Mechanical Behavior of Additively Manufactured Open-Porous Scaffold Structures for Bone Tissue Engineering

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Introduction

- Critical-sized bone defects represent a significant challenge in the orthopedic field.
- Limitations on autograft and allograft as repair techniques led researchers to explore the implantation of artificial bone tissue scaffolds.

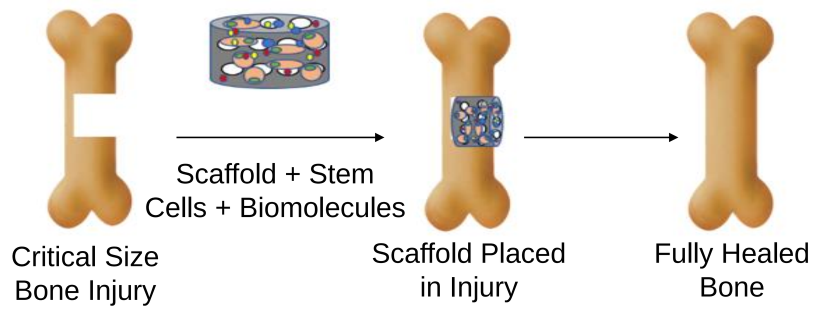

Fig.1: Bone tissue engineering

- Bone scaffold is an open cell three-dimensional biomaterial that provides a proper environment for cells in order to regenerate bone tissues.
- Currently, metallic scaffolds are widely used in orthopedic implants due to their excellent biocompatibility, corrosion resistance, non-toxicity, and superior strength.

Research Hypothesis

- The main hypothesis in this research is stress shielding being the main cause of bone resorption (loss) that leads to eventual failures of bone implants.
- The goal is to design a scaffold structure that is osteoconductive, biocompatible with elastic modulus that matches the structural modulus of cortical bone (15 GPa) to minimize stress shielding.

Research Methodology

- Scaffold structure is designed using numerical optimization tool through finite element analysis.
- Cell size (c) and strut diameter of the diagonal unit cell are optimized to achieve elastic modulus of 15 GPa while fixing the poor size (a) to 800 microns to enable cell ingrowth.

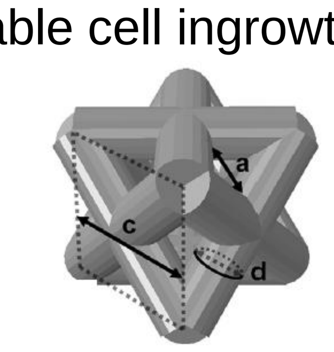

Fig.2: Diagonal unit cell

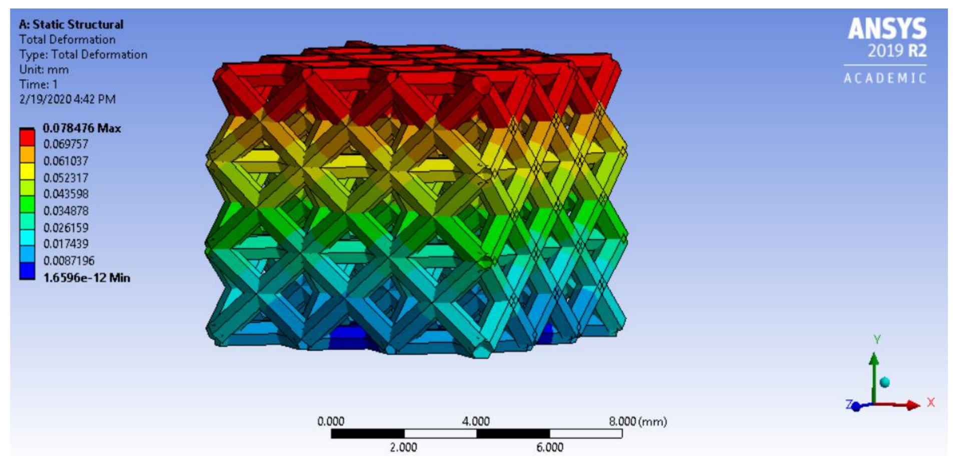

Fig.3: FEA mechanical model

- Final optimized design is fabricated from SS316L through 3D printing machine using direct metal laser sintering (DMLS).

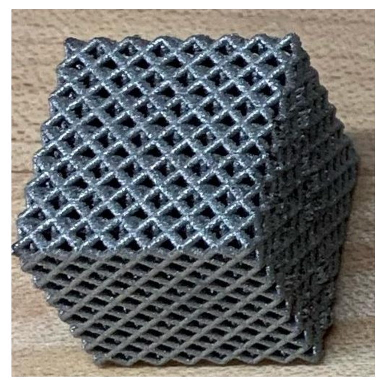

Fig.4: SS316L 3D printed sample

Results

- SEM imaging showed minimal variations in cell and strut sizes.

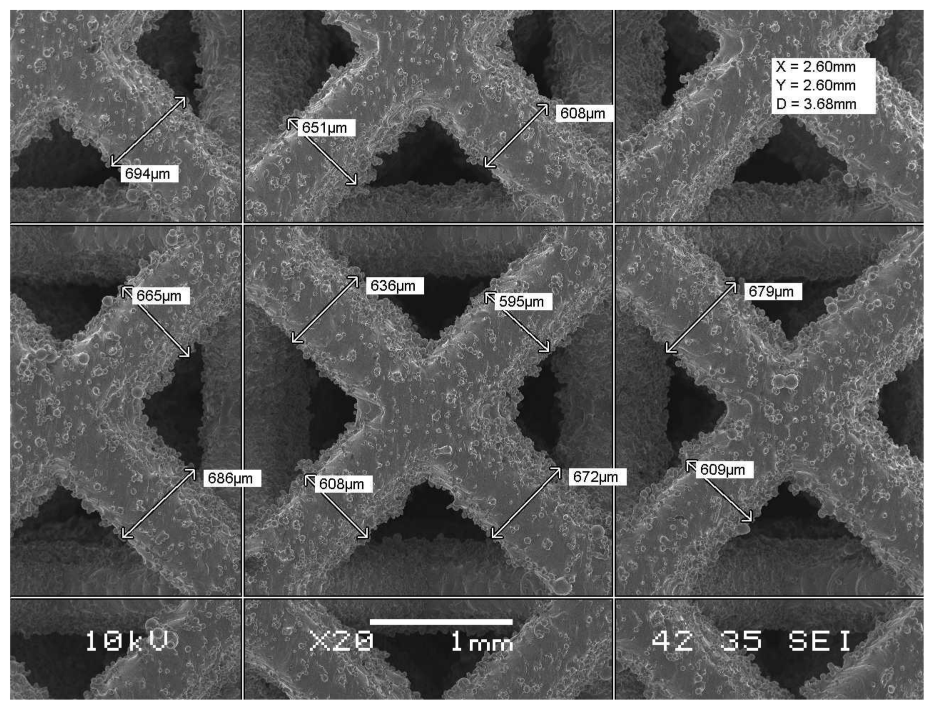

Fig.5: SEM image with cell and strut sizes

- SS316L powder particles have been well sintered as minimal porosity was found in struts.

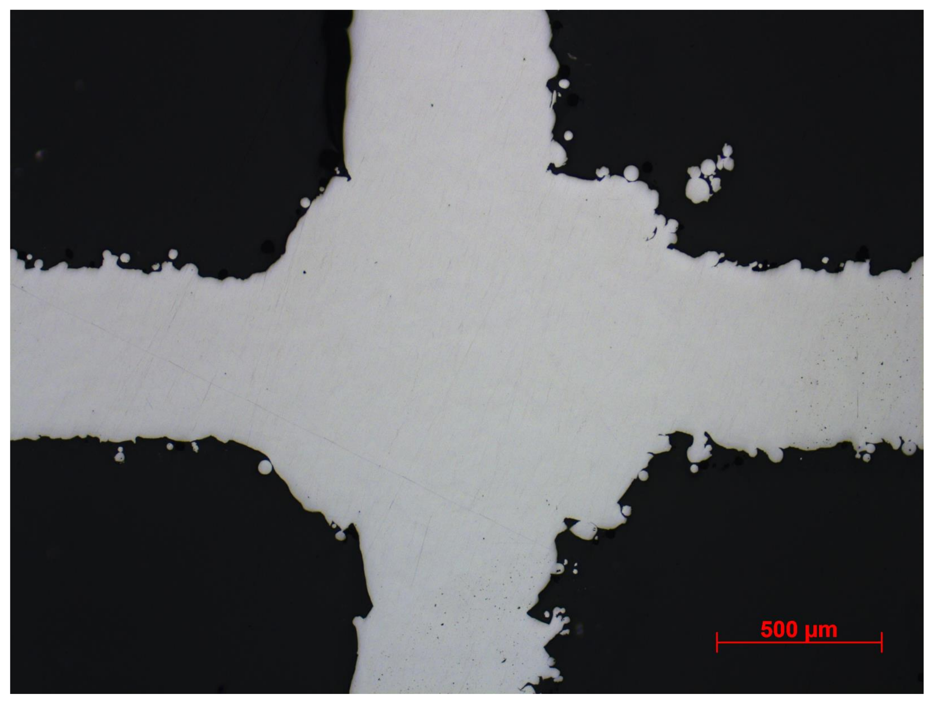

Fig.6: Porosity in struts

- Compression test has been conducted to validate FEA model results according to ISO 13314:2011 standard.

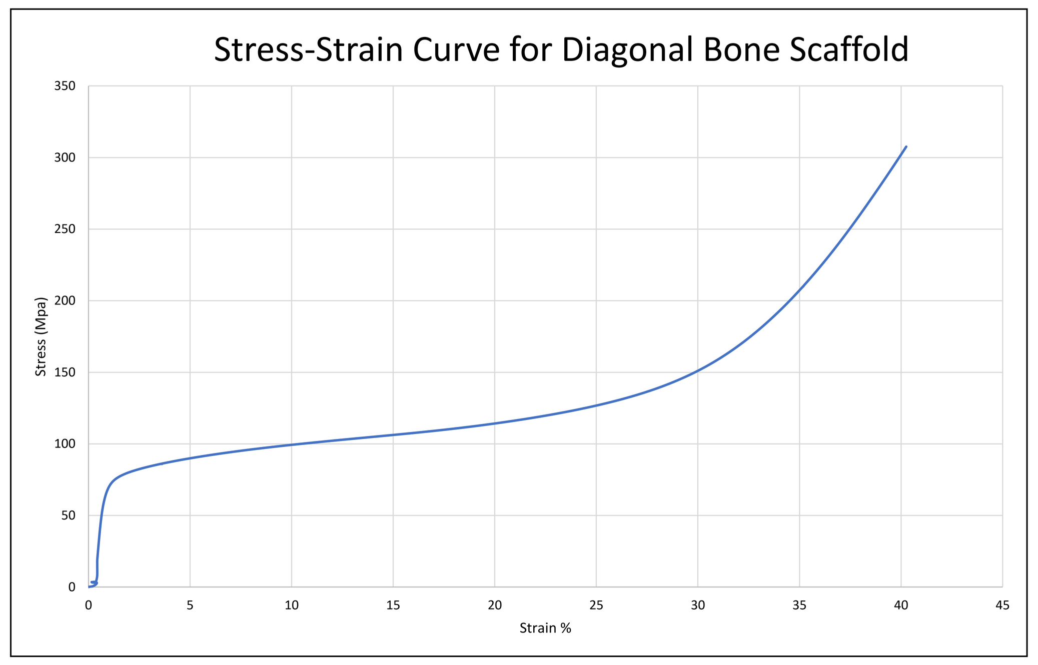

Fig.7: Compressive stress-strain curve

- Elastic modulus from experiment E^* = 14.75 GPa which validates the FEA model.

$$E^* = C\left(\frac{\rho^*}{\rho_s}\right)^2 E_s$$

- C = 0.6328 which falls in the range published in literature from 0.2- 1.0.

Conclusion

- Literature show application of bone scaffolds in clinical field have great ability to facilitate bone tissue regeneration and repair.
- Numerical optimization using FEA is a powerful tool for generating optimized scaffold designs.
- Additive manufacturing enables the fabrication of scaffolds with accurate and controlled mechanical properties.
- Tested scaffold showed to exhibit the stiffness of cortical bone and the behavior of cancellous bone which mimics the bone behavior under loading.

Bibliography

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Future Work

- Explore other unit cell shapes and fabricate scaffolds with multiple unit cells.
- Evaluate other mechanical properties such as bending, torsion and fatigue.
- Conduct non-linear FEA to study the stress distribution of a scaffold implanted in a femur bone.
- Develop a bone growth model to evaluate the osteointegration properties of scaffolds with various porosities.