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

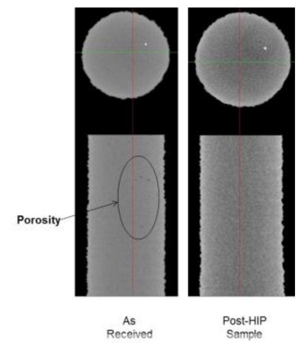
GRC POC: Susan Draper

Materials Characterization of Electron Beam Melted Ti-6Al-4V

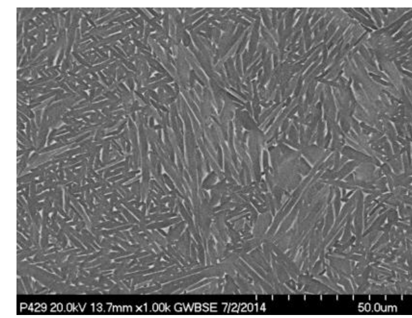
- <u>Objective</u>: Implement Additive Manufacturing to reduce part count, welding, and touch labor required to manufacture the gimbal cone for the RL10 rocket engine.
- <u>Approach</u>: Generate materials characterization database on additively manufactured (AM) Ti-6Al-4V to facilitate the design and implementation.
- <u>Process</u>: Electron Beam Melting (EBM)
  - Electron beam energy source melts powder in a vacuum (~10-5 torr)
- <u>Characterization</u>:
  - 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.

Full Scale from ORNL (A2XX)

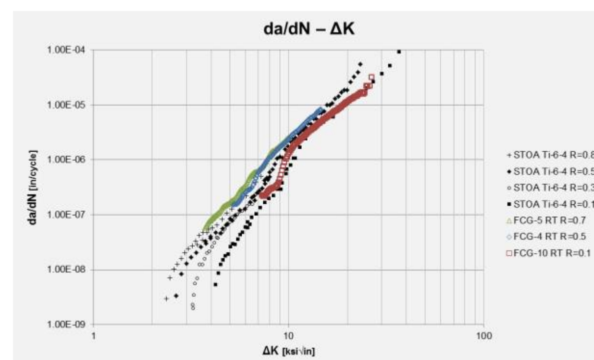
Powder Characterization



CT of pre and post HIP'd builds



Microscopy



Fatigue Testing

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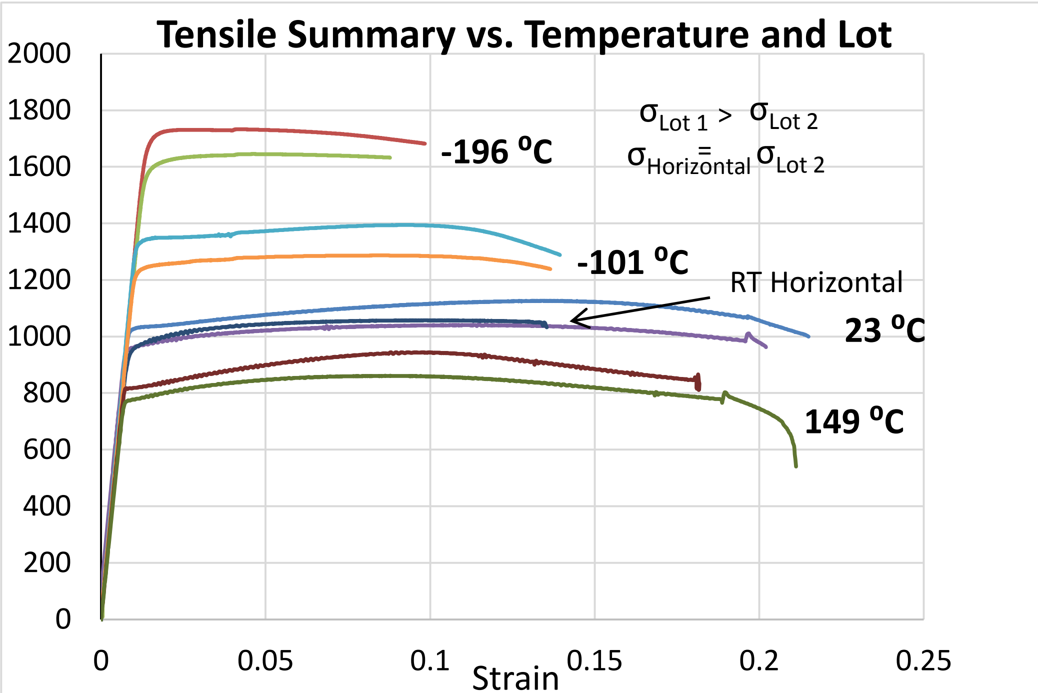
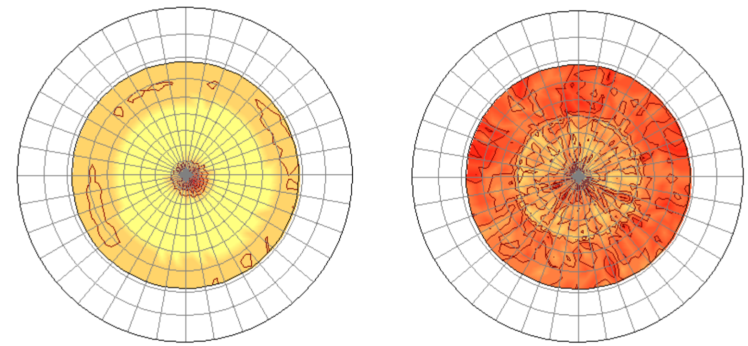


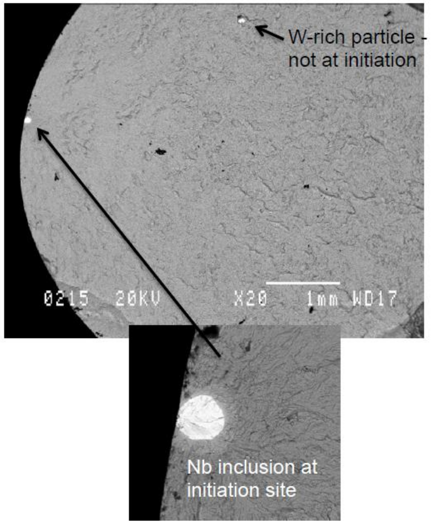
(002)

Lot 1
Fiber texture

Lot 2
Random texture



Fiber texture in (002) direction responsible for higher tensile and fatigue strength for lot 1.



Some fatigue specimens failed at elemental Nb inclusions. Inclusion likely came from powder.

- The mechanical properties of HIP'ed EBM Ti-6Al-4V were equivalent or superior to handbook data on conventionally manufactured Ti-6Al-4V.
- <u>Development Needs</u>:
  - 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.

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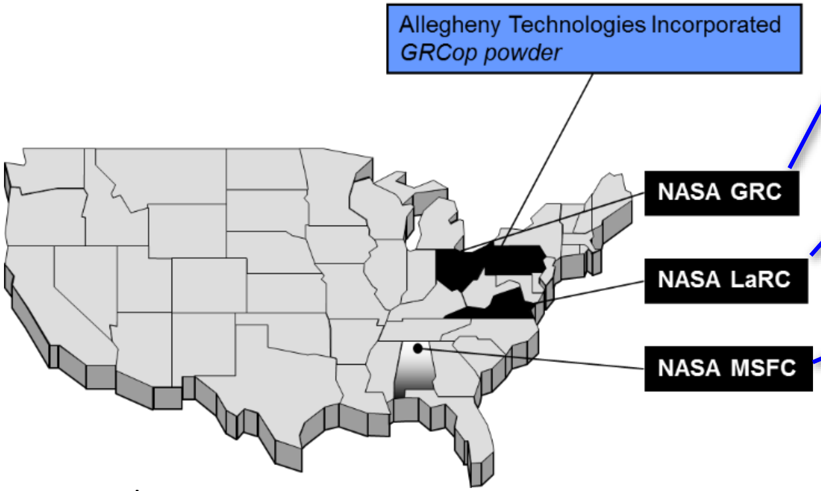
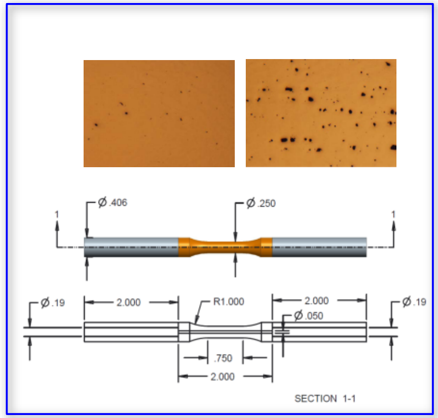
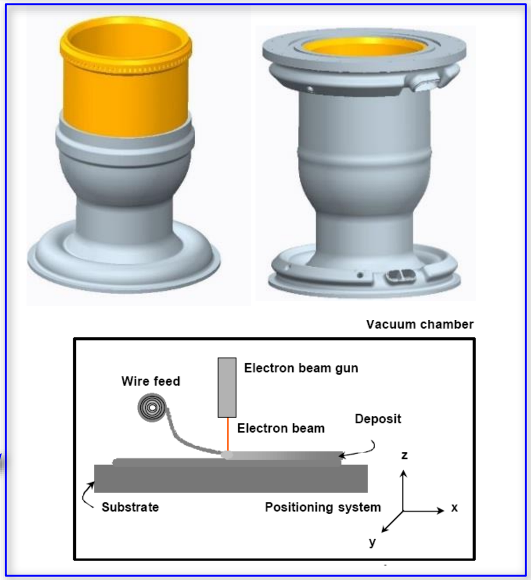
Low Cost Upper Stage Propulsion (LCUSP)

- 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





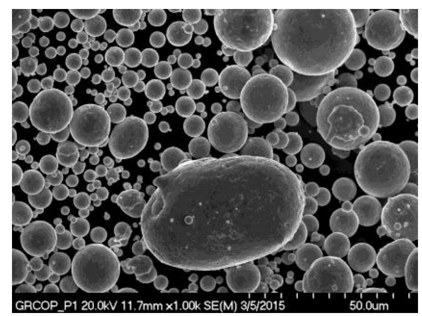


GRC POC: Bob Carter LMA0

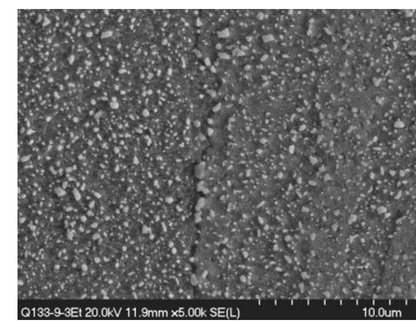
Low Cost Upper Stage Propulsion (LCUSP)

- **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

GRCop-84 Liners produced by SLM



SEM Powder Characterization



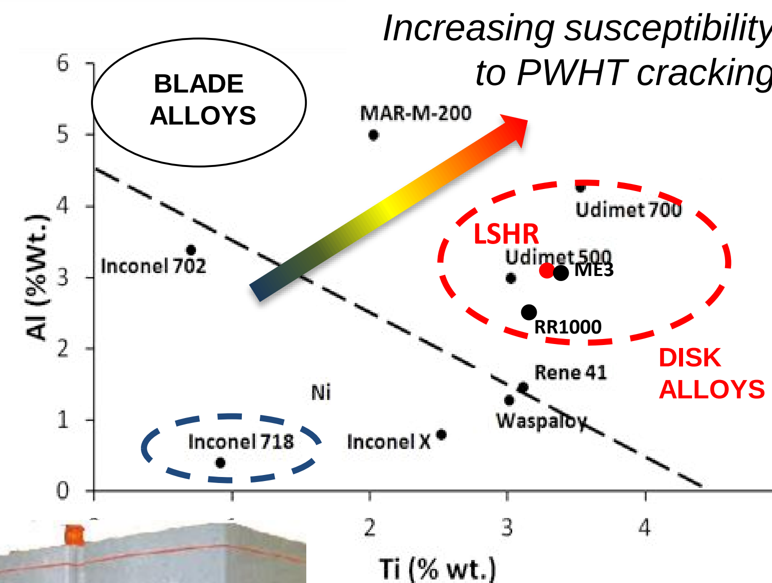
SEM Characterization of builds

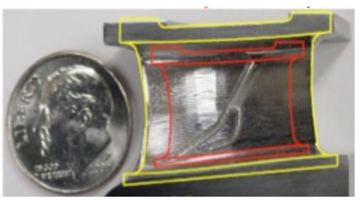
GRC POC: Bob Carter LMA0

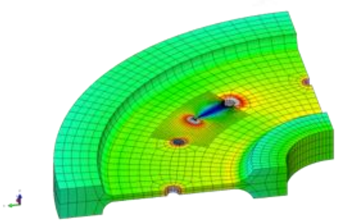
Powder-bed fabrication of high temperature Ni-based superalloys

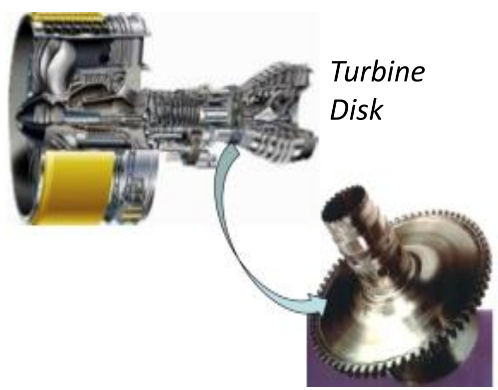
Applications: Turbomachinary for commercial & military aircraft, power-generation, rocket engines

- 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





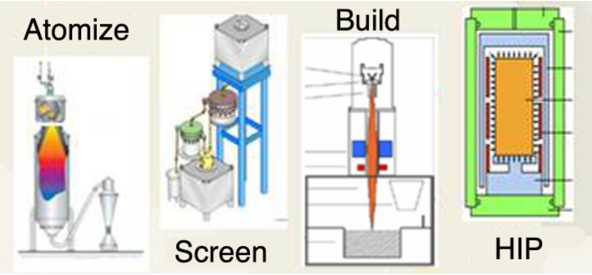


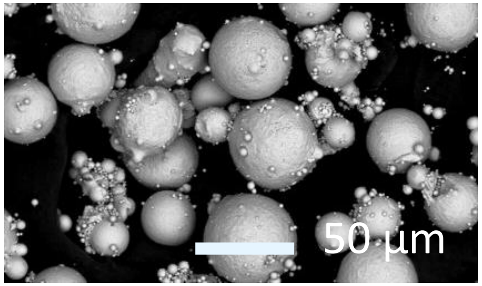


GRC POC: Chantal Sudbrack LMA0

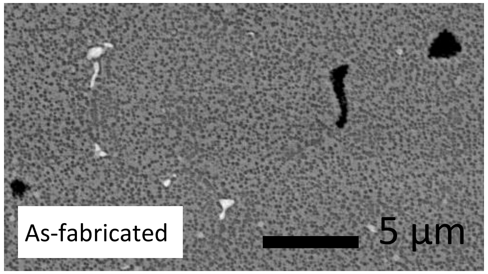
Powder-bed fabrication of high temperature Ni-based superalloys

- 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.

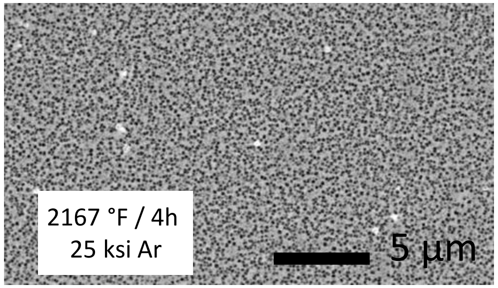


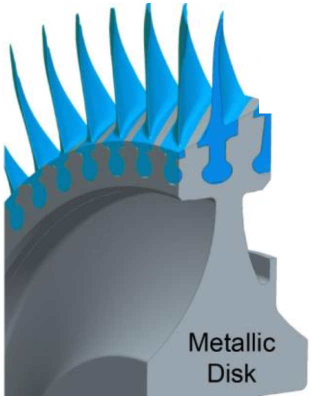


Process induced porosity



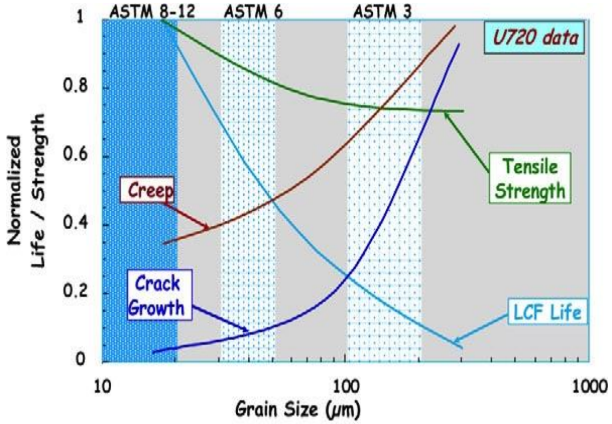
HIP reduces deleterious pores





≥ N+2

Location	Key Property
1500 °F rim	Need high creep life and crack growth resistance
1300 °F web	Creep/fatigue interaction
800 °F bore	Need high tensile strength and low cycle fatigue life



GRC POC: Chantal Sudbrack LMA0

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.
3. Multi Material capabilities – Multifunctional structures.
4. Powder Influence / Effects – Understand how basic powder feedstock characteristics influence a part’s physical, mechanical, and surface properties.
5. Thermal Processing / Effects – Develop AM-specific thermal processing.
6. Surface Improvement / Effects – Understand how as-built and improved AM surface texture influence part performance and fatigue life.
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.