of the fused deposition modeling (FDM) additive manufacturing process.

ABSTRACT:

In this research work, FDM-based additive fabrication of biocompatible femur bone structures is demonstrated, based on a medical-grade polymer composite, composed of polyamide, polyolefin, and cellulose fibers. A new test specimen was designed, based on an X-ray micro-CT scan of a human femur bone as well as the ASTM D638-14 (Type II) standard. Experimental characterization was on the basis of a cascade approach, composed of the following experimental designs: (i) fractional-factorial design, utilized for factor screening and identification of consequential process parameters; (ii) Taguchi design, utilized for process optimization. In addition, a computational finite-element model was forwarded to investigate the underlying physical phenomena behind the experimental observations.

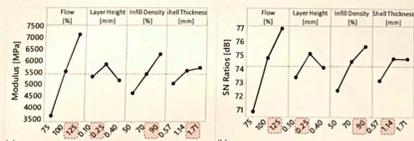
3. RESULTS & DISCUSSION



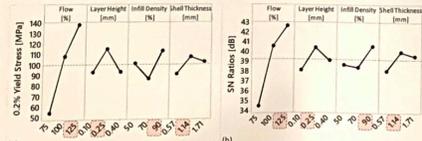
The influence of the main process parameters (i.e., flow, layer height, infill density, and shell thickness) on: (a) the tensile strength, and (b) the tensile strength SN ratio of the fabricated femur bones.



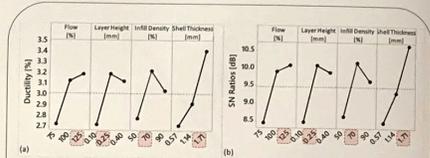
The influence of infill density on the porosity of the cancellous bone structure. While, overall, stronger structures are fabricated when the infill density increases, less space remains available within the cancellous bone structure for *in vitro* cell incorporation.



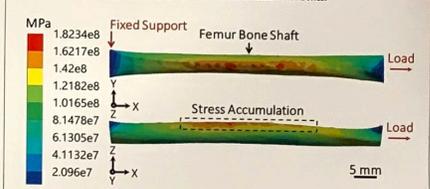
The influence of the main process parameters (i.e., flow, layer height, infill density, and shell thickness) on: (a) the modulus, and (b) the modulus SN ratio of the fabricated femur bones.



The influence of the main process parameters (i.e., flow, layer height, infill density, and shell thickness) on: (a) the 0.2% yield stress, and (b) the yield stress SN ratio of the fabricated femur bones.



The influence of the main process parameters (i.e., flow, layer height, infill density, and shell thickness) on: (a) the ductility, and (b) the ductility SN ratio of the fabricated femur bones.



Modeling of the structural response of the femur bone test standard, subjected to a load (with a velocity of 0.08 mm/s). There is stress accumulation across the convex curvature of the femur bone structure. This phenomenon, if significant, leads to crack propagation and ultimately, fracture.

4. CONCLUSIONS

- As the material flow increases, the tensile strength, modulus, and ductility increase non-monotonously. In fact, more material is deposited layer-by-layer as the material flow increases, resulting in stronger bone structures.
- An increase in the infill density (influencing cancellous bone porosity), led to a uniform increase in both the tensile strength and the modulus. The increase in the infill density, however, resulted in an initial increase and then a decline in the ductility. All in all, these two trends suggested an optimal infill density of 70%.
- Influencing bone layer fusion, an optimal layer height of 0.25 mm was identified, leading to a maximum tensile strength, modulus, and ductility of about 140 MPa, 6500 MPa, and 3.2 %, respectively.
- Unlike the modulus, both the tensile strength and the ductility increased with an increase in the shell thickness (influencing the cortical bone thickness). This trend, overall, implied an optimal shell thickness of 1.14 mm.
- The finite element results revealed stress accumulation across the convex curvature of the femur bone structure. Consequently, this area is most significantly prone to crack propagation and fracture. An increase in shell thickness enhances the strength of the cortical bone structure.

ACKNOWLEDGMENTS

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REFERENCE

- [1] Mahmoudi, M., et al., 26th Annual International Conference of the Iranian Society of Mechanical Engineers, Semnan, Iran (2018).