GRC Metal Additive Manufacturing

Robert Carter
NASA/LMA
216-433-6524
robert.carter@nasa.gov
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

- **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 °F temperatures from 2 lots of material.

GRC POC: Susan Draper
Materials Characterization of Electron Beam Melted Ti-6Al-4V

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.

GRC POC: Susan Draper
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

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.

**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

- **Process induced porosity**
- **HIP reduces deleterious pores**

- **As-fabricated**
  - 2167 °F / 4h
  - 25 ksi Ar

- **40 µm**
  - HIP reduces deleterious pores

- **5 µm**
  - Process induced porosity

- **5 µm**
  - As-fabricated
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.