GRC Metal Additive Manufacturing

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GRC’s Roles in Additive Manufacturing of Metallic Components

- Characterization Database for Additively Manufactured Ti-6Al-4V Rocket Engine Components
- Low Cost Upper Stage Propulsion – Additively Manufactured Rocket Engine Combustion Chamber
  - GRCop-84
  - Inconel 625
- Additively Manufactured Turbomachinery Components
  - Gamma’ Nickel-base superalloys
Materials Characterization of Electron Beam Melted Ti-6Al-4V

- **Objective**: Implement Additive Manufacturing to reduce part count, welding, and touch labor required to manufacture the gimbal cone for the RL10 rocket engine.

- **Approach**: Generate materials characterization database on additively manufactured (AM) Ti-6Al-4V to facilitate the design and implementation.

- **Process**: Electron Beam Melting (EBM)
  - Electron beam energy source melts powder in a vacuum (~10-5 torr)

- **Characterization**:
  - Chemistry, microstructure of powder and manufactured samples.
  - Non-Destructive Evaluation (NDE).
  - Thermal properties and dynamic modulus.
  - Tensile, LCF, HCF, Fatigue crack growth, fracture toughness from cryogenic to 300 ºF temperatures from 2 lots of material.
The mechanical properties of HIP’ed EBM Ti-6Al-4V were equivalent or superior to handbook data on conventionally manufactured Ti-6Al-4V.

**Development Needs:**
- Process/Microstructure characterization and/or modeling to determine the cause of build-to-build fiber texture variation.
- Powder/Process/Property characterization to understand and quantify the impact of powder quality/characteristics on build properties.

Some fatigue specimens failed at elemental Nb inclusions. Inclusion likely came from powder.
Low Cost Upper Stage Propulsion (LCUSP)

- Multi-Center Project funded by the Space Technology Mission Directorate
- Objective:
  - Fully additively manufactured rocket engine combustion chamber. Reduced cost and schedule to fabricate, also enables design features not conventionally possible.
- Processes:
  - GRCop-84 Combustion Chamber Liner produced at MSFC using Selective Laser Melting (SLM)
  - Inconel 625 structural jacket applied to the liner using EB Free Form Fabrication (EBF3) at LaRC

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Low Cost Upper Stage Propulsion (LCUSP)

- Three Sets of Material properties / Material characterizations are being performed:
  - SLM GRCop-84
  - EBF3 Alloy 625
  - Joint between GRCop-84 and Alloy 625

- Characterization:
  - Powder Characterization (Chemistry, Size Distribution, Porosity)
  - Post-fabrication chemistry
  - Computed Tomography
  - Porosity pre- and post- HIP
  - Microstructure
  - Mechanical Testing (Tensile, LCF, HCF, FCG, Creep, Stress Rupture, Toughness)

- Development Needs:
  - Multi-Material AM capabilities
  - Predictive models for residual stress and distortion during AM builds.
  - Quality assessment tools
    - In particular for characteristic defects associated with power loss / layer loss scenarios in SLM

GRC POC: Bob Carter LMA0
Powder-bed fabrication of high temperature Ni-based superalloys

**Applications:** Turbomachinery for commercial & military aircraft, power-generation, rocket engines

- **Objective:** Expand Additive Manufacturing to high temperature gamma’ superalloys. Overcome the technical barriers due to poor weldability in these alloys.
- **Process:** Electron-beam melting
  - Heated powder-bed for reduced residual stresses and slower cooling rates
  - Multiple beam for faster builds
  - Vacuum for lower risk of contamination
- **Multi-Agency Team:**
  - ORNL- State-of-the art fabrication with in-situ monitoring, Arcam development center on-site
  - NASA GRC (PI)– Powder properties, analytical chemistry, microstructure evaluation, mechanical behavior
  - AFRL– microstructural modeling
  - Developing partnerships with engine OEMs

**Increasing susceptibility to PWHT cracking**

GRC POC: Chantal Sudbrack LMA0
Powder-bed fabrication of high temperature Ni-based superalloys

• **Technical Approach:**
  - Benchmarking of A.M. feedstock
    – We are using Low Solvus High Refractory (LSHR) disk alloy
  - Identify preferred manufacturing pathway
    – Optimization of processing & post heat treatments
  - Durability assessment and detailed characterization
    – Differentiate properties of AM from conventional PM and casting technologies

• **Long-range vision:**
  - Development of new alloys that leverage AM capabilities and mitigate cracking
    – May not be gamma’ strengthened...
  - Tailored material properties for light weight and durability
    – Chemistry and microstructural gradients.

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**GRC POC:** Chantal Sudbrack LMA0

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<thead>
<tr>
<th>Location</th>
<th>Key Property</th>
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<tbody>
<tr>
<td>1500 °F rim</td>
<td>Need high creep life and crack growth resistance</td>
<td>Creep/fatigue interaction</td>
</tr>
<tr>
<td>1300 °F web</td>
<td>Creep/fatigue interaction</td>
<td>Need high tensile strength and low cycle fatigue life</td>
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**As-fabricated**

2167 °F / 4h 25 ksi Ar

**HIP reduces deleterious pores**

Process induced porosity

5 µm

**Normalized Lives / Strength**

- Creep
- Tensile Strength
- LCF Life

**Normalized Grain Size (µm)**

10 100 1000

- ASTM 8-12
- ASTM 5
- ASTM 3
- U720 data

**< N+2**
Summary of potential areas for development and maturation

1. Predictive process models are needed to reduce the time and cost for development, implementation, and industrial acceptance.  
   – microstructural evolution, residual stress, post build thermal treatments
2. Alloy Development – New alloys to leverage AM capabilities. For high T nickel alloys we need to mitigate cracking.
4. Powder Influence / Effects – Understand how basic powder feedstock characteristics influence a part’s physical, mechanical, and surface properties.
7. Characteristic Defects / NDE – Identify, catalog, and reproduce defects characteristic of the AM process.
8. Build Interactions / Effects – Understand how basic AM build factors influence part properties.