Prediction of Mechanical Behavior and Microstructure of Additively Manufactured Parts

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Background and Project Benefits

Background

With increased complexities in industrial applications, the demand on the accuracy of prediction of manufacturing and materials ahs been escalating. On the other hand, additive manufacturing (AM) has attracted a huge attention due to its capability of building complex geometries with a low cost. AM has been used for both metals and polymers in a layer-by-layer manner to produce various parts from biomedical implants to jet engine parts. The methodology pursued here uses computational design to predict the mechanics behavior of materials and microstructure evolution during the metal additive manufacturing process.

With the proposed methodology, mechanical attributes of materials, material microstructural attributes, processing paths, and macro-scale material properties can be accurately predicted for use in material selection and design.

Benefits

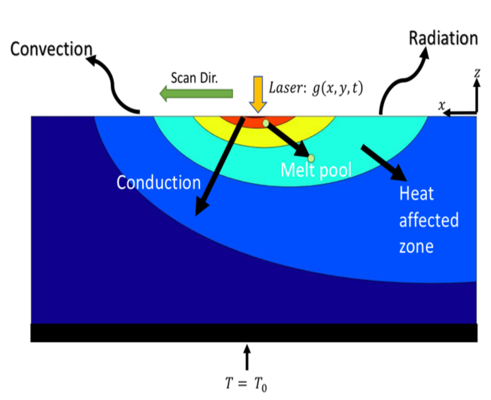
- **Development of a methodology for upfront design and optimization of metal additive manufacturing to avoid tedious, costly, and time consuming experimentation.**
- **Development of a methodology for modeling additive manufacturing of Ti64 and high-performance steels.**
- **Development of a methodology for predicting microstructure and properties for additive manufacturing which can be extended to many different material systems.**

Work Flow

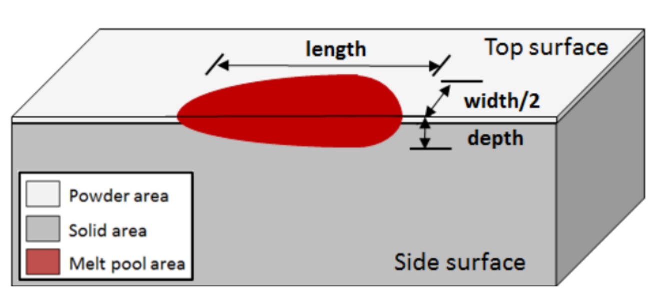
Case Study 1: Metal Parts

AM Process Parameters

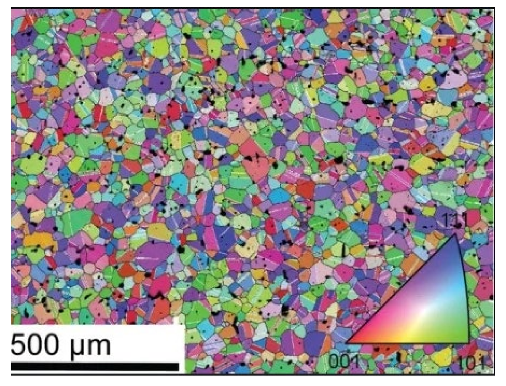
Temperature Profile



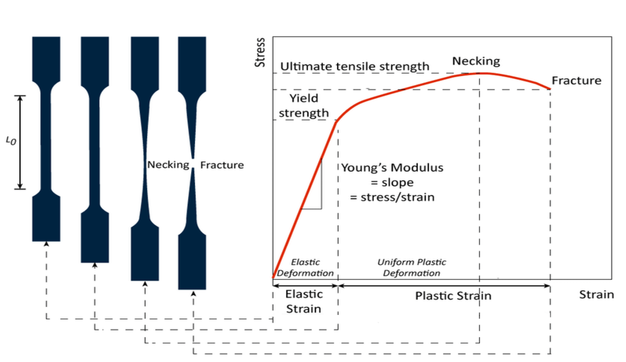
Melt Pool Geometry



Microstructure

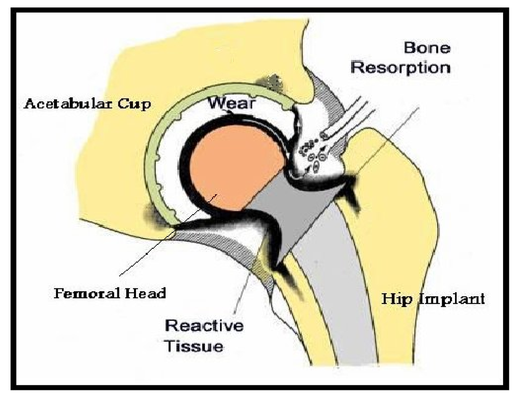


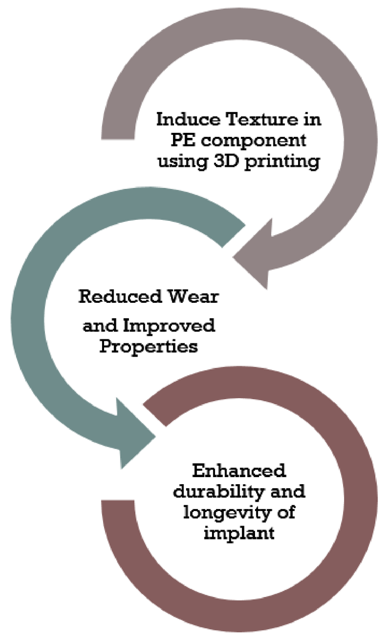
Material Property



Case Study 2: Polymer Parts

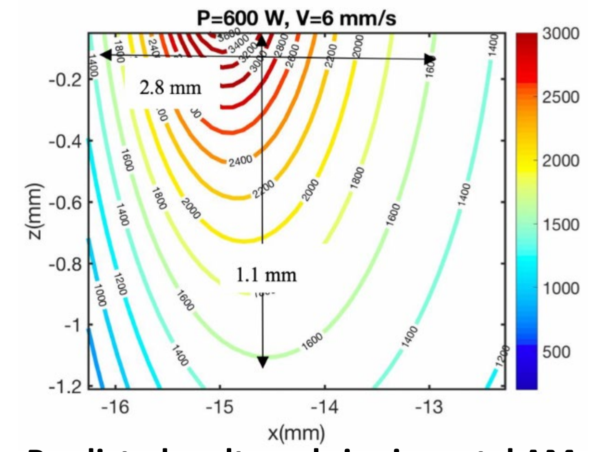
Application of 3D Printing and Texture in Implants



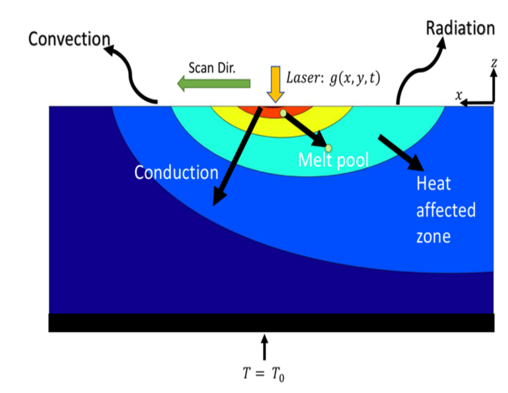


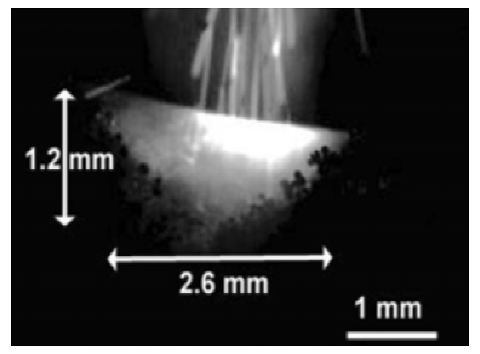
Prediction of Materials Characteristics

Temperature Profile Prediction



Predicted melt pool size in metal AM process for (a) P = 600W, V = 6mm/s





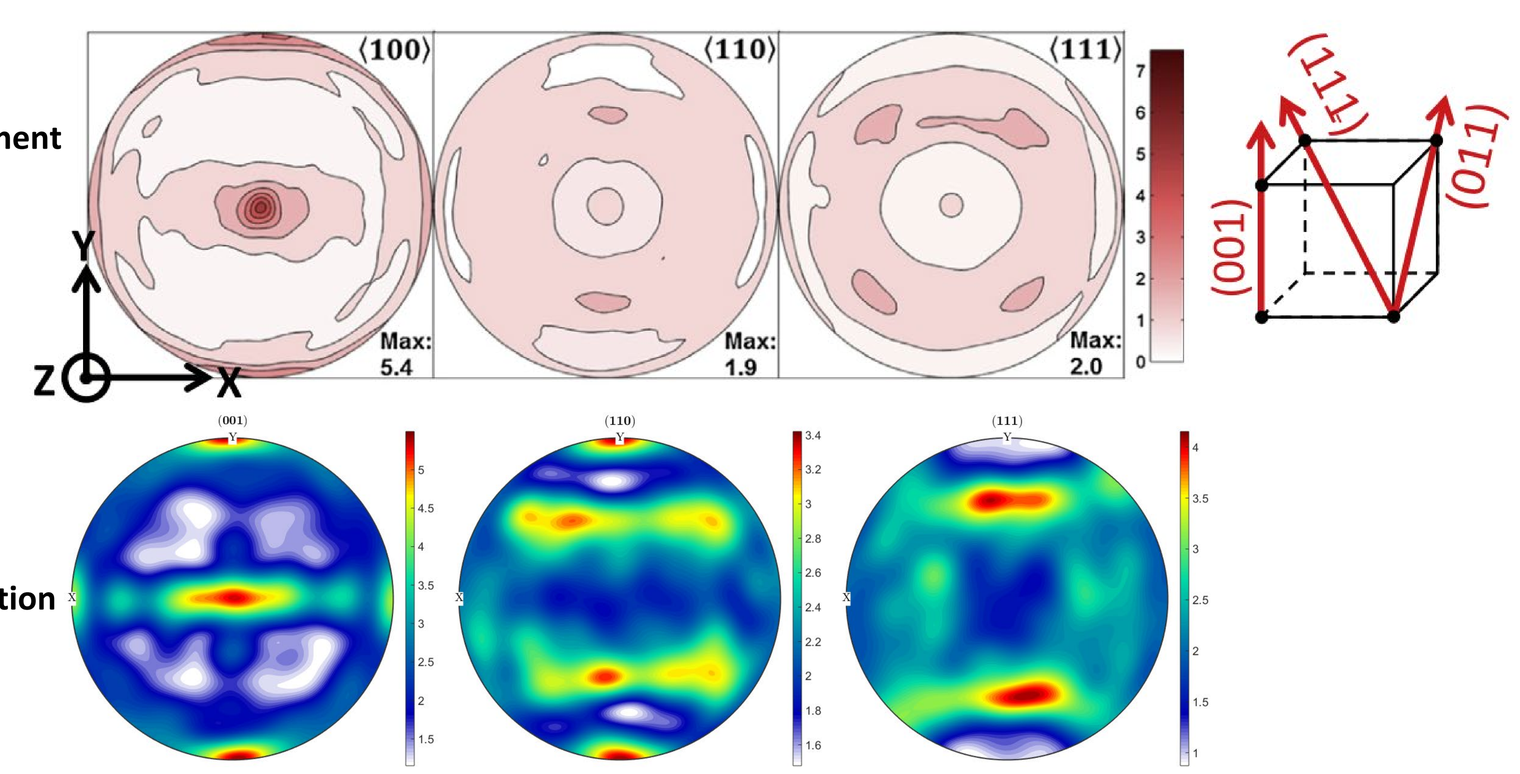
Experimental measurement of melt pool size for P = 600 W and V = 6 mm/s.

Crystallographic Texture Prediction

Selective Laser Melted Ti64 P=250 W, V=1600 mm/s

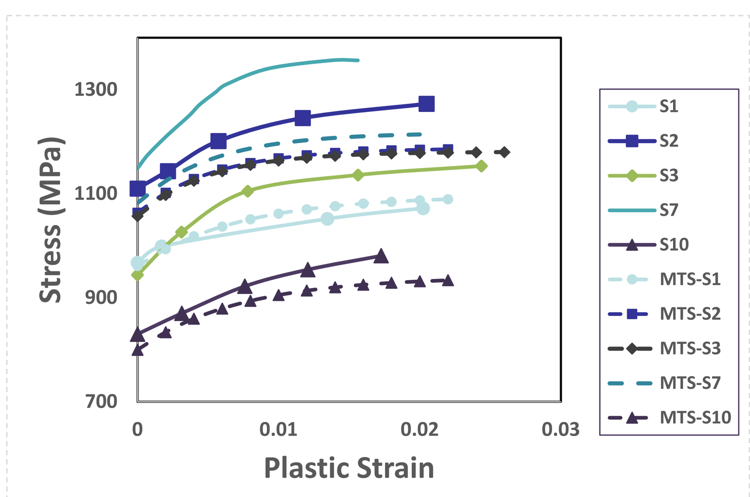
Experiment

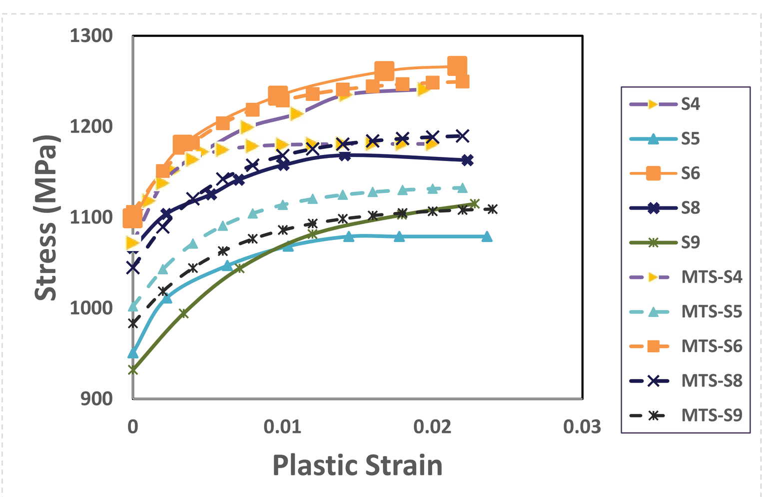
Simulation



Deformation Behavior Prediction

10 Different Selective Laser Melted Ti64 Samples



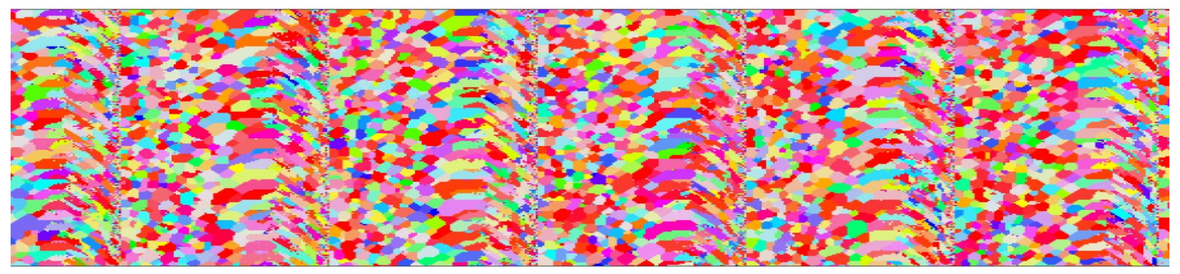


Microstructure Prediction

IN718

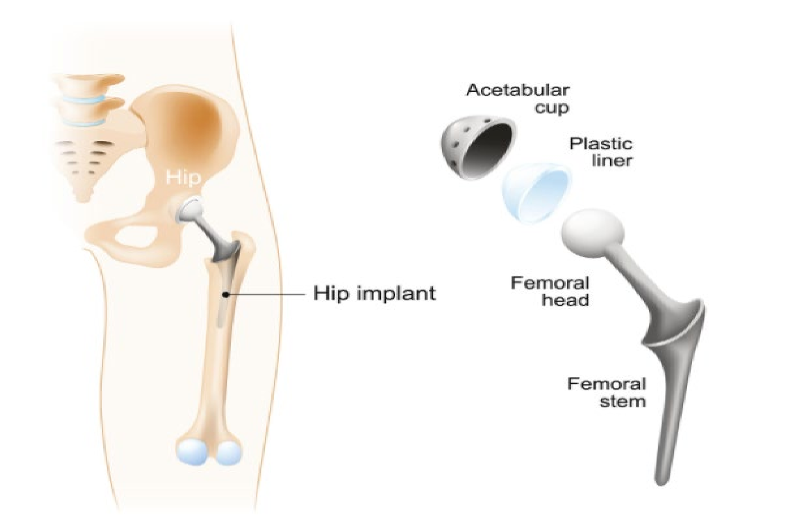
Experiment

Simulation

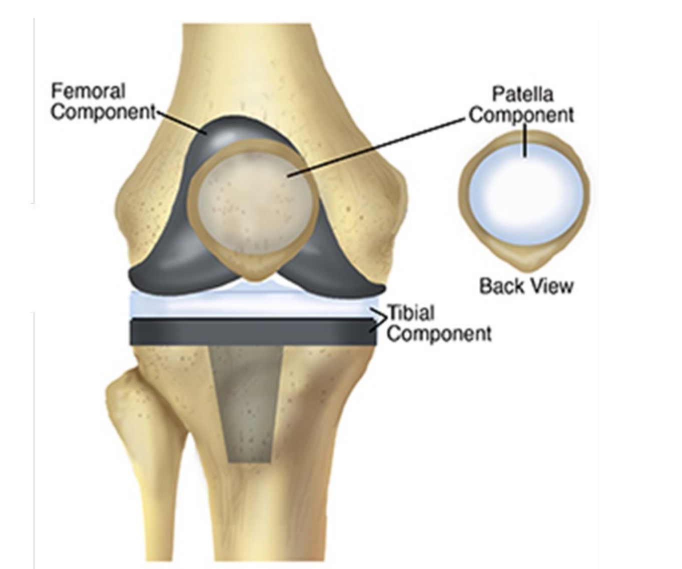


3D Printing Applications in Implants

Components of the Implants Where Polymer is Used

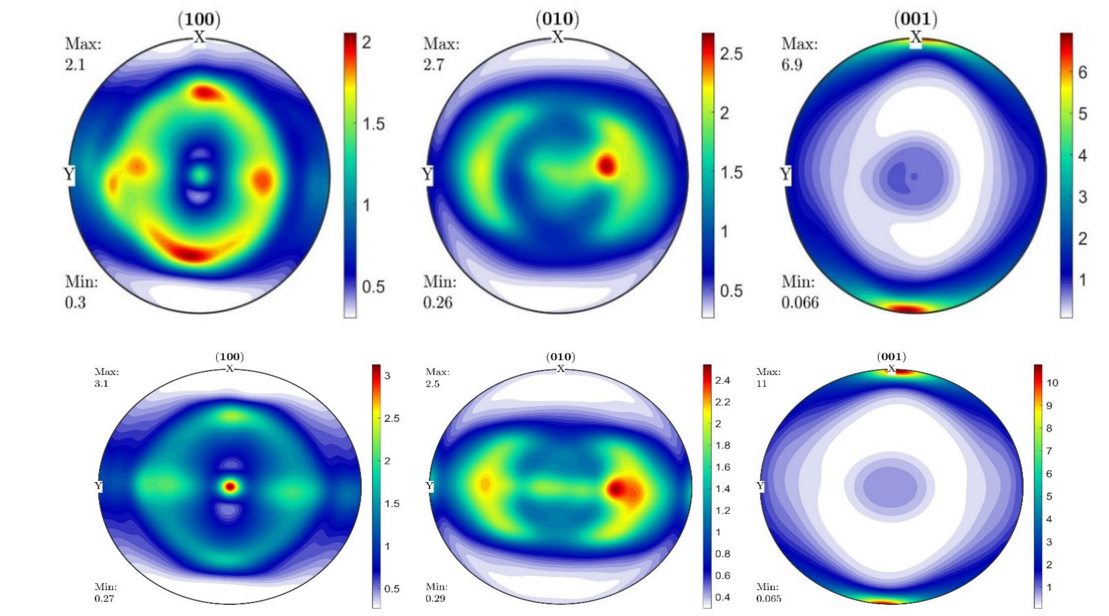


Total Hip Arthroplasty



Total Knee Arthroplasty

Variation of Texture with Printing Speed



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More durable implants

Induce Texture by 3D printing → Preferred orientation of crystallites reduces wear in specific directions and results in improved mechanical properties → Less wear and osteolysis leads to durable implant with enhanced longevity

Conclusions & Future Work

Conclusions:

- Developed and validated a methodology to predict melt-pool size, temperature profile, and deformation behavior for metal additive manufacturing.
- Studied the effect of crystallographic texture components of the strength of SLM Ti-6Al-4V alloy.
- Developed a methodology to predict the 3D microstructure including volume fraction, grain size, and texture of the manufactured part.
- Developed a methodology to predict the resulting strength of the additively manufactured part.

Future Work:

- Expansion of microstructure modeling to include more materials systems with more phases.
- Expansion of property modeling for any polycrystal material and multiple different properties (including hardness, fatigue toughness and modulus).
- Optimization of material formulation and processing technique for higher performance and longevity of the implants in total joint arthroplasty.