Optimization of Rocket Engine Components using Multi-Metallic Additive Manufacturing

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Introduction

• Objectives and Project Overview
• Why bimetallic and multi-alloy AM?
• Process Development
• Hardware Development
• Hot-fire and Component Testing
• Summary
Additive manufacturing (AM) is advancing component fabrication for liquid rocket engines allowing for reduced cost, reduced lead time, and performance opportunities over traditional manufacturing.

Much of AM is focused on single alloys, where further opportunities exist to optimize performance.

- Weight reduction (higher strength to weight).
- Use of materials as required locally based on various properties.

Copper-based alloys, such as GRCop-42 and GRCop-84 are used for high conductivity, such as regenerative-cooling for combustion chambers.

- Although have high strength, better metal alloys (superalloys) available to react pressure, thermal, and thrust loads (↑ strength to weight).

There is a need to advance bimetallic and multi-alloy components using additive manufacturing processes.
Traditional Manufacturing...Forging to final assembly
A rocket combustion chamber case study for AM

As AM process technologies evolve using multi-materials and processes, additional design and programmatic advantages are being discovered.

<table>
<thead>
<tr>
<th>Category</th>
<th>Traditional Manufacturing</th>
<th>Initial AM Development</th>
<th>Evolving AM Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design and</td>
<td>Multiple forgings, machining, slotting, and joining operations to complete a final multi-alloy chamber assembly</td>
<td>Four-piece assembly using multiple AM processes; limited by AM machine size. Two-piece L-PBF GRCop-84 liner and EBW-DED Inconel 625 jacket</td>
<td>Three-piece assembly with AM machine size restrictions reduced and industrialized. Multi-alloy processing; one-piece L-PBF GRCop-42 liner and Inconel 625 LP-DED jacket</td>
</tr>
<tr>
<td>Manufacturing Approach</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schedule (Reduction)</td>
<td>18 months</td>
<td>8 months (56%)</td>
<td>5 months (72%)</td>
</tr>
<tr>
<td>Cost (Reduction)</td>
<td>$310,000</td>
<td>$200,000 (35%)</td>
<td>$125,000 (60%)</td>
</tr>
</tbody>
</table>

*Low volume production
A variety of AM processes are used to build a base material and then deposit/apply a secondary material to create a bimetallic component.
AM Processes evaluated for bimetallic joints

- Laser Powder Bed Fusion
- Cold spray
- Laser Powder Directed Energy Deposition
- Electron Beam Wire Directed Energy Deposition
- Arc Wire Directed Energy Deposition
AM bimetallic provides various joint options

- AM provides a variety of options for bimetallic and multi-alloy joints.
- The type of joint design is highly dependent on the end use and component loads.
- NASA is investigating several types of joints to mature the AM process technology.
• Residual stresses can be very high and cause significant shrinkage
• Material modeling to aid with selection using CALPHAD
• High bond strength can be achieved with proper thermal control from deposition parameters
• Intermediate metal alloys may be required to avoid deleterious phases
• Microtensile testing provides a method to characterize joints directly on hardware
Bimetallic and Multi-metallic Additive Manufacturing for Thrust Chambers

- Bimetallic and multi-metallic joints necessary to join various alloys to optimize strength-to-weight materials by using materials locally based on component requirements
  - Locations include for joining manifolds on the chamber and axial joint between chamber and nozzle
  - Eliminates bolted interfaces
  - Nickel interface layers allow for material transition
- Evaluation various processes including Cold Spray, Laser Hot Wire, and Blown Powder DED

Microtensile testing of Bimetallic/Multi-metallic Joints

Inconel 625

GRCop-42
Examples of Component Fabrication

40K-lbf LP-DED Chambers

- L-PBF GRCop-42 to LP-DED Inconel 625

7K-lbf L-PBF GRCop-42 to NASA HR-1 Cold spray Chamber

- Post-Build
- HIP
- Final Machining, Weld, Flow Test
- Final Testing
- Cold Spray

L-PBF GRCop-42 to LP-DED NASA HR-1
Multi-metallic Additive Manufacturing under RAMPT Project

- Develops commercial supply chain
- Optimizes weight based on selective material deposition
- Reduces costs
- Evaluating DED and solid-state AM processes
- Significantly reduces weight for high chamber pressure TCA’s
- Reduces distortions caused by bimetallic cladding
- Reduces overall cost and fabrication schedules
- Builds upon prior composite overwrap pressure vessel (COPV) technology

Bimetallic Deposited Manifolds and Nozzle Interface

Integrated Large Scale DED Freeform Manufacturing Deposition Regen-Cooled Nozzle

L-PBF AM Copper Chamber

Composite Overwrap

- Based on prior LCUSP development
- Proven Technology for GRCop alloys
- Expand to GRCop-42
- Advances and expands commercial supply chain

Selected Laser Powder Directed Energy Deposition (LP-DED)

Demonstrate integral channels using DED process

Demonstrate coupled chamber and nozzle configuration to reduce weight

Reduces complexity

Significantly increases scale for AM processes for regen-cooled components
Combining key technologies into an integrated thrust chamber assembly using:

1. GRCop-42 L-PBF chamber as central component and “build plate”
2. Large scale laser powder directed energy deposition
3. Bimetallic and multi-alloys for joints
4. Composite overwrap jacket
• Decoupled versions built and tested during development
• Technology improvements made continuously throughout project
RAMPT Multi-alloy Radial and Axial Hardware

- L-PBF Chamber
- Manifold Prep LP-DED Setup
- Axial LP-DED Nozzle
- Radial LP-DED
- Final Machining
- Manifold EB Welded
Multi-metallic and multi-process hardware development

L-PBF Liner / LP-DED Jacket

L-PBF Liner / Coldspray Jacket

L-PBF Liner / EBW-DED Jacket

L-PBF GRCop-42 to Inco 625

Direct deposit LP-DED nozzle (Radial and Axial Bimetallic)

Credit: RPMI
Hot-fire Testing of Bimetallic Chambers

- Completed various test programs from 2k to 40k-lbf in LOX/H2, LOX/RP-1, and LOX/CH4
- Hot-fire tested using various bimetallic AM processes

<table>
<thead>
<tr>
<th>Project</th>
<th>Propellants</th>
<th>Thrust (lbₜ)</th>
<th>Metal Alloys</th>
<th>Multi-Alloy Process</th>
<th>Starts</th>
<th>Seconds</th>
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<tr>
<td>PF086</td>
<td>LOX/LH2</td>
<td>30,000</td>
<td>GRCop-84 / Inconel 625</td>
<td>EB-DED</td>
<td>9</td>
<td>147</td>
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<td>PJ024</td>
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<td>475</td>
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<td>405</td>
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<td>76</td>
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<td>321</td>
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<tr>
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<td>GRCop-42 / NASA HR-1</td>
<td>LP-DED</td>
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<td>328</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>73</strong></td>
<td><strong>2,512</strong></td>
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</table>
Conclusions / Summary

- NASA has advanced state-of-the-art bimetallic and multi-alloy GRCop-alloy to superalloy AM for liquid rocket engine components.
- Advancements were made through evaluations of various multi-alloy AM processes, material characterization, and successful component manufacturing and hot-fire testing for various combustion devices.
- Manufactured 2K-lbf through 40K-lbf bimetallic chambers and have hot-fire tested various configurations using both radial and axial multi-metallic joints
  - Accumulated 73 starts and 2,512 seconds of hot-fire time across multi-alloy AM chambers
- NASA continuing to develop the bimetallic AM techniques
  - Investigating modeling, characterization, and improvements for bimetallic joints
  - Mechanical and hot-fire data available to industry partners
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References

References


