ICAM 2022

Size Effects on laser powder bed fusion and laser powder directed energy deposition GRCop-42 alloy

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Bio

Gabriel Demeneghi

NASA – Marshal Space Flight Center (MSFC), Huntsville AL

-Materials and Processes Lab

Failure Analysis/Materials Engineer

-Work with government, commercial, and academic partners

Additive manufacturing alloy development and characterization

-**Size effect characterization** on AM components

Outline

- Background
  - Size effects
  - Applications of thin walls
  - GRCop-42 alloy
  - Deposition technology
- Comparison between L-PBF and DED
  - Tensile response
    - specimens with as-printed surface
    - Polished surface
  - Surface topography
    - Roughness vs waviness
  - Porosity
  - Microstructure/Crystallographic texture
- Summary
- Future work

Size Effects

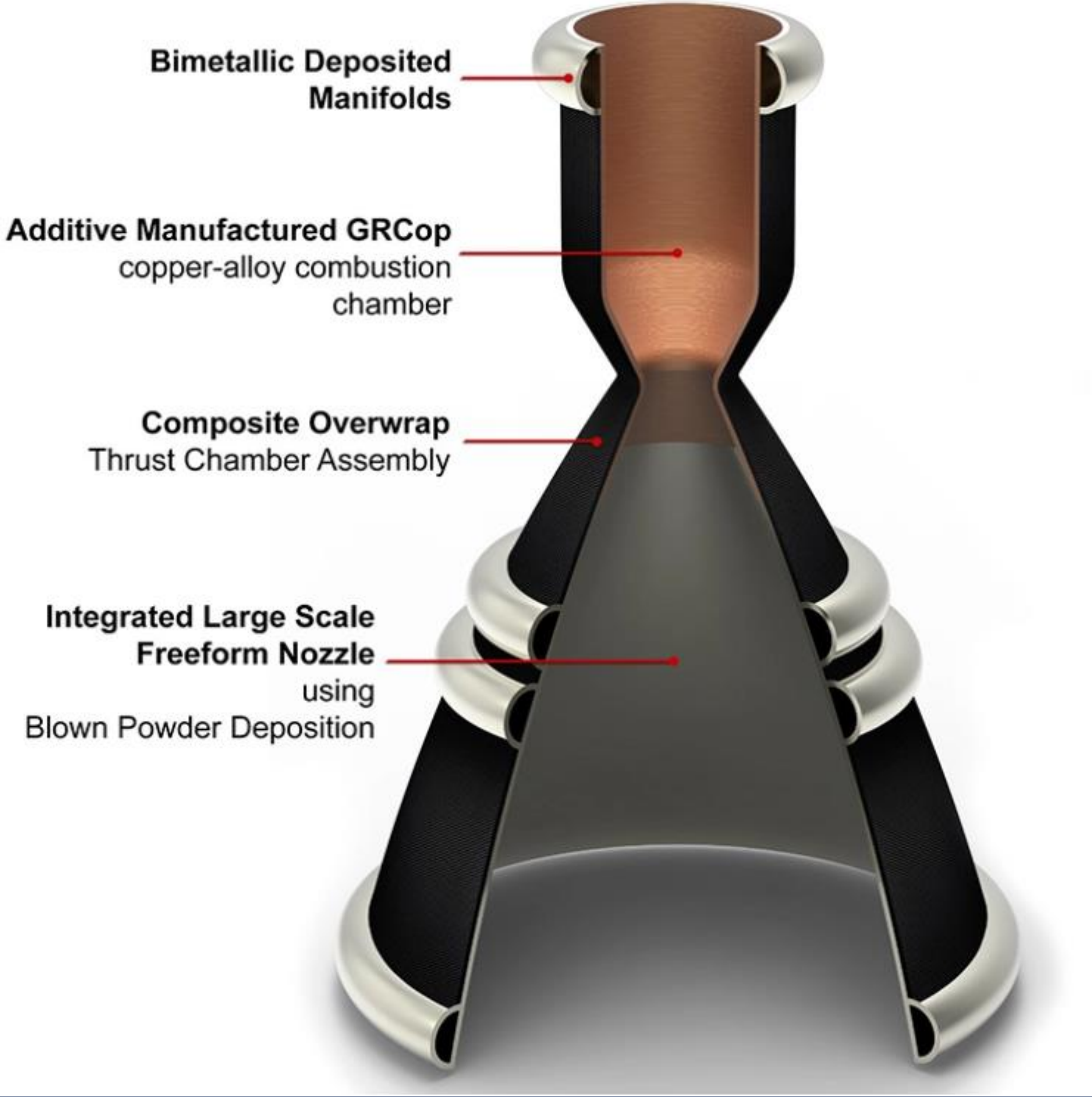
Thin Part Property ≠ **Bulk Part Property**

As the thickness on a part decreases, the mechanical behavior is more greatly affected by AM features, such as:

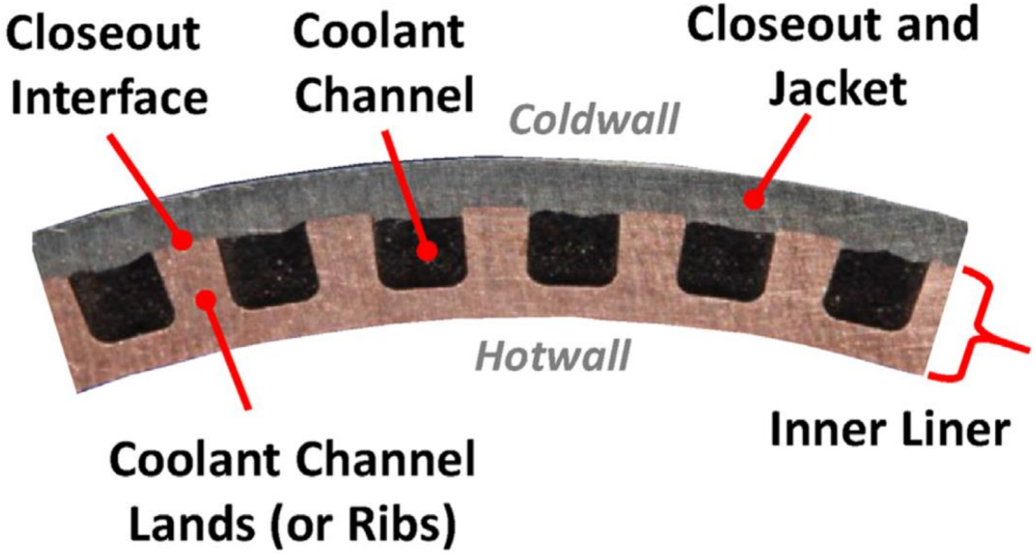
- Surface topography (roughness and waviness)
- Internal/surface connected porosity
- Crystallographic texture
- Grain structure
- Number of grains across thickness
- Anisotropic properties

Bulk properties cannot be extrapolated to thin walls

Applications of Thin Parts



Regeneratively cooled chambers are designed with internal coolant channels used to flow high pressure liquid or gaseous propellants to prevent over heating.



The Hotwall is a thin wall that separates the coolant from the combustion gases, experiencing a large thermal gradient and as a result, large strains.

Gradl, P. R., & Protz, C. S. (2020). Technology advancements for channel wall nozzle manufacturing in liquid rocket engines. *Acta Astronautica*, *174*, 148-158.

Materia - GRCop-42

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Copper alloys are used sough after for applications that require **high conductivity and mechanical strength simultaneously**.

GRCop-42 (Cu – 4at%Cr – 2at%Nb) is **dispersion hardened** copper alloy developed for combustion chambers. Developed at NASA Glenn Research Center (GRC).

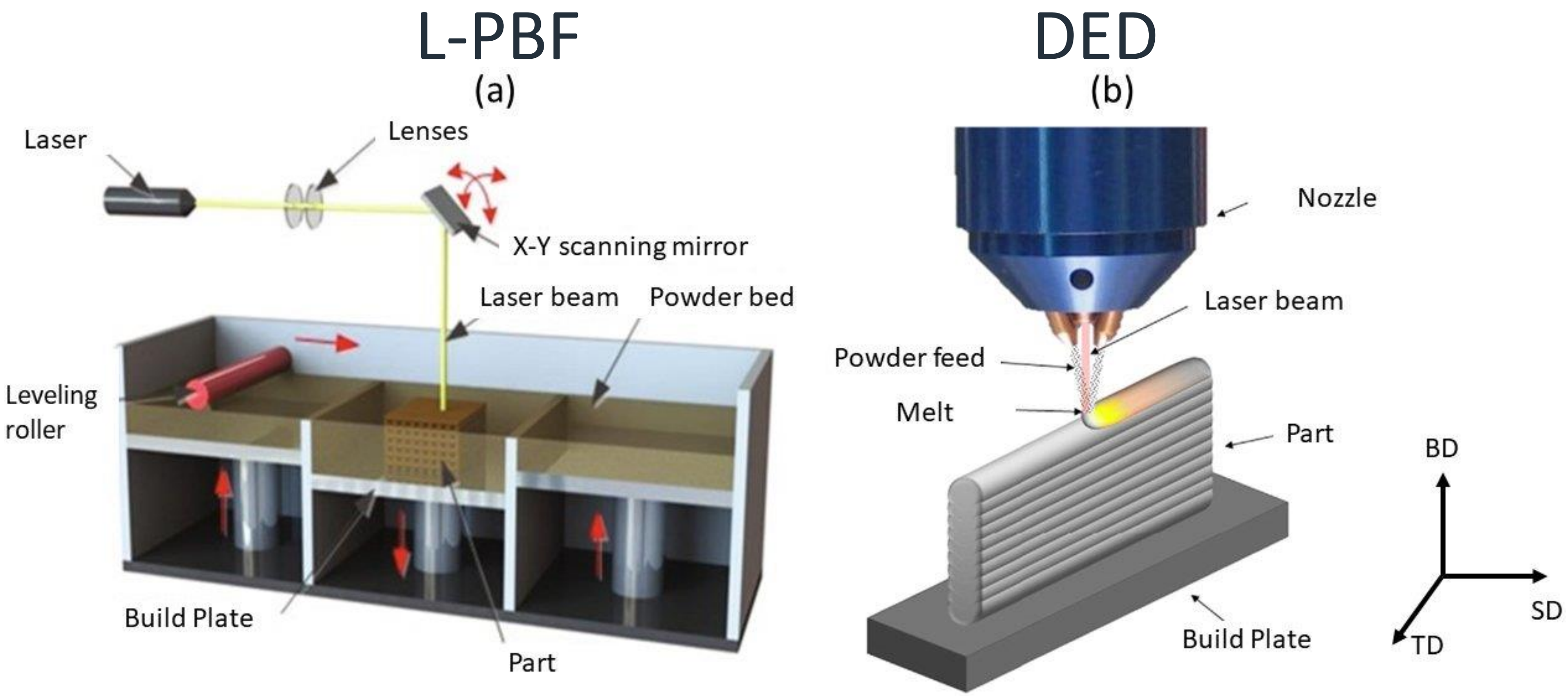
Cr_2Nb low solubility in Cu increases strength while maintaining a high conductivity.

Cr_2Nb is stable at high temperatures up to 800°C, allowing GRCop alloys to maintain a high strength for high performance chambers in high heat fluxes.

https://www.nasa.gov/sites/default/files/thumbnails/image/elg39671.jpg

Deposition Methods

3D constraints - Solidifying material is constrained by material behind, under, sides of the melt pool since the melt pool penetrates the previous layers as well as adjacent spaces



2D constraints - Solidifying material is constrained by material from the bottom of the melt pool and on the scanning direction behind the melt pool.

When compared to L-PBF, DED can deposit material at a faster rate, but at a lower resolution

(a) C Vyas, G Poologasundarampillai, J Hoyland, and P Bartolo. 3d printing of biocomposites for osteochondral tissue engineering. In Biomedical Composites, pages 261–302. Elsevier, 2017.

(b) Xiaoyi Guan and Yaoyao Fiona Zhao. Modeling of the laser powder– based directed energy deposition process for additive manufacturing: a review. The International Journal of Advanced Manufacturing Technology, 107(5):1959–1982, 2020.

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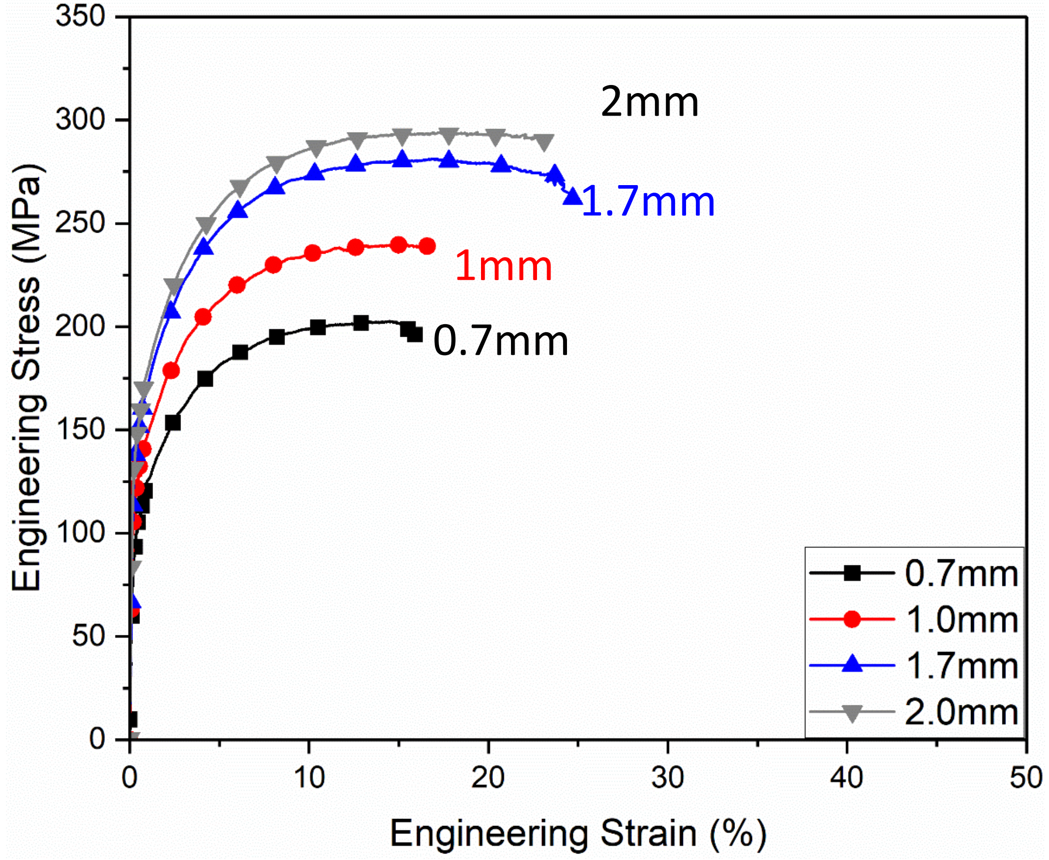
Tensile response – as printed surface

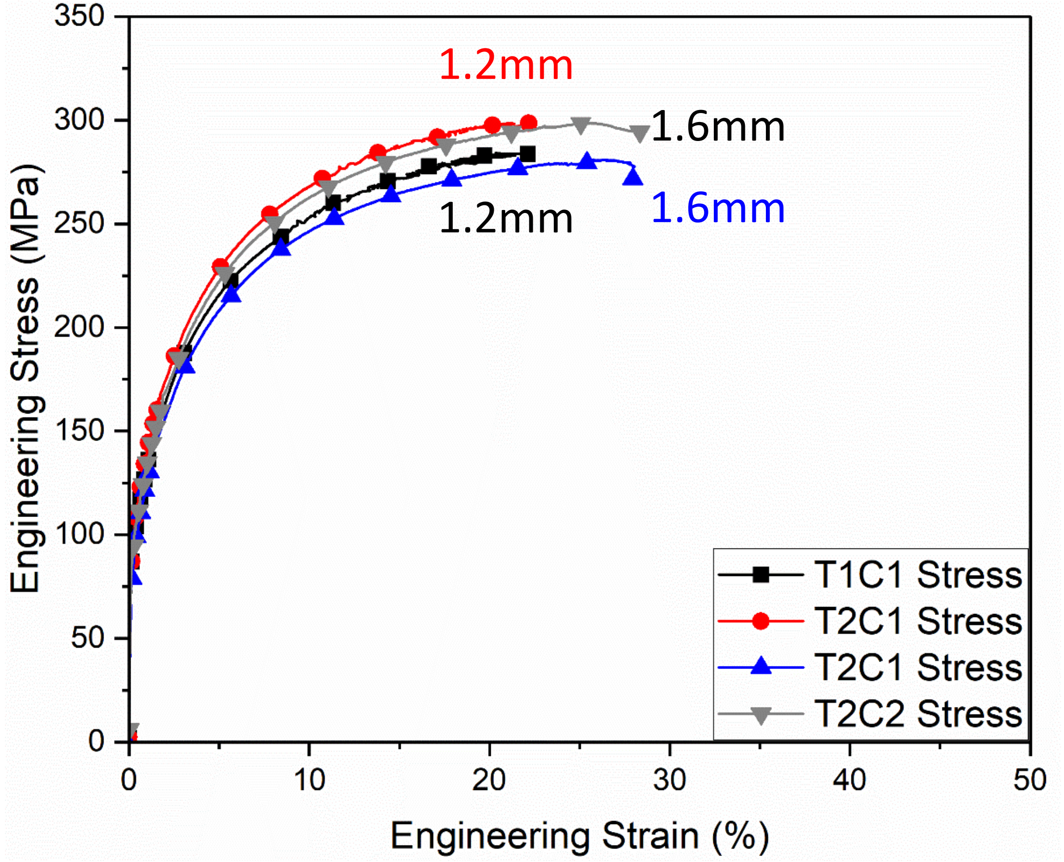
L-PBF



Load Direction

BD

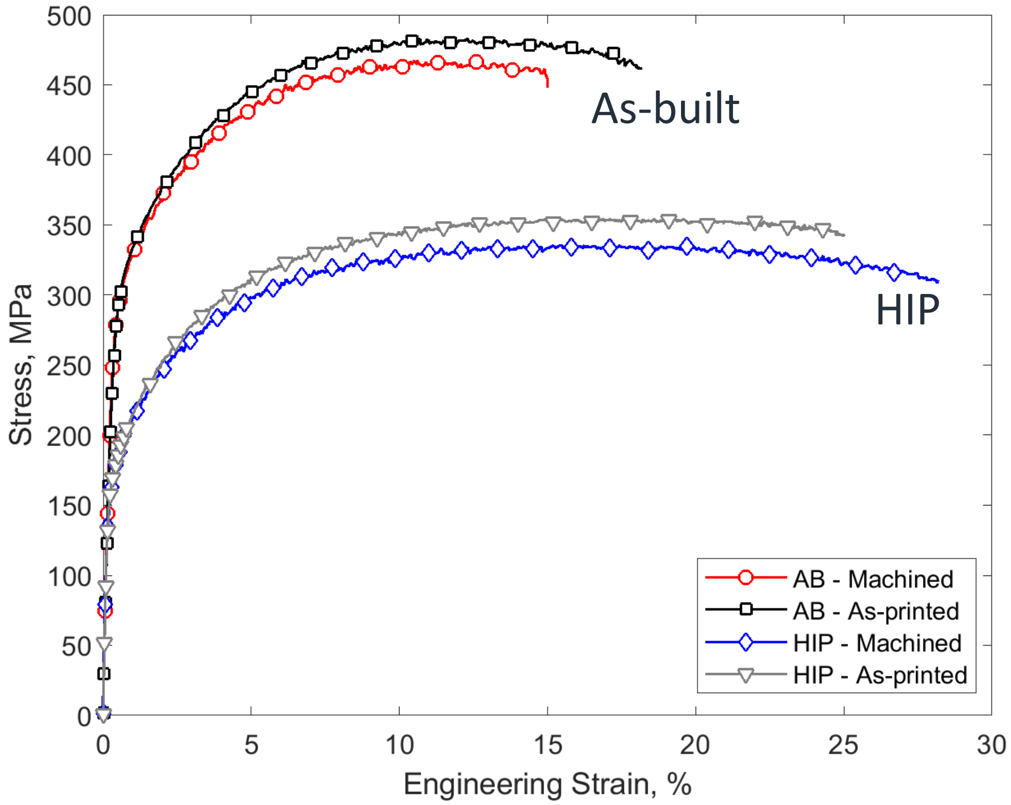
LP-DED



Vertical build, as-printed surface

Tensile response – Polished Surface

L-PBF



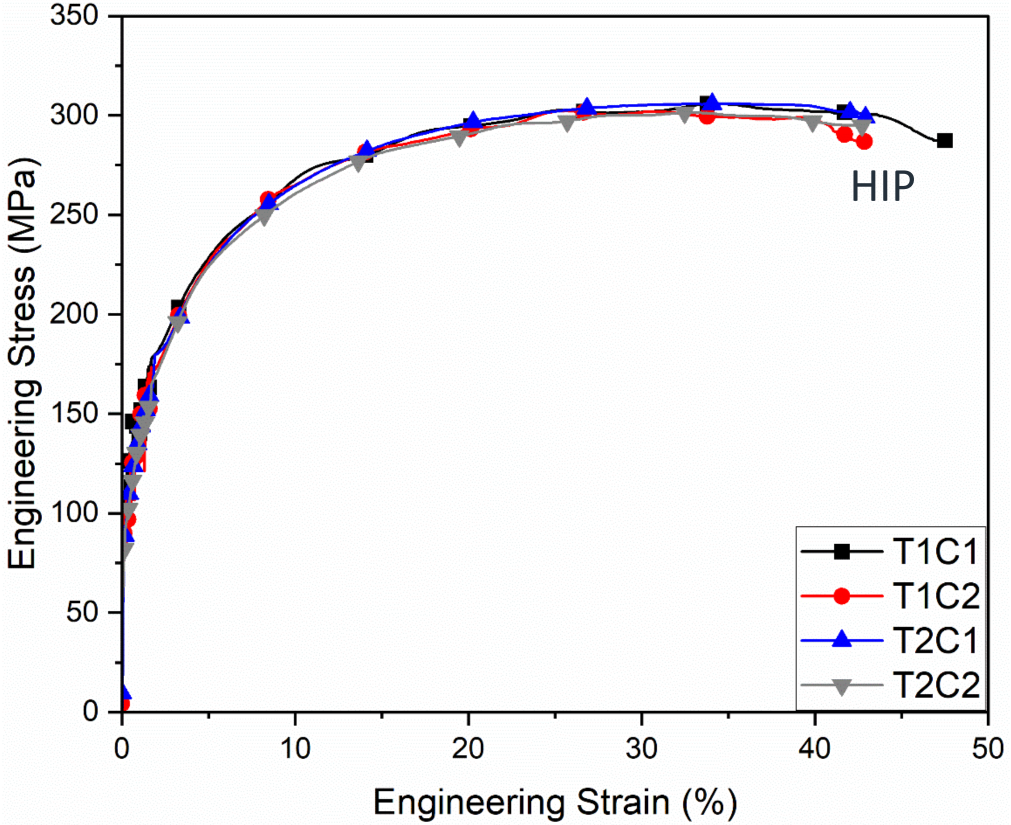
$A_{eff} = \mu CT_{area}$

Load Direction

BD

Vertical, polished surface

LP-DED



$A_{eff} = (t\text{-}S_P) * W$

Surface Topography

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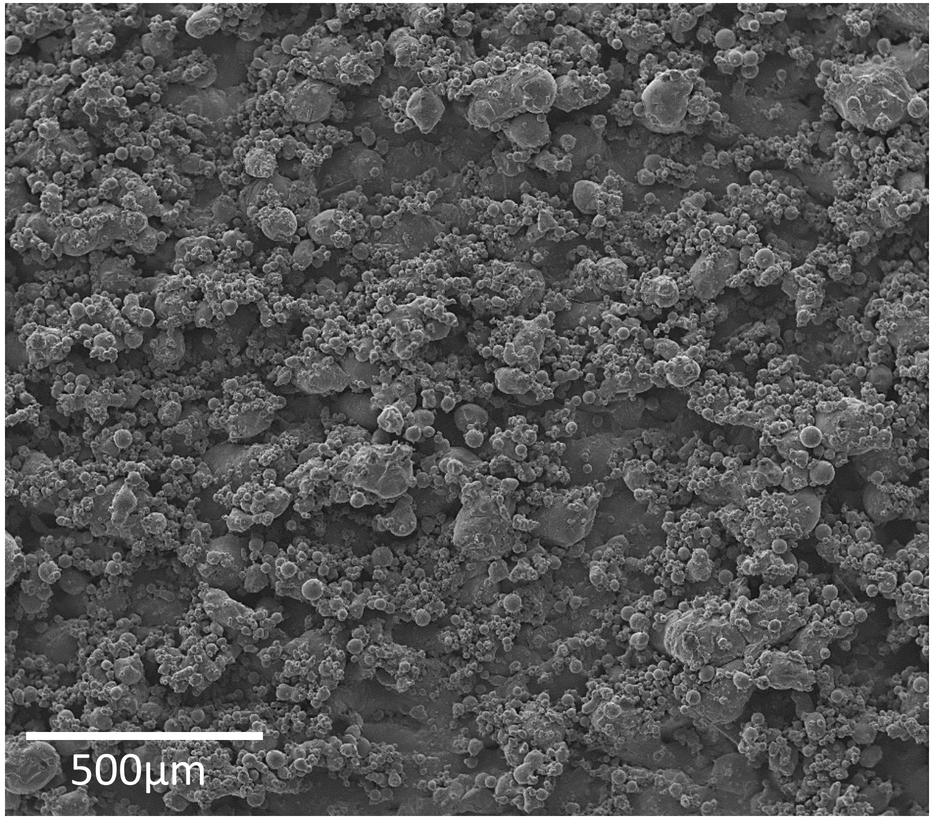
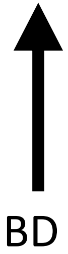
L-PBF



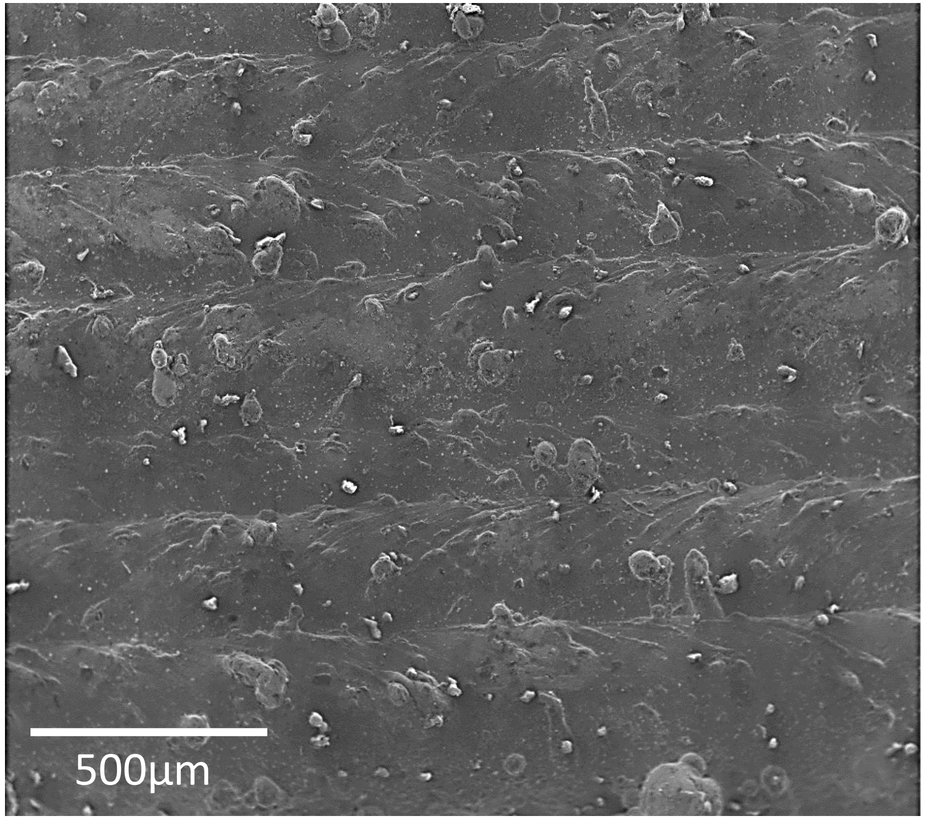
Sa = 15.7±5.0µm

^ powder adhered to the surface

^ unmelted powder



LP-DED



Sa = 13.0 ±1.5µm

^ defined layers (interlayers)

Microstructure - Voids

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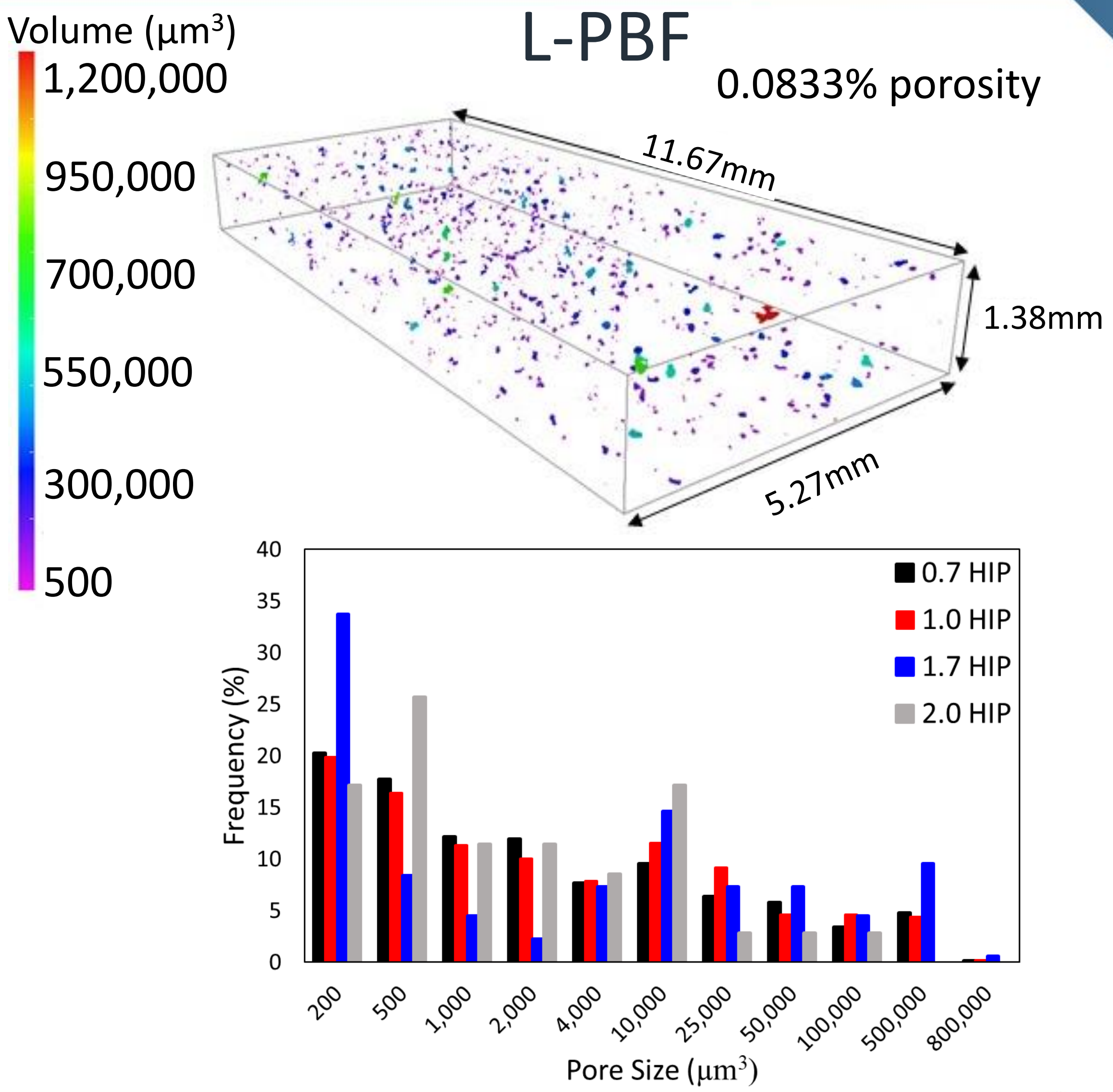
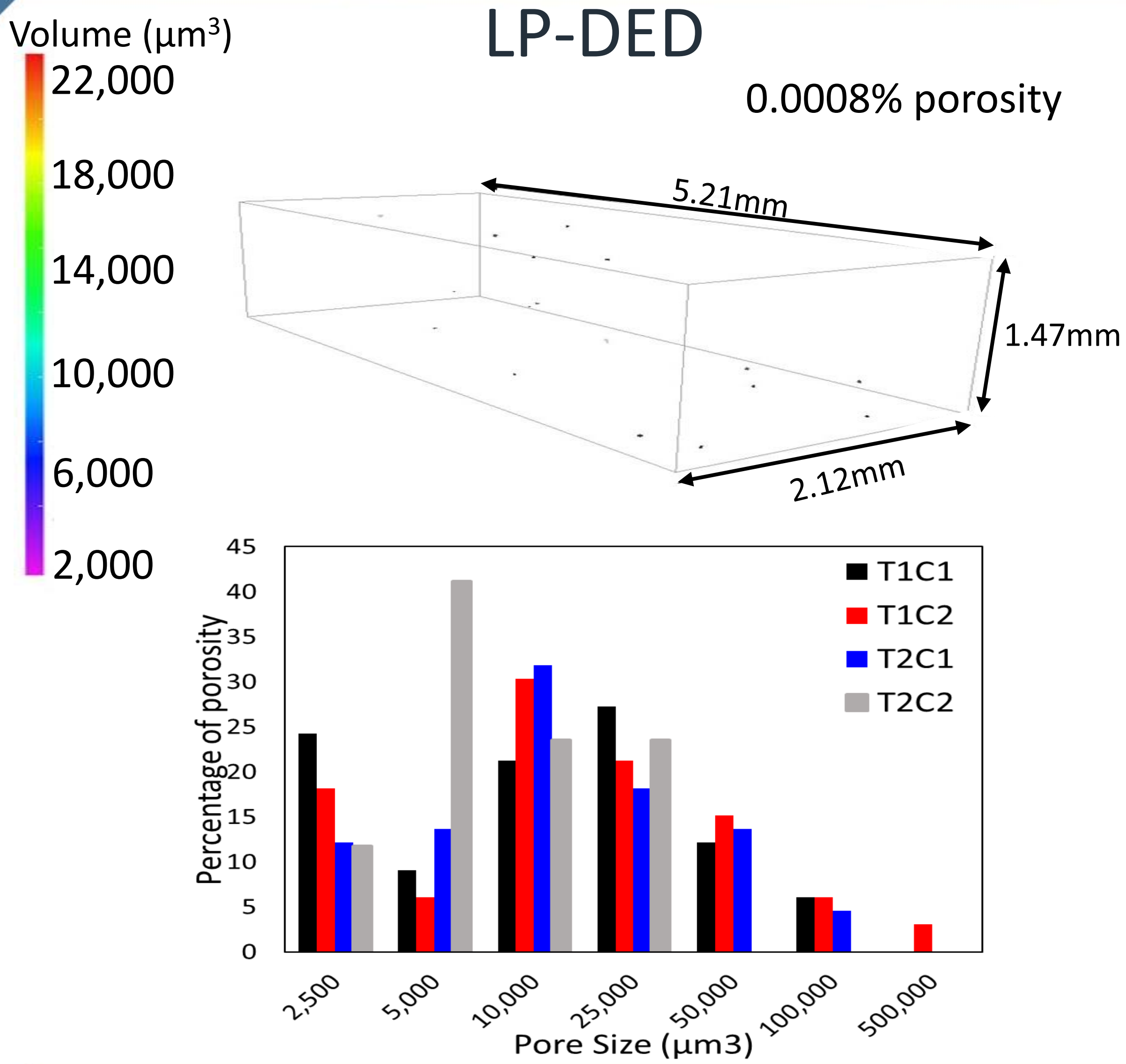
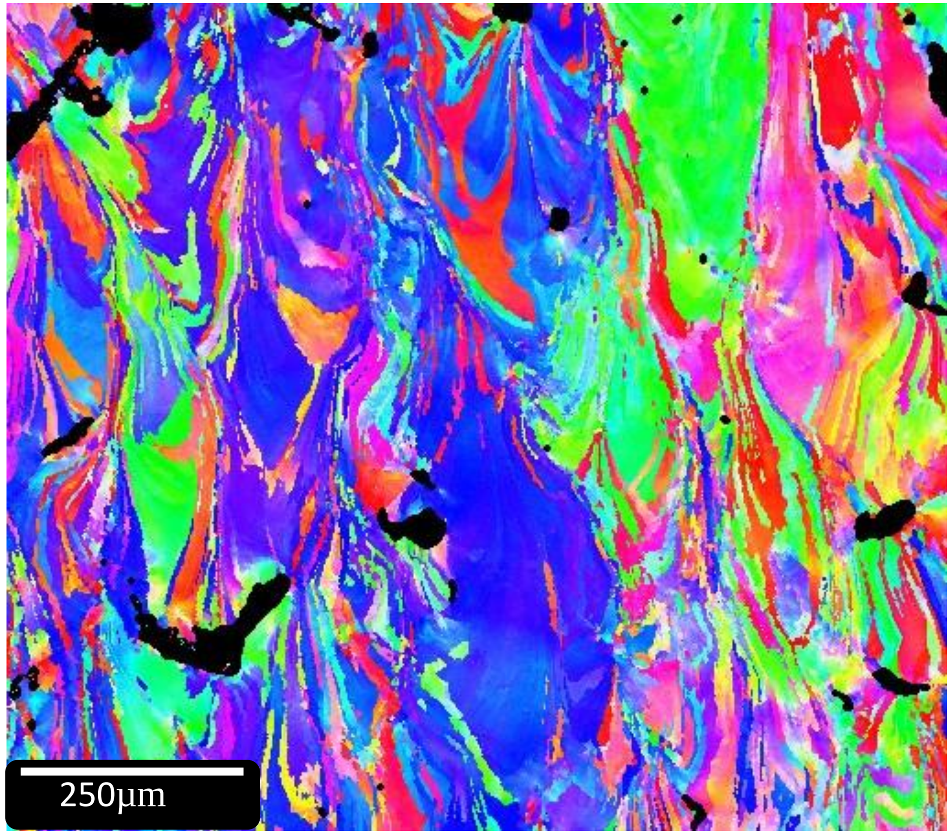
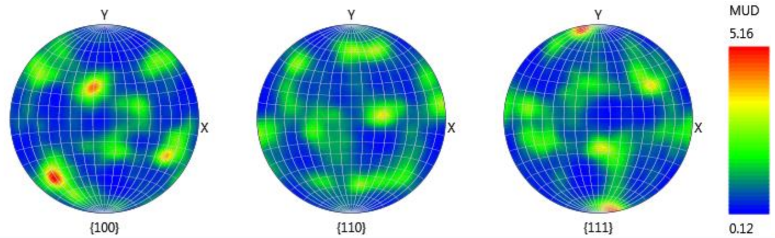




Microstructure - Texture

L-PBF

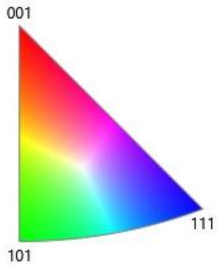




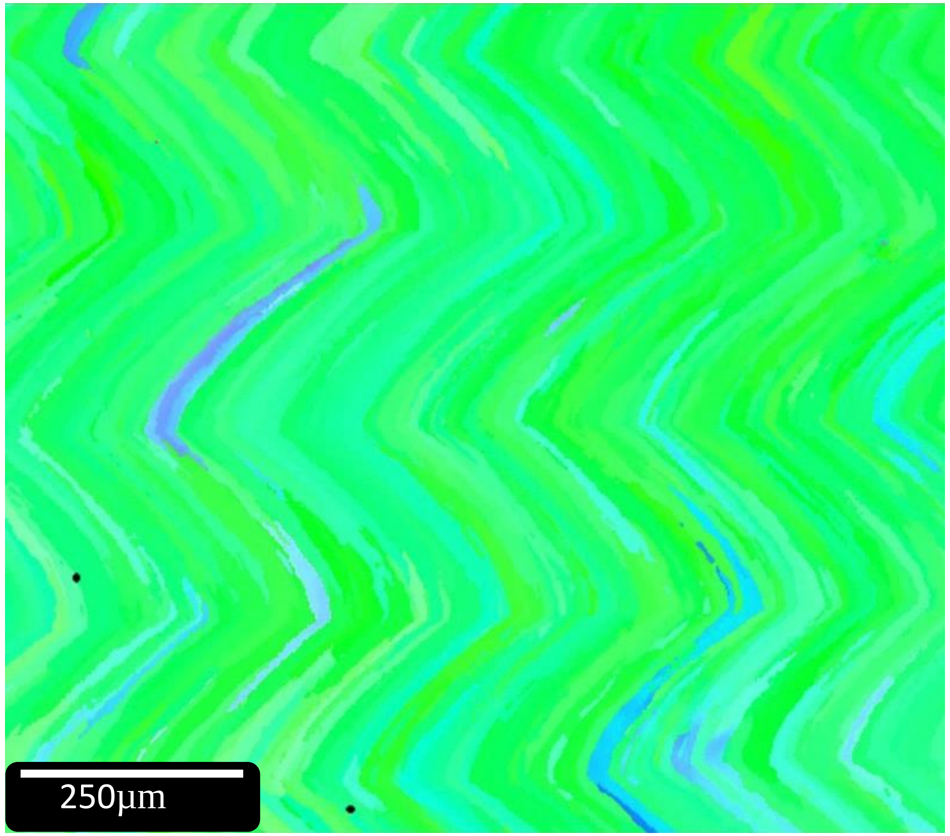
L-PBF – weak texture

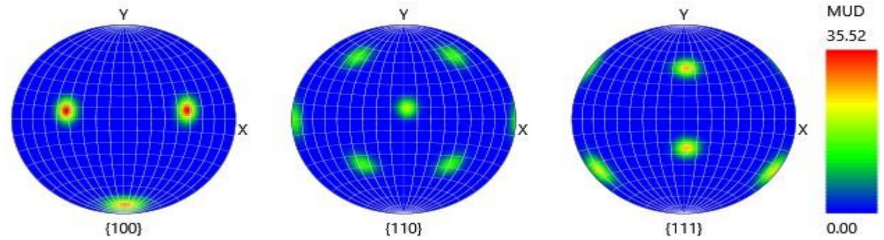
DED – Highly texture along build direction

BD



LP-DED





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Summary

- L-PBF had a more dramatic difference in mechanical response with variation in thickness than LP-DED
  - Surface topography had little effect on the tensile response (<6%) of L-PBF specimens
- Surface topography was found to be the major contributor to the reduced elongation in LP-DED specimens
  - Porosity was found to be minimal in the DED specimens
- Internal and surface connected porosity was found to be the major contributor to the size effects in L-PBF specimens
- L-PBF specimens showed a large amount of powder adhered to the surface little waviness.
- LP-DED specimens had low powder adhesion to the surface, but high waviness
  - Waviness leads to a smaller load bearing areas and stress concentrations.
- Percent volume was higher in L-PBF than LP-DED
  - Thinner L-PBF specimens showed a higher porosity volume percentage than thicker specimens
- L-PBF specimens showed a week crystallographic texture along the build direction, independent of specimen thickness
- LP-DED showed highly textured specimens along the build direction, independent of specimen thickness

Future work

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- Low cycle fatigue testing
- Characterization of microstructural damage accumulation during and post test
- Effects of cryogenic and elevated temperatures on the mechanical response
- Effects of various surface polishing methods and their impact on the mechanical behavior
- Influence of surface finish and temperature on mechanical behavior
- Similar characterization efforts are currently underway for several alloy systems, and the intention is to expand this to additional alloys.

Questions?

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