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

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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
    o specimens with as-printed surface
    o Polished surface
  • Surface topography
    o Roughness vs waviness
• Porosity
• Microstructure/Crystallographic texture
• Summary
• Future work
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*
Regeneratively cooled chambers are designed with internal coolant channels used to flow high pressure liquid or gaseous propellants to prevent overheating.

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.

Copper alloys are used sought 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).

Cr2Nb low solubility in Cu increases strength while maintaining a high conductivity.

Cr2Nb 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.
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.

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

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


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Tensile response – as printed surface

L-PBF

LP-DED

Vertical build, as-printed surface
Tensile response – Polished Surface

L-PBF

\[ A_{\text{eff}} = \mu C T_{\text{area}} \]

Vertical, polished surface

LP-DED

\[ A_{\text{eff}} = (t-S_p) \times W \]
Surface Topography

L-PBF

^ powder adhered to the surface
^ unmelted powder

Sa = 15.7±5.0µm

LP-DED

^ defined layers (interlayers)

Sa = 13.0 ±1.5µm
Microstructure - Voids

L-PBF

- 0.0833\% porosity
- Volume (µm³): 22,000
- 11.67mm
- 5.27mm

LP-DED

- 0.0008\% porosity
- Volume (µm³): 22,000
- 5.21mm
- 2.12mm

### Pore Size Distribution

**L-PBF**

- Frequency (%)
- Pore Size (µm³)
- 0.7 HIP
- 1.0 HIP
- 1.7 HIP
- 2.0 HIP

**LP-DED**

- Percentage of porosity
- Pore Size (µm³)
- T1C1
- T1C2
- T2C1
- T2C2
Microstructure - Texture

L-PBF

- Weak texture

DED - Highly texture along build direction

LP-DED
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- 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

• 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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