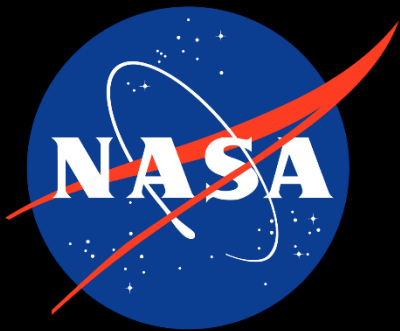




EXPLORE MOON *to* MARS

Advancing GRCop-based Bimetallic Additive Manufacturing to Optimize Component Design and Applications for Liquid Rocket Engines

Paul Gradl, Thomas Teasley, Chris Protz, Marissa Garcia
NASA Marshall Space Flight Center (MSFC)

Christopher Kantzos, David Ellis
NASA Glenn Research Center (GRC)

August 9-11, 2021



Motivation and Objectives



- 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

General Process Fabrication for Combustion Chambers

Liner Fabrication

- Forging
- Spin Forming
- Shear Forming
- Powder Metallurgy
- Directed Energy Deposition
 - Laser Powder
 - Laser Wire
 - Arc Wire
- Platelets
- Coldspray
- Casting
- Hydroforming
- Vacuum Plasma Spray

Channel Forming / Slotting

- Slitting Saw
- End Milling
- Water Jet Milling
- Electrochemical
- Plunge EDM
- Pulsed ECM
- Multi-Piece L-PBF
- Platelets
- Freeform DED Cladding

Channel Closeout and Jackets

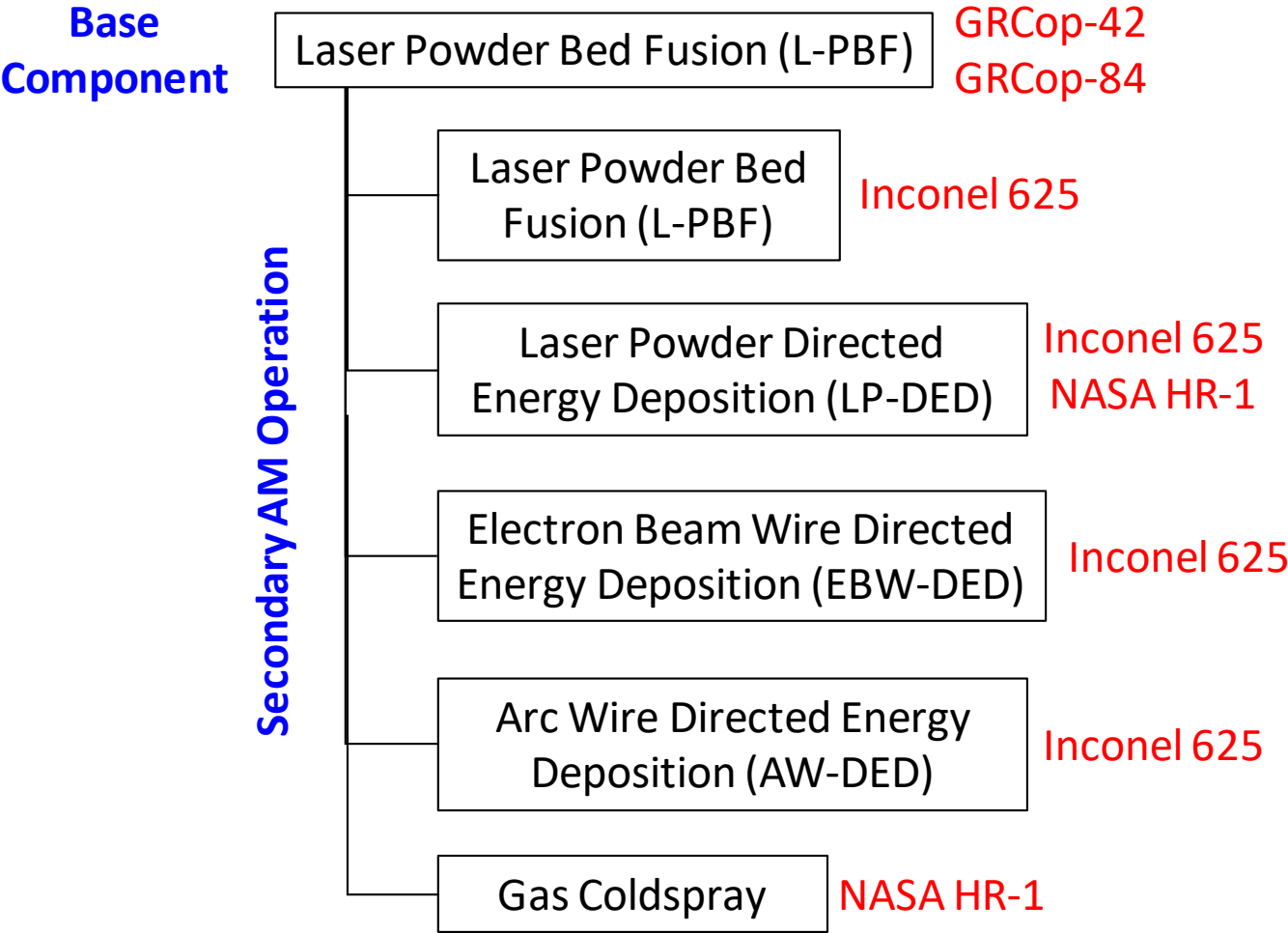
- Pressure Assisted Braze
- Standard Atmosphere Braze
- Vacuum Plasma Spray
- Electroplating
- Coldspray
- Directed Energy Deposition
 - Laser Powder
 - Laser Wire Direct Closeout
 - Arc Wire
- Explosive Bonding
- Ultrasonic
- Diffusion Bonding
- Platelets
- Casting
- Composite Overwrap

Manifold Application

- Wrought and Machined
- Directed Energy Deposition
 - Laser Powder
 - Laser Wire
 - Arc Wire
- Coldspray
- Platelets
- Casting
- Molded Composites

Bimetallic AM Process Overview

A variety of AM processes are used to build a base material and then deposit/apply a secondary material to create a bimetallic component

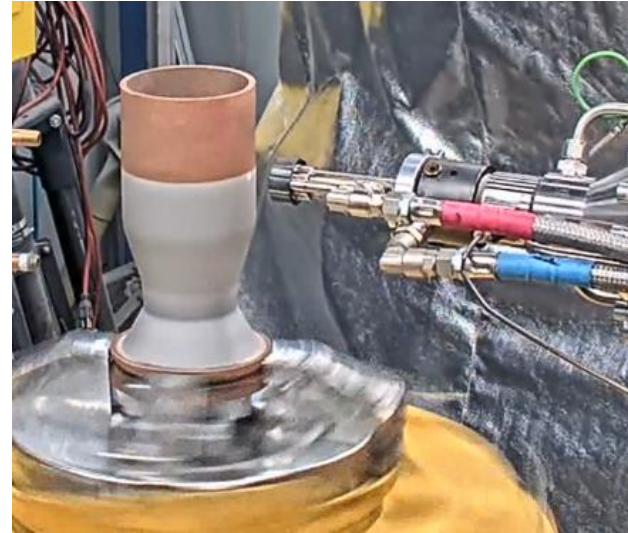


AM Processes evaluated for bimetallic joints

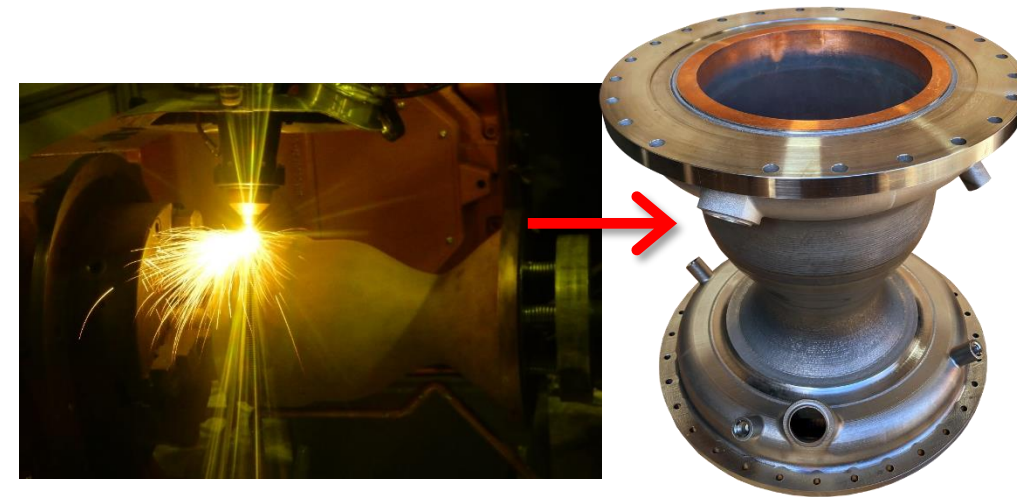
Laser Powder Bed Fusion



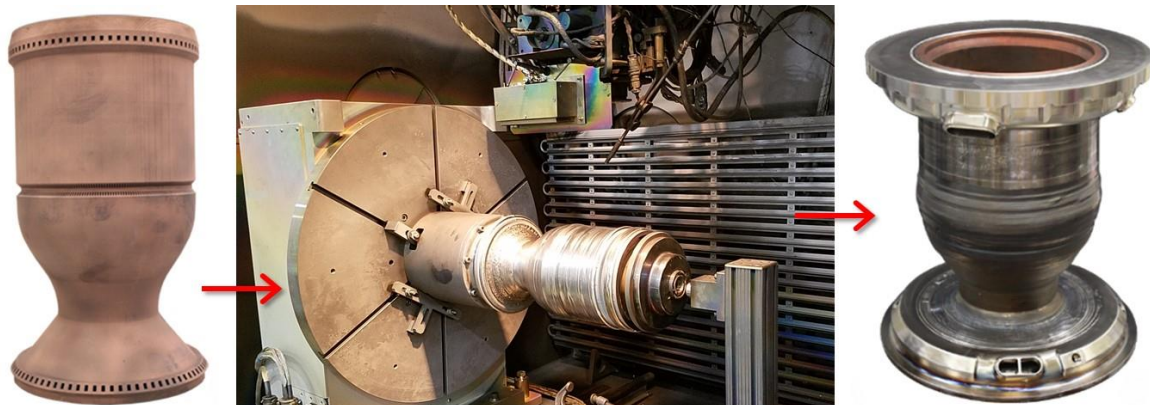
Cold spray



Laser Powder Directed Energy Deposition



Electron Beam Wire Directed Energy Deposition

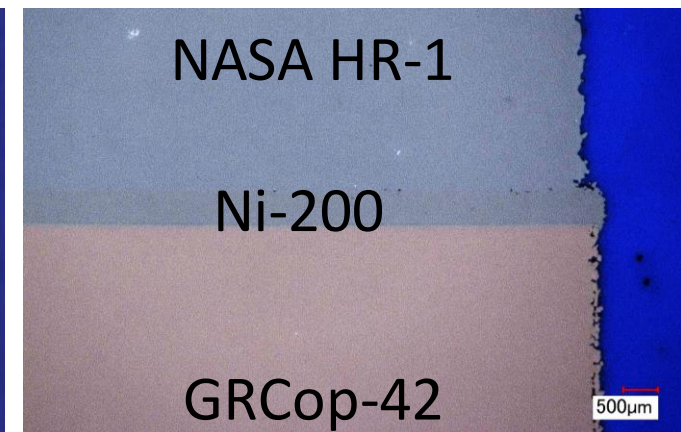
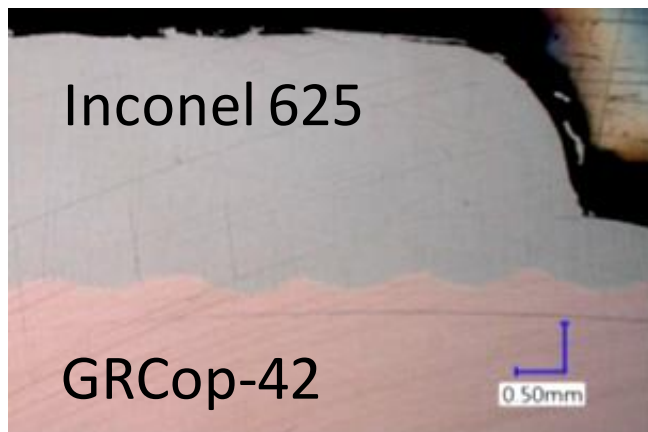
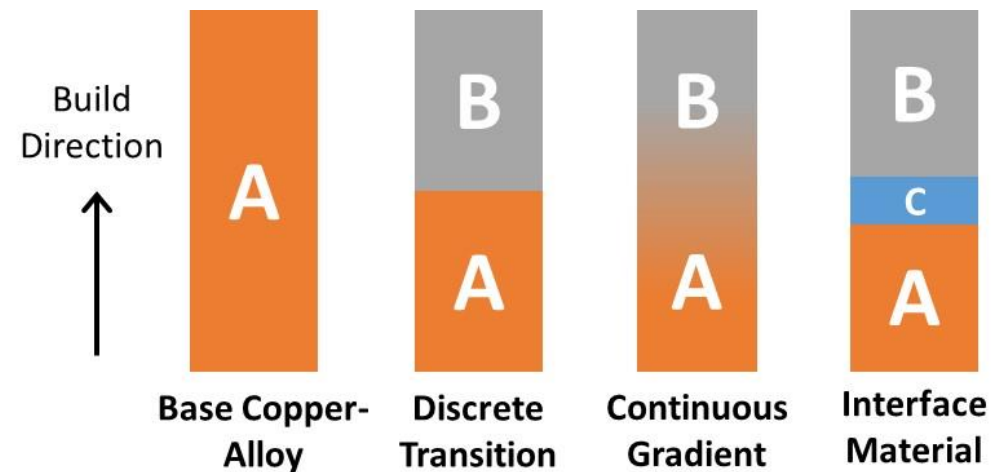


Arc Wire Directed Energy Deposition



AM bimetallic provides various joint options

- AM provides an 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

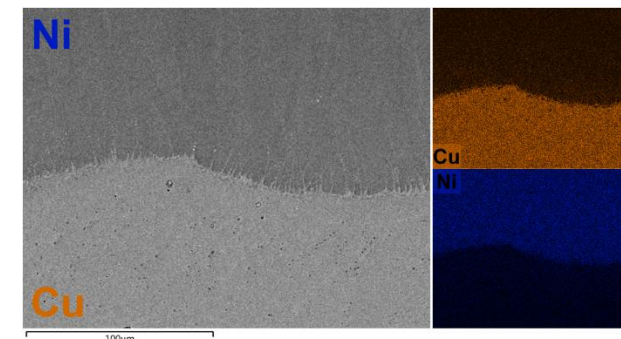
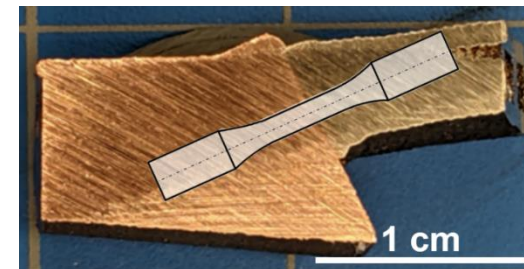
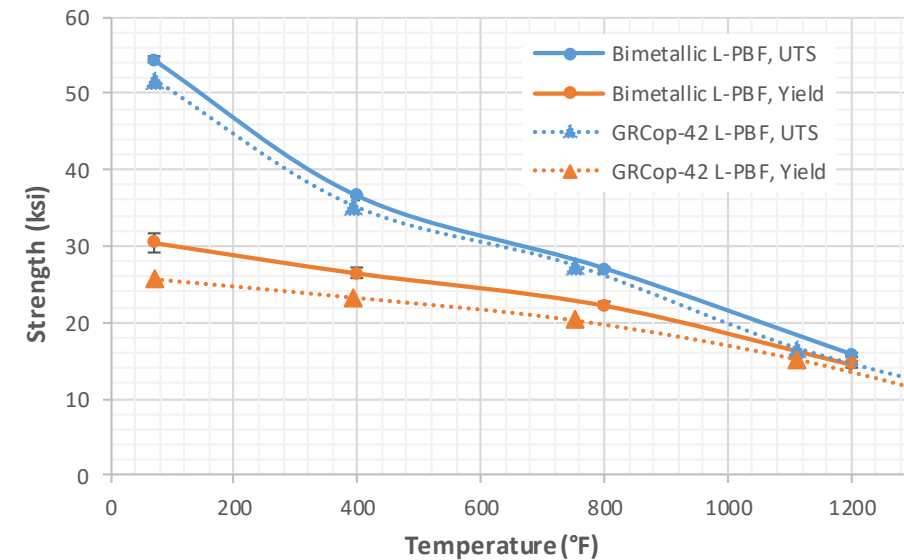




Joint Characterization and Lessons learned from bimetallic AM

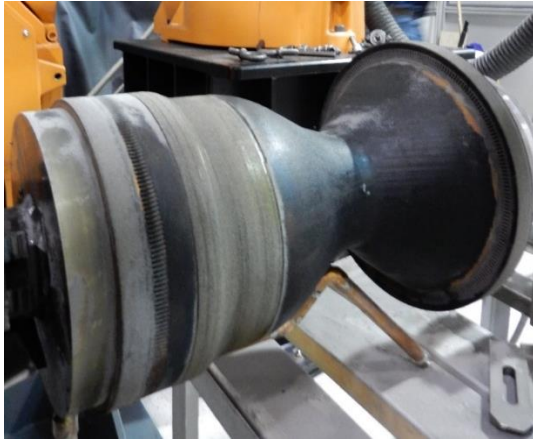


- Residual stresses can be very high and cause significant shrinkage
- Material modeling to aid with selection using CALPHAD
- High bond strength can be achieved with proper thermal control from deposition parameters
- Intermediate metal alloys may be required to avoid deleterious phases
- Microtensile testing provides a method to characterize joints directly on hardware



Examples of Component Fabrication

40K-lbf LP-DED Chambers

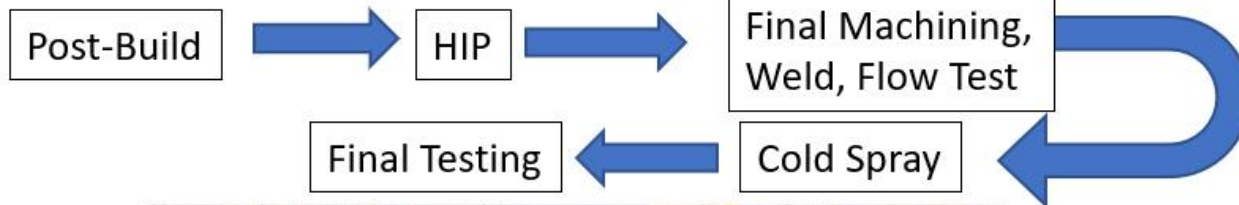


L-PBF GRCop-42 to LP-DED Inconel 625



L-PBF GRCop-42 to LP-DED NASA HR-1

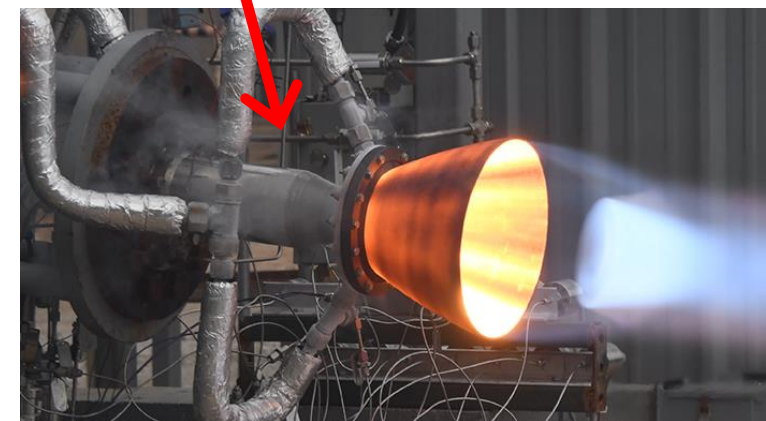
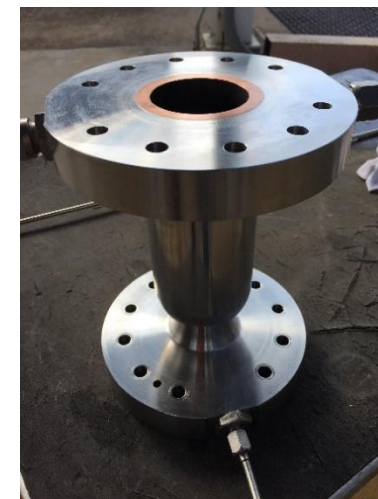
7K-lbf L-PBF GRCop-42 to NASA HR-1 Cold spray Chamber



Hot-fire Testing of Bimetallic Chambers

- Completed various test programs from 2k to 30k-lbf in LOX/H₂, LOX/RP-1, and LOX/CH₄
- Hot-fire tested using various bimetallic AM processes
- Completed ALPACA hot-fire testing at MSFC Stand 115
 - 6 starts and 356 seconds of hot-fire time in LOX/CH₄

Project	Propellants	Thrust (lb _f)	Metal Alloys	Jacket Process	Starts	Seconds
PF086	LOX/LH ₂	30,000	GRCo-84 / Inconel 625	EB-DED	9	147
PJ024	LOX/RP-1	2,400	GRCo-84 / Inconel 625	LP-DED	11	475
PJ024	LOX/RP-1	2,000	C-18150 / Inconel 625	LP-DED	9	405
PI043	LOX/LCH ₄	2,200	GRCo-84 / Inconel 625	LP-DED	6	76
PK076	LOX/LCH ₄	7,000	GRCo-42 / NASA HR-1	Coldspray	6	356
PJ051	LOX/LH ₂	40,000	GRCo-42 / Inconel 625 GRCo-42 / NASA HR-1	LP-DED	--	--

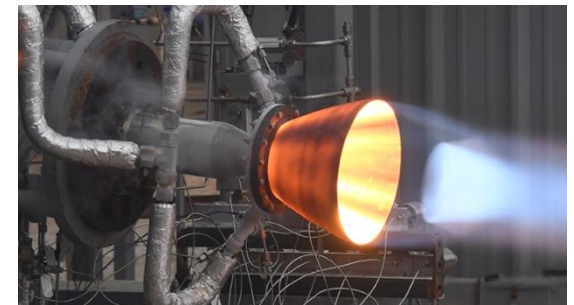
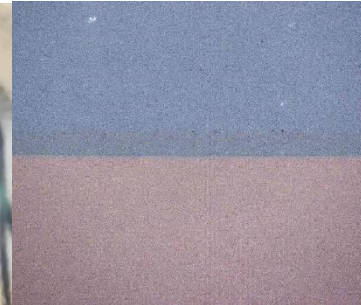
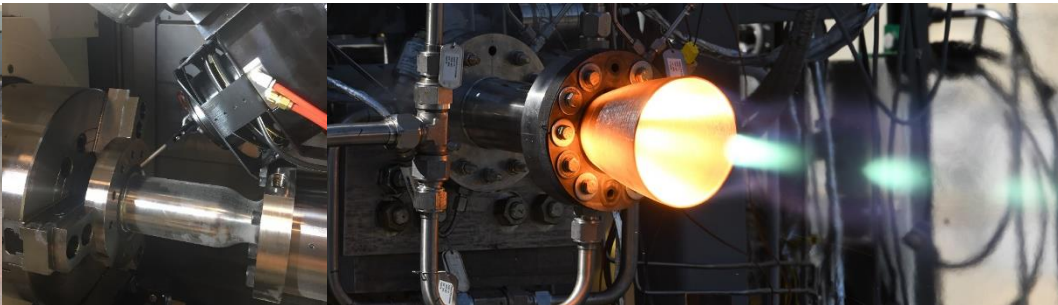




Conclusions / Summary



- 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 7K-lbf and 40K-lbf bimetallic chambers and have hot-fire tested the 7K chamber
 - Cold spray completed 6 starts and 356 seconds of hot-fire time
 - Accumulated 41 starts and 1,459 seconds of hot-fire time across bimetallic 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





Contact:

Paul Gradl

NASA MSFC

256.544.2455

Paul.R.Gradl@nasa.gov



Acknowledgements



This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the National Aeronautics and Space Administration (NASA) or the United States Government.

Tal Wammen
Scott Chartier
Test Stand 115 crew
Sandy Greene
Adam Willis
Will Bransdmeier
Kevin Baker
Dwight Goodman
Lynn Machamer
Karen Taminger/LaRC
Ian Johnston
Hannah Cherry
Megan LeCorre
Jim Lydon
Zach Jones
Tyler Blumenthal
RPM Innovations (RPMI)
Bhaskar Dutta
DM3D
Leo Ajdelsztajn
GE Research
Ken Cooper/NamPros

Additive Manufacturing and Engineering
Elementum 3D
Powder Alloy Corporation (PAC)
Westmoreland Mechanical Testing and
Research (WMTR)
Bryant Walker/Keystone
DMG Mori Seiki
Fraunhofer USA Center for Laser Applications
Quadrus Advanced Manufacturing
3DMT
Sturbridge Metallurgical
Judy Schneider/UAH
ASB Industries
Laser Technology Associates
Steve Wofford
John Fikes
Mike Shadoan
Keegan Jackson



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