Internal Channel Polishing and Controlled Orifice Geometry Modification via Chemical Polishing for Liquid Rocket Engine Fuel Injector Optimization

Justin Michaud
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REM Surface Engineering

ICAM2022

CENTER of EXCELLENCE
Research to Standards
ADDITIVE MANUFACTURING

Presenter Biography

Justin Michaud

Mr. Michaud is President and CEO of REM Surface Engineering where he works closely with the Research Team, supports REM’s government projects and awards, and focuses heavily on REM’s surface finishing solutions for metal additive manufacturing applications. Mr. Michaud serves on the American Gear Manufacturers Association (AGMA) Emerging Technology Committee and is the chair to the 3D Printing sub-committee. Mr. Michaud is an author of multiple technical papers on topics including additive manufacturing, isotropic superfinishing, gear failure modes, surface texture and measurement, high value gear repair, and the superfinishing of high hardness steels.

Relevant Awards: 80NSSC18P2192 NASA Phase I SBIR *“Internal/External Surface Finishing of Additively Manufactured IN-625 Components”*; 80NSSC19C0211 NASA Phase II SBIR *“Internal/External Surface Finishing of Additively Manufactured IN-625 Components”*; 80NSSC20C0080 NASA Phase III SBIR; FA864921P0815 Air Force Phase II SBIR *“Internal/External Surface Finishing of Additively Manufactured Aluminum Components”*; FA864921P0854 Air Force Phase II SBIR *“Development of Manufacturing, Heat Treatment, and Surface Finishing Guidelines to Yield Ready-to-Use IN-718 Additive Manufacturing Components”;* FA864922P0969 Air Force SBIR *“Additively Manufactured Heat Exchanger and Channel Fabrication Optimization via Chemical Powder Blockage Removal, Surface Roughness Reduction, and Wall Thickness Optimization/Component Lightweighting”*.

Coauthors

- NASA MSFC
  - Paul Gradl – Principal Engineer
  - Thomas Teasley – AST Liquid Propulsion Engineer
- REM Surface Engineering
  - Agustin Diaz – Advanced Manufacturing & Innovation Manager
  - Patrick McFadden – Research Chemist

Company Introduction

- Founded in 1965
- Family owned and operated
- Experts in Isotropic Superfinishing
- Inventors of the:
  - REM® Process
  - ISF® Process
  - Rapid ISF® Process
  - Extreme ISF® Process
- Locations:
  - Southington, CT, USA
  - Brenham, TX, USA
  - Merrillville, IN, USA
  - St. Neots, Cambridgeshire, UK
- All site are AS9100:2016 Rev. D & ISO9001:2015

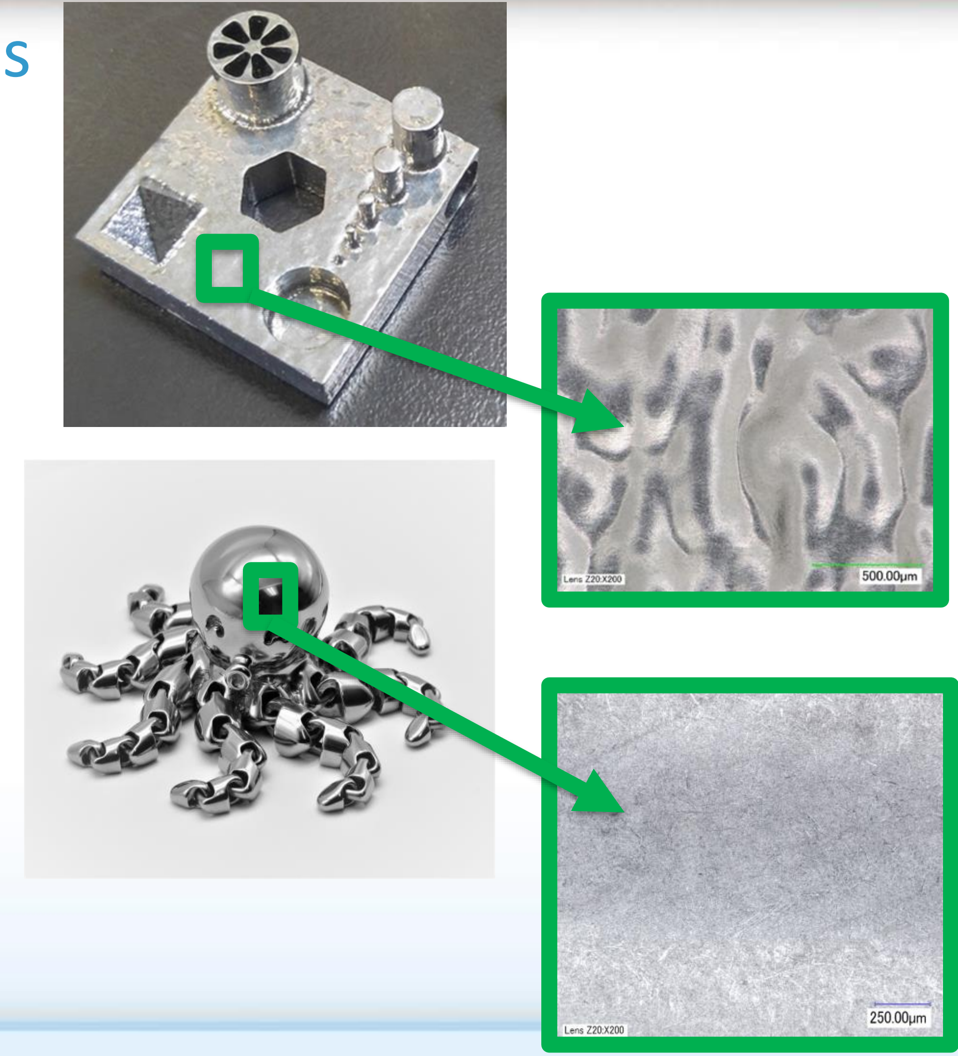
Extreme ISF® Process

– Chemical & Chemical-Mechanical Technologies

- Compatible with complex geometries
- Generate isotropic surfaces
- Remove surface & near surface defects
- Improve component properties/performance

Alloy Experience

- Titanium Alloys
  - Ti-6Al-4V, Ti-5Al-2.5Sn, CP Ti
- Stainless Steel Alloys
  - 17-4 PH, 15-5 PH, 316/316L
- Carbon Steel Alloys
  - SAE 4340, 16MnCr5, Ferrium® C64
- Maraging and Tool Steels
  - A2, L40, M300, H13
- Copper Alloys
  - GRCop-42/84, CP Cu, CuCrZr
- Ni-Cr Superalloys
  - IN-718, IN-625, HX
- Fe-Ni-Cr Superalloys
  - JBK-75, NASA HR-1
- Nickel Alloys
  - Invar 36, Permalloy
- Aluminum Alloys
  - AlSi10Mg, F357, 7A77, Scalmalloy®, A6061-R2, A7050-R2, A205/A20X
- Bulk Metallic Glass Alloys



SBIR Acknowledgements

NASA MSFC

Phase I

“Internal/External Surface Finishing of Additively Manufactured IN-625” (80NSSC18P2192)

Phase II & Phase II-E*:

“Post-Process Optimizing of Additive-Manufactured Nickel-Based Superalloys” (80NSSC19C0211)

Phase III*:

“Surface Enhancement using ISF of Additively Manufactured Hardware” (80NSSC20C0080)

AFWERX, OO-ALC, AFLCMC/EBW

Phase I:

“Internal/External Surface Finishing of Additively Manufactured Aluminum-6061-RAM2 Components” (FA864920P0930)

Phase I:

“Internal Channel Polishing for GRCop-42 Additively Manufactured Regeneratively Cooled Liquid Rocket Engine Applications” (FA864922P0396)

Phase II*:

“Internal/External Surface Finishing of Additively Manufactured Aluminum-Based Components” (FA864921P0815)

Phase II (direct)*:

“Development of Manufacturing, Heat Treatment, and Surface Finishing Guidelines to Yield Ready-to-Use IN-718 Additive Manufacturing Components (FA864921P0854)

Phase II (direct)*:

Additively Manufactured Heat Exchanger and Channel Fabrication Optimization via Chemical Powder Blockage Removal, Surface Roughness Reduction, and Wall Thickness Optimization/Component Lightweighting (FA864922P0969)

* Denotes currently active SBIR’s

AM & Liquid Rocket Engines

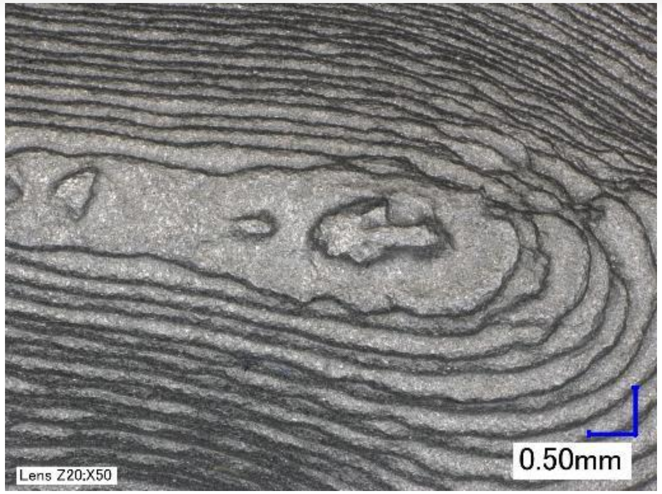
- AM offers many advantages for the fabrication of rocket engine components [1, 2, 3, 4]
  - Increased design complexity
  - Reduced cost
  - Reduced lead time
- Component Applications
  - TCA’s
  - Nozzles
  - Turbomachinery
  - **Fuel Injectors**

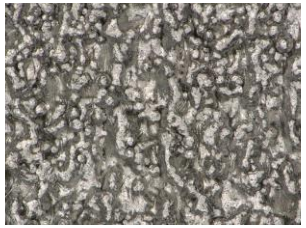
Images courtesy of NASA MSFC

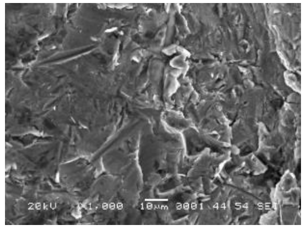
1. Michaud, J. “Advancing rocket propulsion: Metal 3D printing and novel surface finishing”. Metal AM 6, 133–143 (2020).
2. Dale, M. “Changing the game of spaceflight”. Laser Systems Europe, Issue 54, 10 – 13 (2022).
3. Gradl, P., et al. “Lightweight Thrust Chamber Assemblies using Multi-Alloy Additive Manufacturing and Composite Overwrap”. AIAA Propulsion and Energy Forum (2020).
4. Gradl, P., et al. “Integral Channel Nozzles and Heat Exchangers using AM DED NASA HR-1 Alloy”. 73rd Intern. Astronautical Congress, Paris, France (2022).

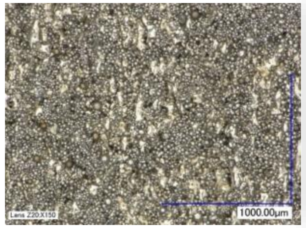
AM Surfaces

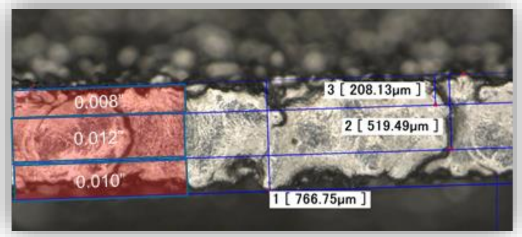
- AM Surfaces provide challenges (and opportunities)
  - Surface & Near Surface Defects
  - Partially Sintered/Melted Particles
  - High Surface Roughness
  - Significant Surface Waviness

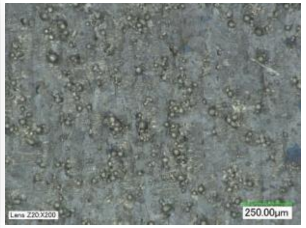


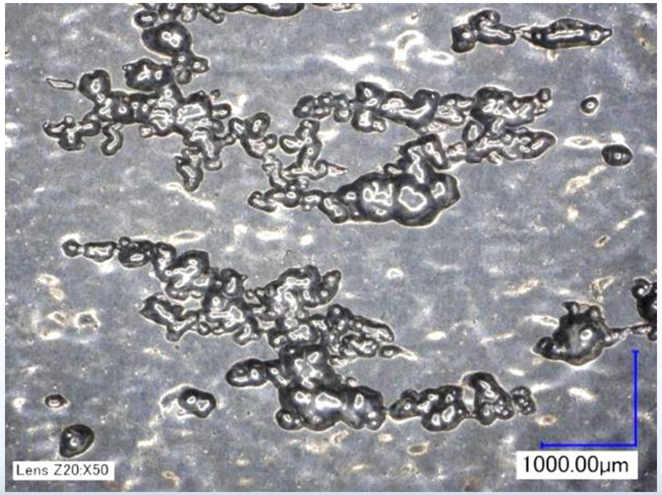


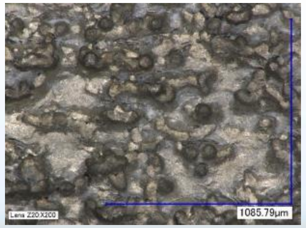


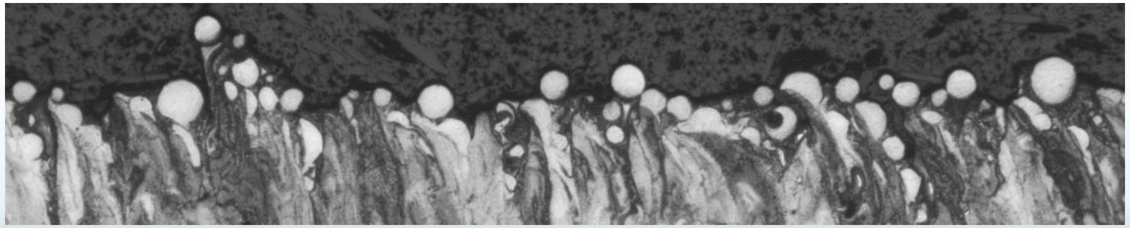


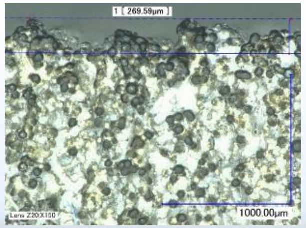






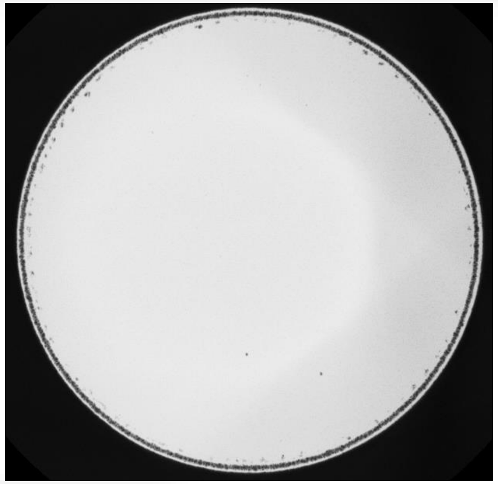


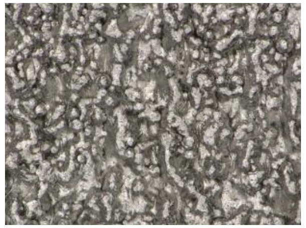


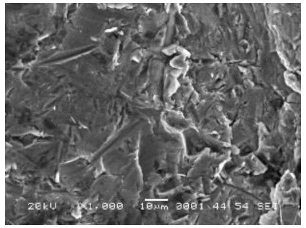


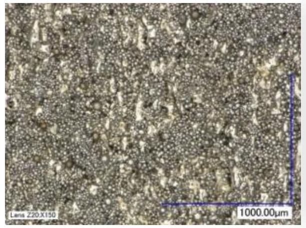
AM Surfaces

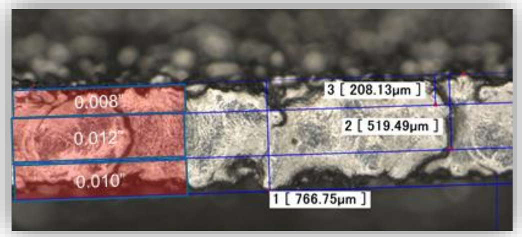
- Effects of AM Surfaces
  - Particle shedding/cleanliness
  - Increased pressure drop
  - Increased heat load
  - Decreased fatigue life

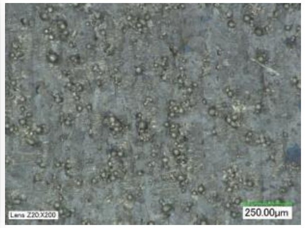


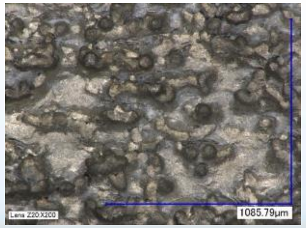


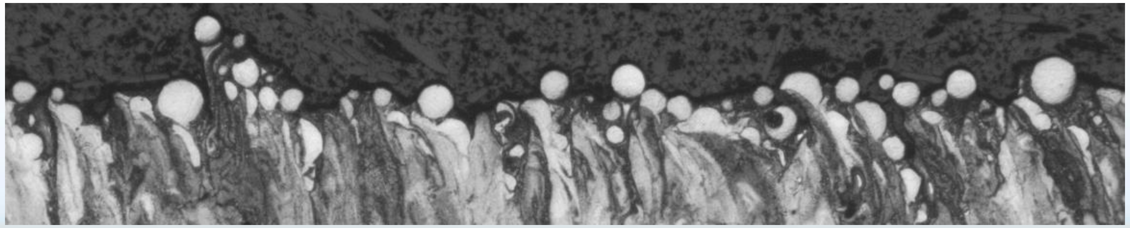


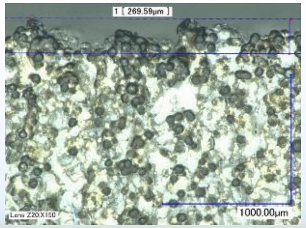










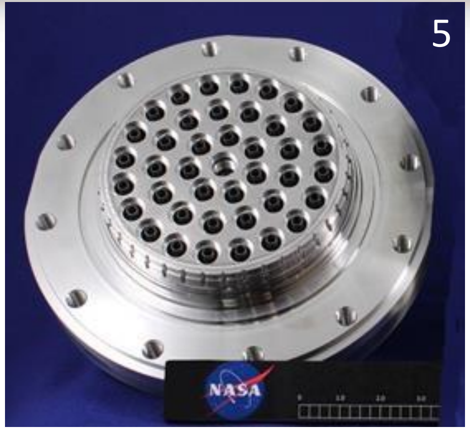


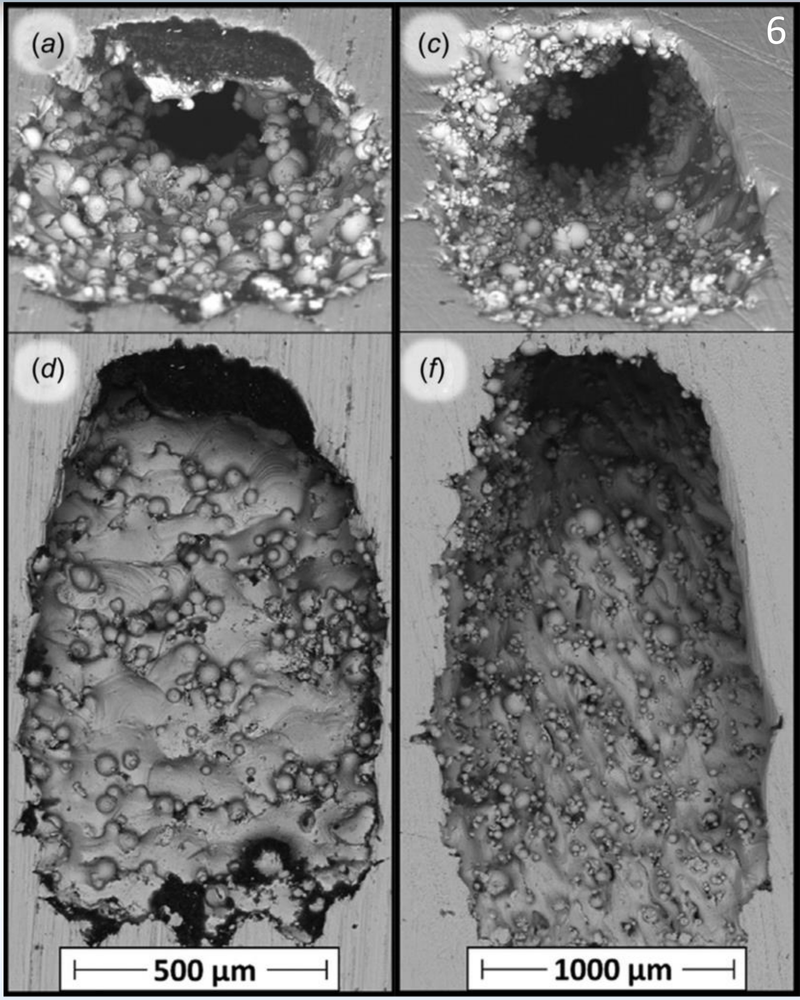
AF SBIR Phase 2: “Internal/External Surface Finishing of Additively Manufactured Aluminum-Based Components” (FA864921P0815)

AM Fuel Injectors

- Advantages[5]
  - Part consolidation (coaxial element)
  - Reduced machining (impinging element)
  - Enhanced design flexibility

- Disadvantages[5, 6]
  - Feature size/resolution
  - Design complexity
  - Excessive surface roughness





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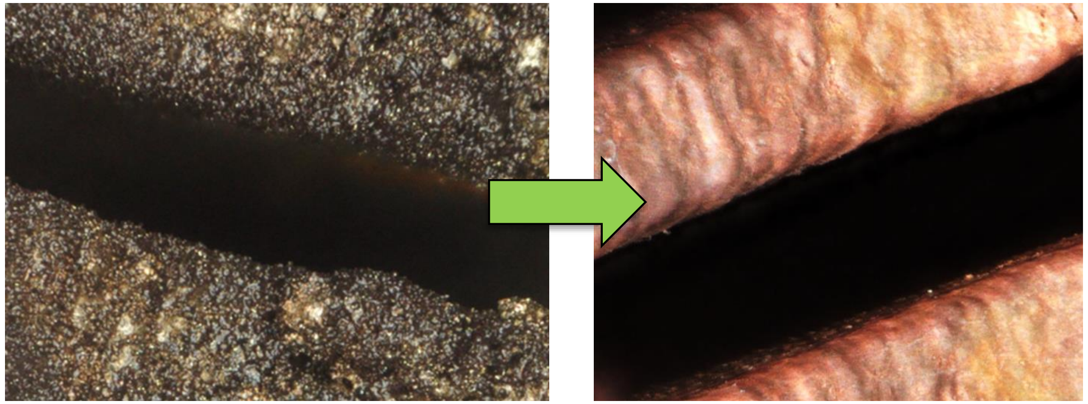
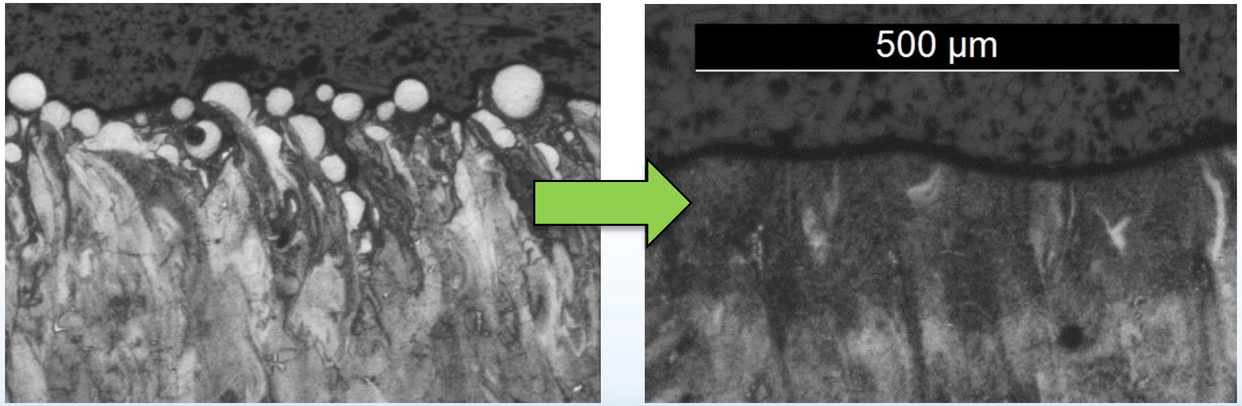
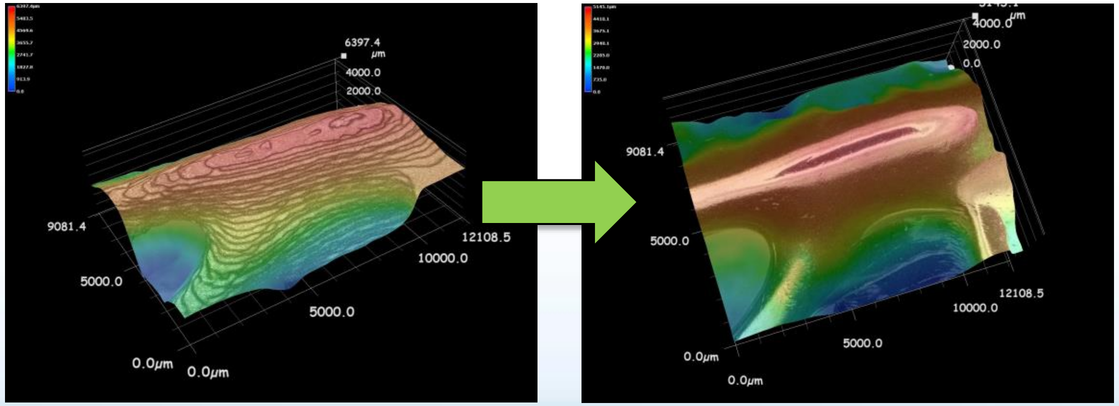
5. Gradl, P., Greene, S., Protz C., Bullard, B., Buzzell, J., Garcia, C., Wood, J., Osborne, R. Hulka, J., Cooper, K. “Additive Manufacturing of Liquid Rocket Engine Combustion Devices: A Summary of Process Developments and Hot-Fire Testing Results”. 54th AiAA/SAE/ASEE Joint Propulsion Conference (2018), https://arc.aiaa.org/doi/abs/10.2514/6.2018-4625.
6. Stimpson, C., Snyder, J., Thole, K., Mongillo, D. “Effectiveness Measurements of Additively Manufactured Film Cooling Holes”. Journal of Turbomachinery, Volume 140, 1 - 11 (2018).

AM Fuel Injectors

- Surface Finishing to Minimize Disadvantages:
  - Reduce surface roughness
  - Remove partially trapped powder
  - Improve as-printed feature geometry

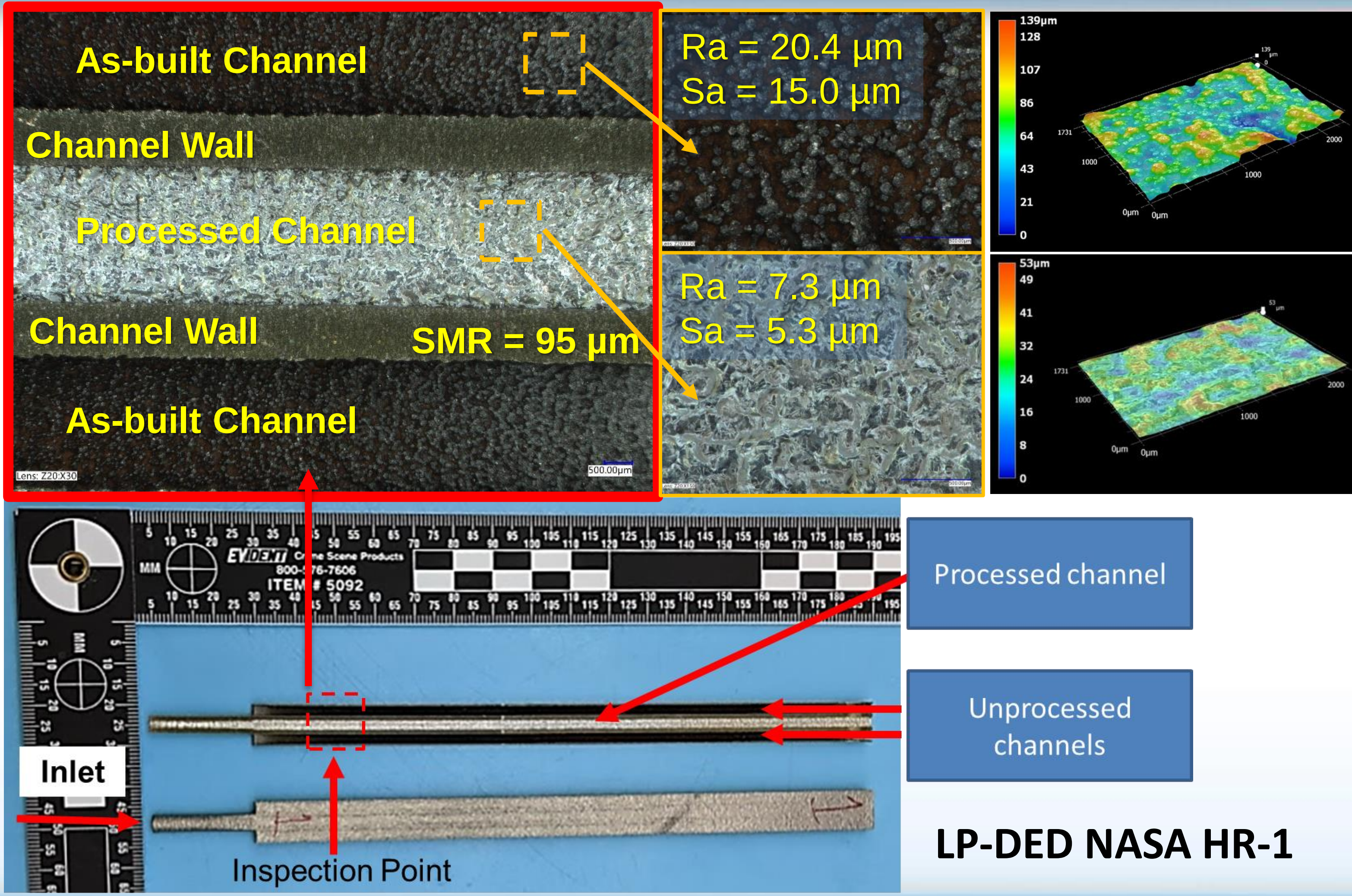






Channel Roughness

- Chemical Polishing (CP) of internal channels
  - Alter granular surface texture
  - Reduce pressure drop
  - Eliminate particle shedding
  - Alter surface texture (roughness + waviness)



Processed channel

Unprocessed channels

LP-DED NASA HR-1

4. Gradl, P., Cervone, A., Colonna, P. “Integral Channel Nozzles and Heat Exchangers using Additive Manufacturing Directed Energy Deposition NASA HR-1 Alloy”. 73rd International Astronautical Congress, Paris, France (2022), https://repository.tudelft.nl/islandora/object/uuid%3Af57baddc-15d1-4557-9c9c-899bbc74f345.

NASA SBIR Phase 2: “Post-Process Optimizing of Additive-Manufactured Nickel-Based Superalloys” (80NSSC19C0211)
NASA SBIR Phase 3: “Surface Enhancement using ISF of Additively Manufactured Hardware” (80NSSC20C0080)

Channel Roughness

- Chemical Polishing (CP) of internal channels
  - Alter granular surface texture
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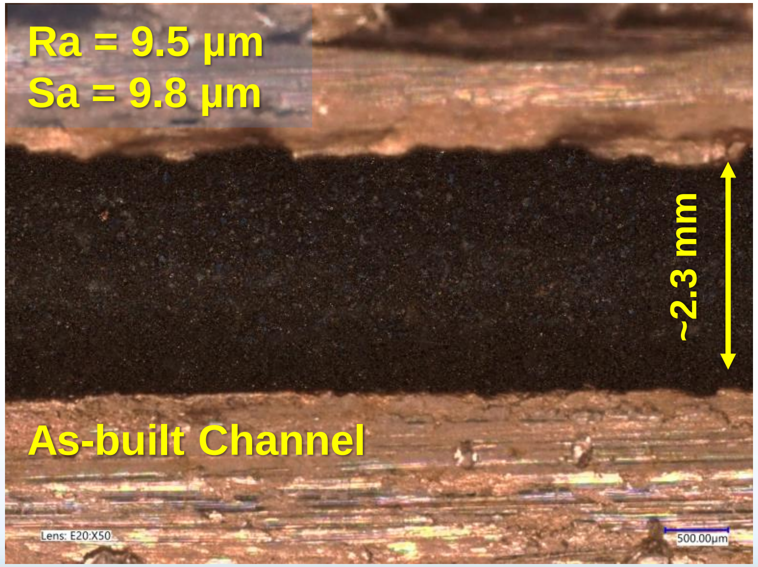
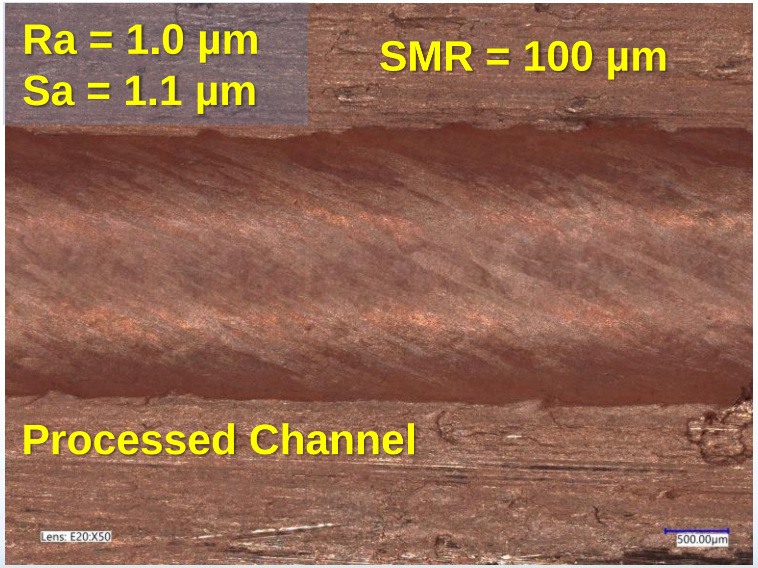
L-PBF GRCop-42





AF SBIR Phase 1:“Internal Channel Polishing for GRCop-42 Additively Manufactured Regeneratively Cooled Liquid Rocket Engine Applications” (FA864922P0396)

Channel Roughness

- Chemical Polishing (CP) of internal channels
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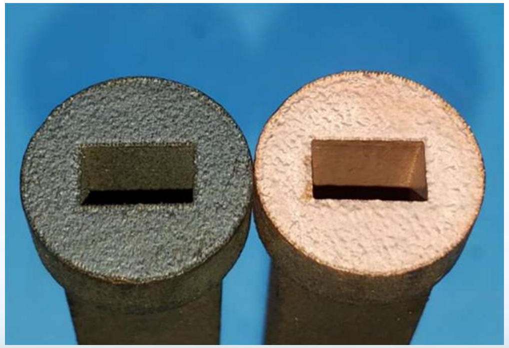
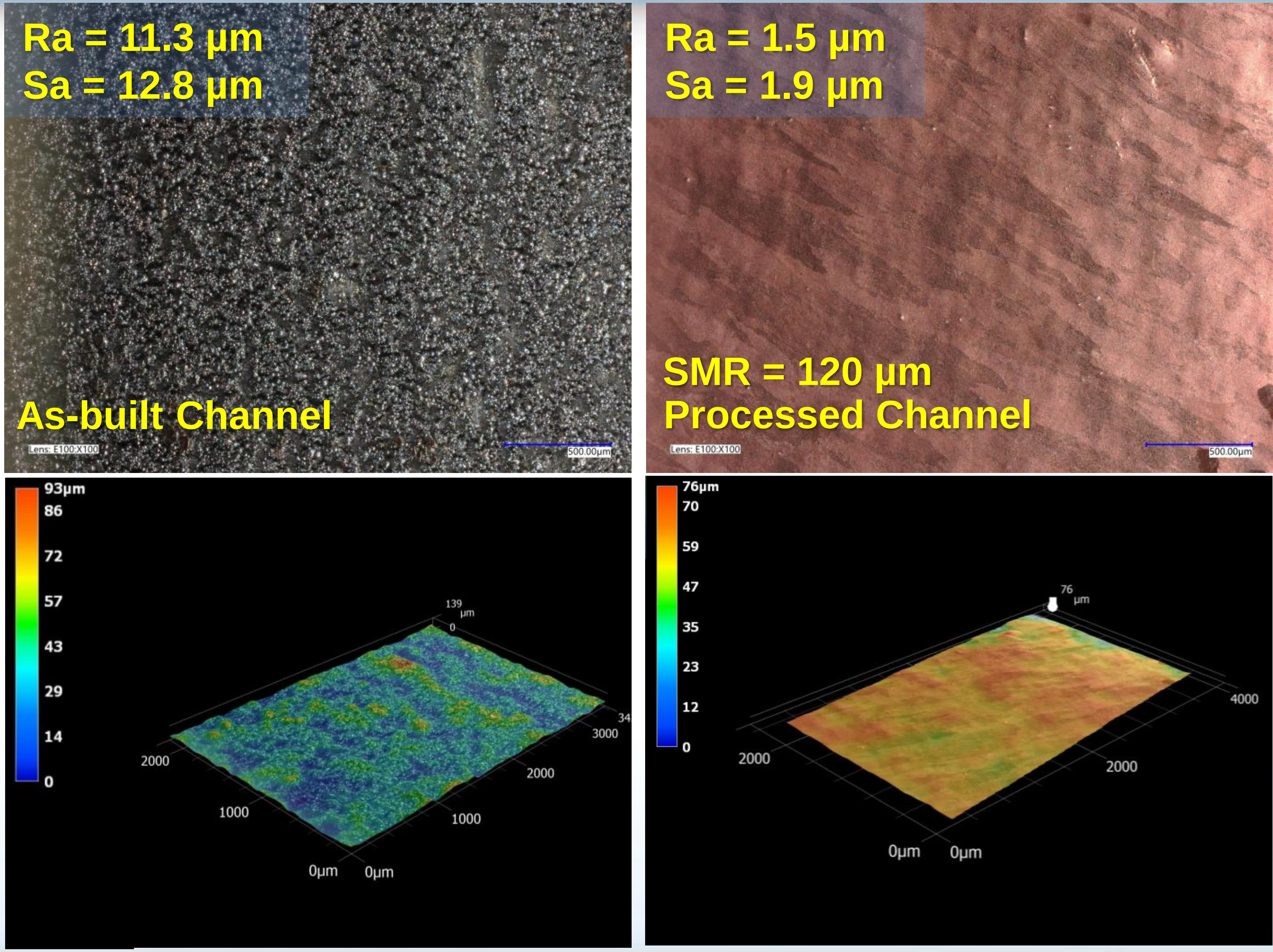
  - Reduce pressure drop
  - Eliminate particle shedding
  - Alter surface texture (roughness + waviness)

L-PBF GRCop-42





Ra = 11.3 µm
Sa = 12.8 µm
As-built Channel

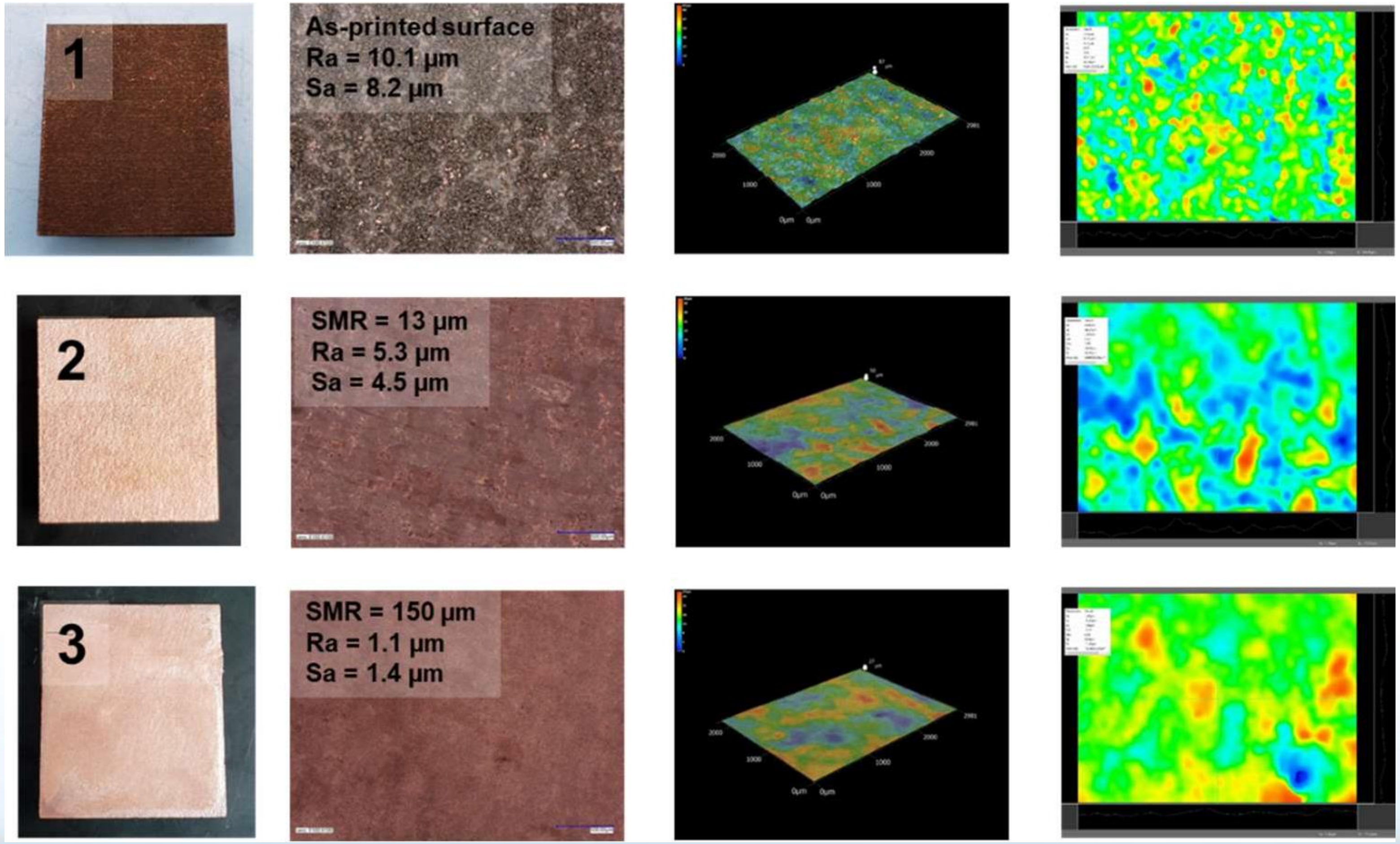
Ra = 1.5 µm
Sa = 1.9 µm
SMR = 120 µm
Processed Channel

AF SBIR Phase 1 (FA864922P0396)

Channel Roughness

- Chemical Polishing (CP) of internal channels
  - Alter granular surface texture
  - Reduce pressure drop
  - Eliminate particle shedding
  - Alter surface texture (roughness + waviness)

L-PBF GRCop-42



AF SBIR Phase 1 (FA864922P0396)

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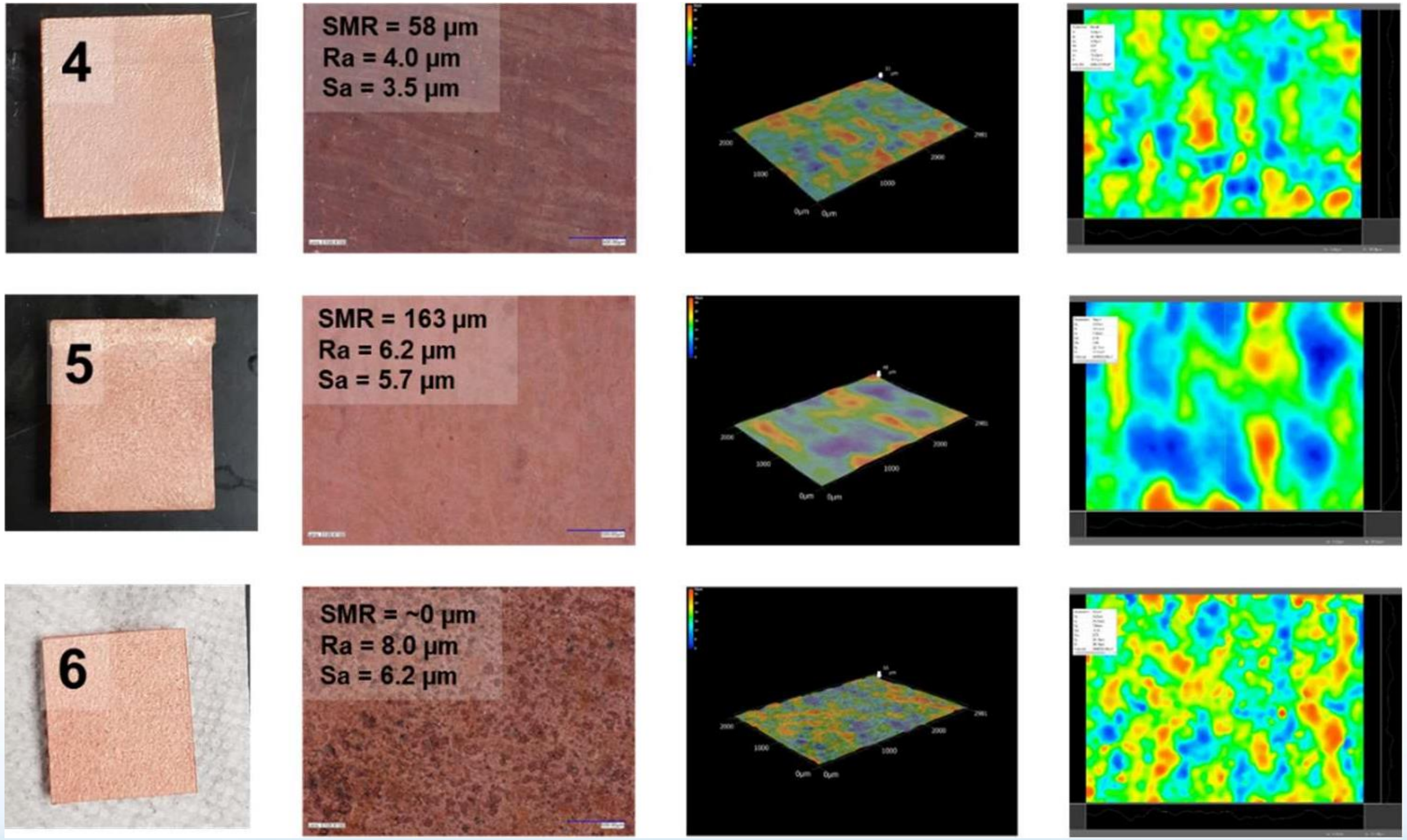
L-PBF GRCop-42



Combustion Chamber

– NASA MSFC Combustion Chamber Testing

- Cooling Channel Pressure Drop Testing[7]
  - As-Built vs. REM Processed 1.2K Chamber
    - » 75 µm Surface Material Removal from cooling channels → 71% Pressure Drop Reduction
- Heat Load Testing[7]
  - As-Built vs. REM Processed 1.2K Chamber
    - » 75 µm Surface Material Removal from Hot Wall → 28% Reduction in Total Heat Load

Images courtesy of NASA MSFC

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7. Teasley, T., Gradl, P., Garcia, M., Williams, B., Protz, C. “Extreme Environment Hot Fire Durability of Post Processed Additively Manufactured GRCop-Alloy Combustion Chambers”. AIAA Propulsion and Energy Forum (2021), https://doi.org/10.2514/6.2021-3233.

NASA SBIR Phase 2: “Post-Process Optimizing of Additive-Manufactured Nickel-Based Superalloys” (80NSSC19C0211)
NASA SBIR Phase 3: “Surface Enhancement using ISF of Additively Manufactured Hardware” (80NSSC20C0080

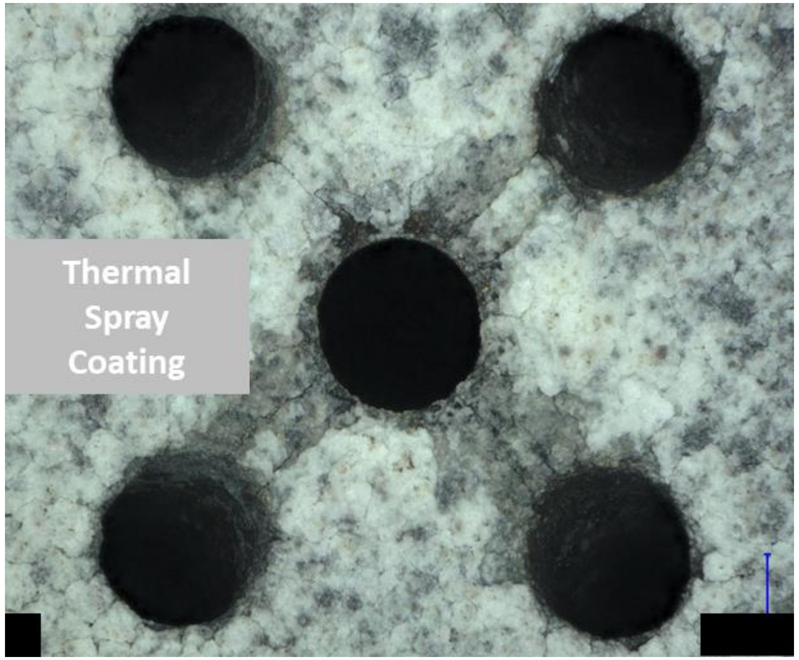
Fuel Injectors

- Chemical Polishing (CP) of Fuel Injectors
  - Orifice/feature alteration
  - Controlled pressure drop modification

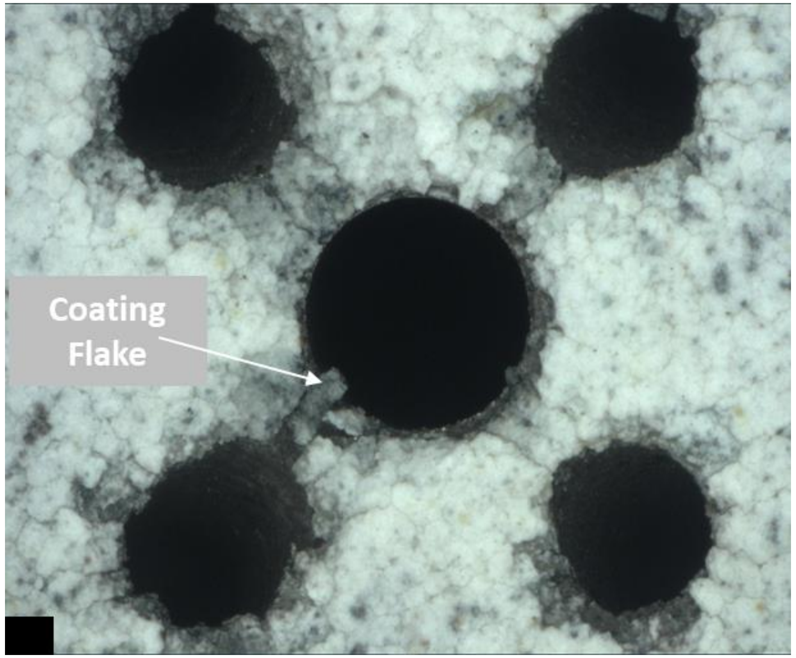
L-PBF IN-718

- 7K Injector
- Previously Hot Fired
- Target Increase in Flow Area/Orifice Size

Example Holes



After Processing



- ➢ LOX Ports expanded by 171% of design area and achieved 161% of original flow area
- ➢ Pressure drop decrease from 50% ΔP/Pc to 20%

NASA SBIR Phase 2: “Post-Process Optimizing of Additive-Manufactured Nickel-Based Superalloys” (80NSSC19C0211)
NASA SBIR Phase 3: “Surface Enhancement using ISF of Additively Manufactured Hardware” (80NSSC20C0080)
Images and data courtesy of NASA MSFC

Fuel Injectors

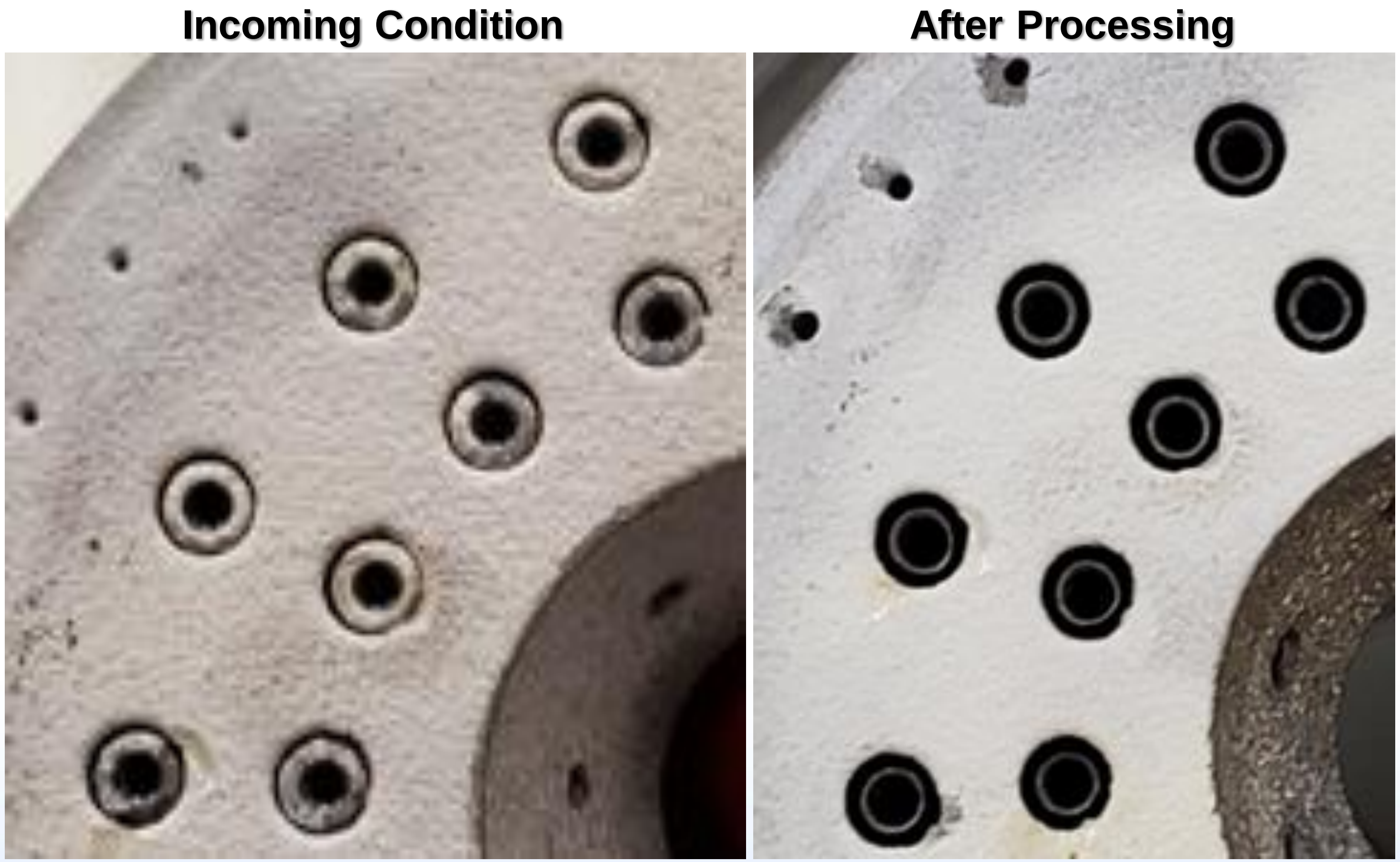
- Chemical Polishing (CP) of Fuel Injectors
  - Orifice/feature alteration
  - Controlled pressure drop modification

L-PBF IN-718

- Previously Hot Fired & flow was too restrictive
- Target ~ 250 µm SMR from Inner & Outer Ports

➢ SMR Targets achieve +/- 25 µm

➢ All Orifices showed free/clear flow with desirable dispersion



NASA SBIR Phase 2: "Post-Process Optimizing of Additive-Manufactured Nickel-Based Superalloys" (80NSSC19C0211)
NASA SBIR Phase 3: "Surface Enhancement using ISF of Additively Manufactured Hardware" (80NSSC20C0080)
Images and data courtesy of NASA MSFC

Fuel Injectors

- Chemical Polishing (CP) of Fuel Injectors
  - Orifice/feature alteration
  - Controlled pressure drop modification

L-PBF IN-718

- Previously Hot Fired & flow was too restrictive
- Target Increase in Flow Area/Orifice Size from Inner & Outer Ports

- ➢ SMR Targets achieve +/- 25 µm
- ➢ All Orifices showed free/clear flow with desirable dispersion

After Processing

LOX Orifices

Fuel Orifices

NASA SBIR Phase 2: “Post-Process Optimizing of Additive-Manufactured Nickel-Based Superalloys” (80NSSC19C0211)
NASA SBIR Phase 3: “Surface Enhancement using ISF of Additively Manufactured Hardware” (80NSSC20C0080)
Images and data courtesy of NASA MSFC

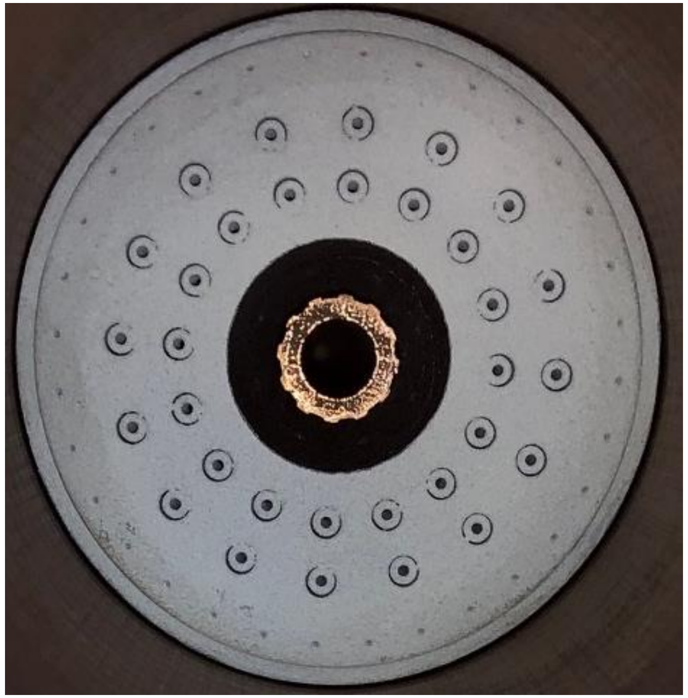
Fuel Injectors

- Chemical Polishing (CP) of Fuel Injectors
  - Orifice/feature alteration
  - Controlled pressure drop modification

L-PBF IN-718

- Previously Hot Fired & flow was too restrictive
- Target Increase in Flow Area/Orifice Size from Inner & Outer Ports

Incoming Condition



After Processing & Post Hot-Fire

- ➢ Achieved 36 Hot Fire Starts After Processing with a Total Duration of 17 minutes
- ➢ Successfully Salvaged Injector and demonstrated Chemical Polishing viability

NASA SBIR Phase 2: “Post-Process Optimizing of Additive-Manufactured Nickel-Based Superalloys” (80NSSC19C0211)
NASA SBIR Phase 3: “Surface Enhancement using ISF of Additively Manufactured Hardware” (80NSSC20C0080)
Images and data courtesy of NASA MSFC

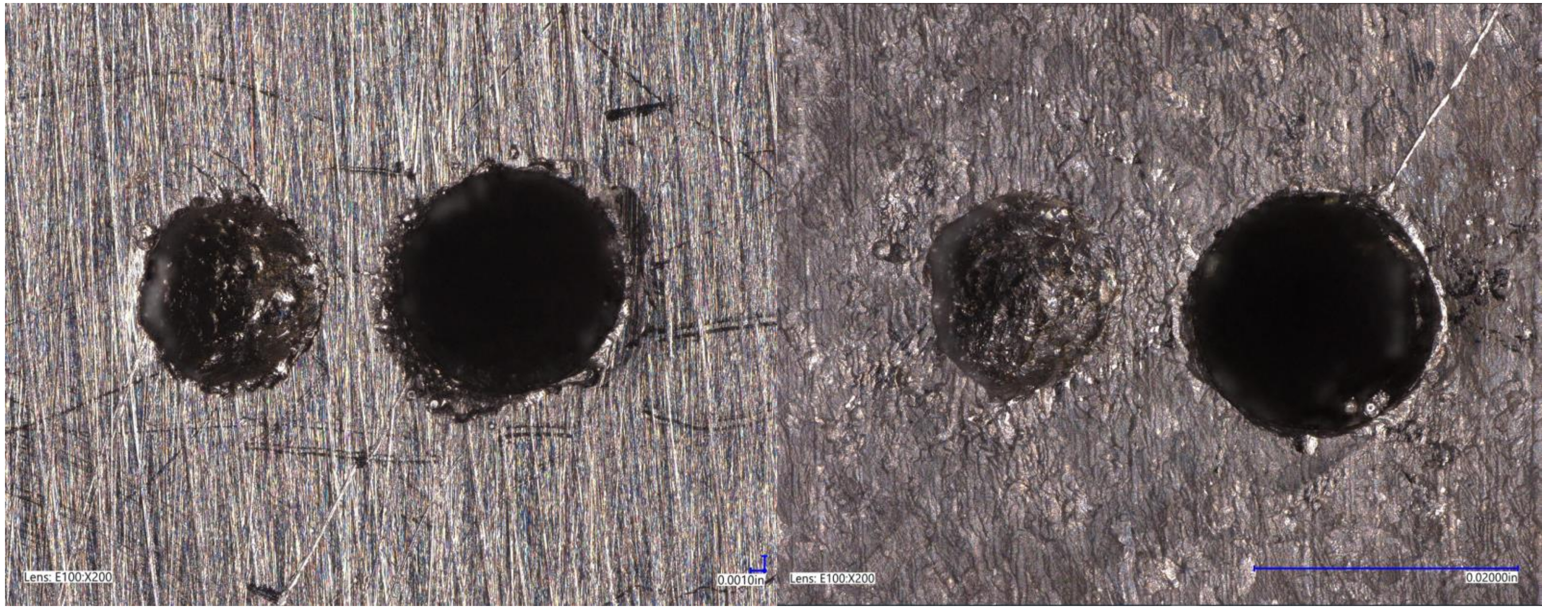
Example Internal Channels

- Chemical Polishing (CP) of Example Channels
  - Orifice/feature alteration
  - Controlled pressure drop modification

L-PBF IN-718

- Tighter Tolerance/Lower SMR

Orifice/Channel Example A		
(µm)	"Left" Port	"Right" Port
Starting Dimensions	368	267
Final Dimensions	417	345
Target Dimensions	406	330
Tolerance	+/- 12	
SMR	24.5	39



Incoming Condition

After Processing

NASA SBIR Phase 2: “Post-Process Optimizing of Additive-Manufactured Nickel-Based Superalloys” (80NSSC19C0211)
NASA SBIR Phase 3: “Surface Enhancement using ISF of Additively Manufactured Hardware” (80NSSC20C0080)
Images and data courtesy of NASA MSFC

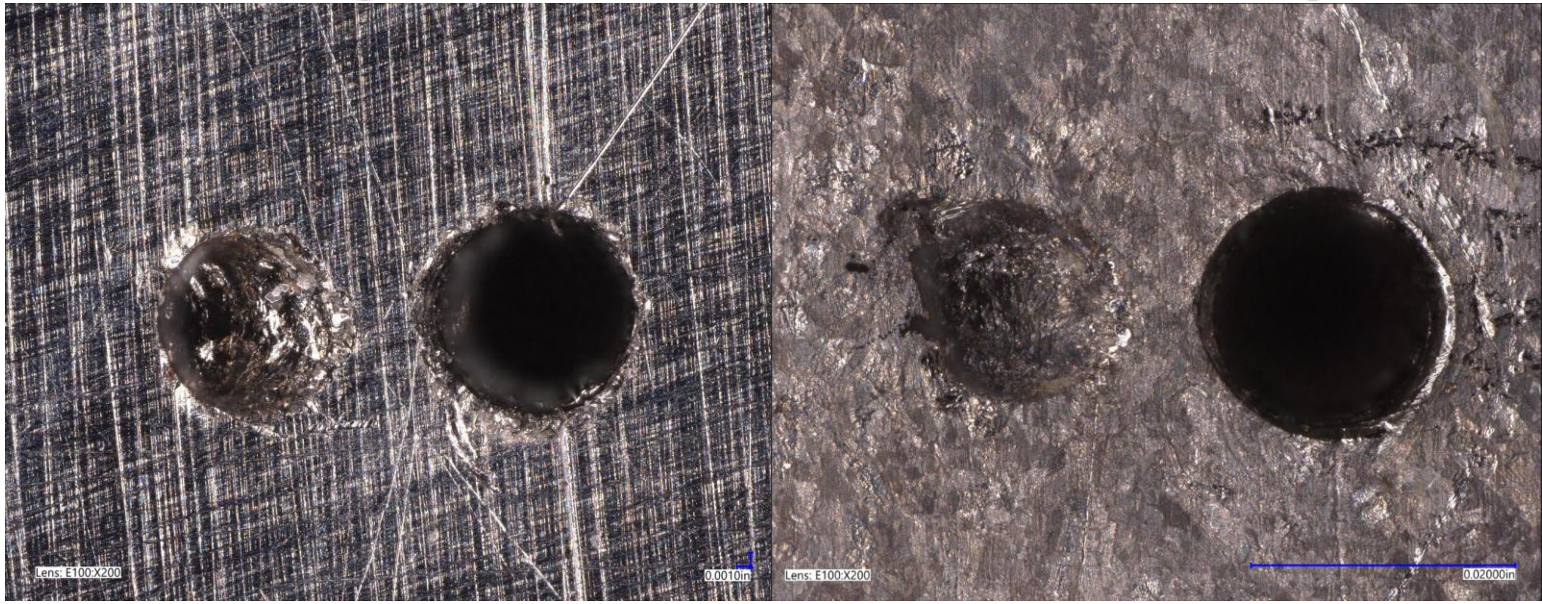
Example Internal Channels

- Chemical Polishing (CP) of Example Channels
  - Orifice/feature alteration
  - Controlled pressure drop modification

L-PBF IN-718

- Tighter Tolerance/Lower SMR

Orifice/Channel Example C		
(µm)	**"Left" Port**	**"Right" Port**
Starting Dimensions	358	279
Final Dimensions	404	345
Target Dimensions	406	330
Tolerance	+/- 12	
SMR	23	33



Incoming Condition

After Processing

NASA SBIR Phase 2: “Post-Process Optimizing of Additive-Manufactured Nickel-Based Superalloys” (80NSSC19C0211)
NASA SBIR Phase 3: “Surface Enhancement using ISF of Additively Manufactured Hardware” (80NSSC20C0080)
Images and data courtesy of NASA MSFC

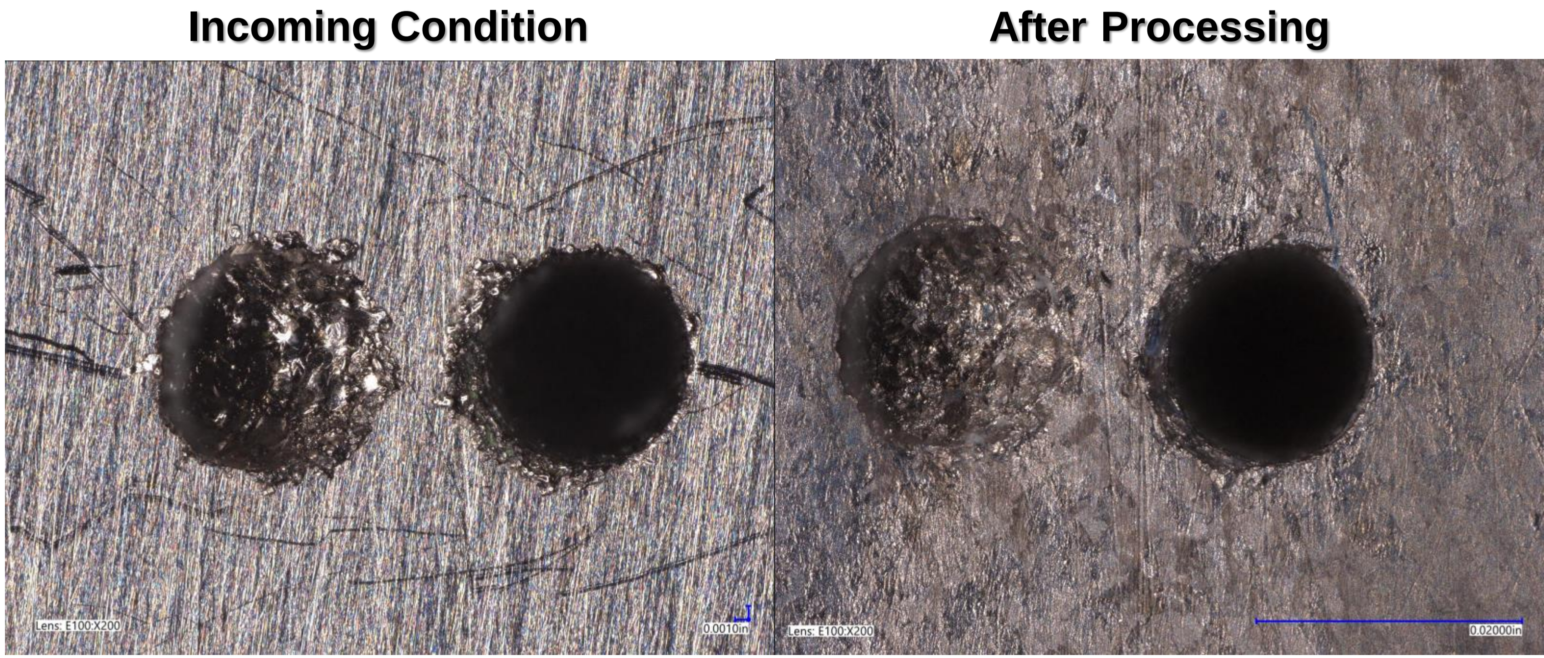
Example Internal Channels

- Chemical Polishing (CP) of Example Channels
  - Orifice/feature alteration
  - Controlled pressure drop modification

L-PBF IN-718

- Tighter Tolerance/Lower SMR

Orifice/Channel Example D		
(µm)	**"Left" Port**	**"Right" Port**
Starting Dimensions	366	368
Final Dimensions	394	396
Target Dimensions	356	356
Tolerance	+ 51	
SMR	14	14



Incoming Condition

After Processing

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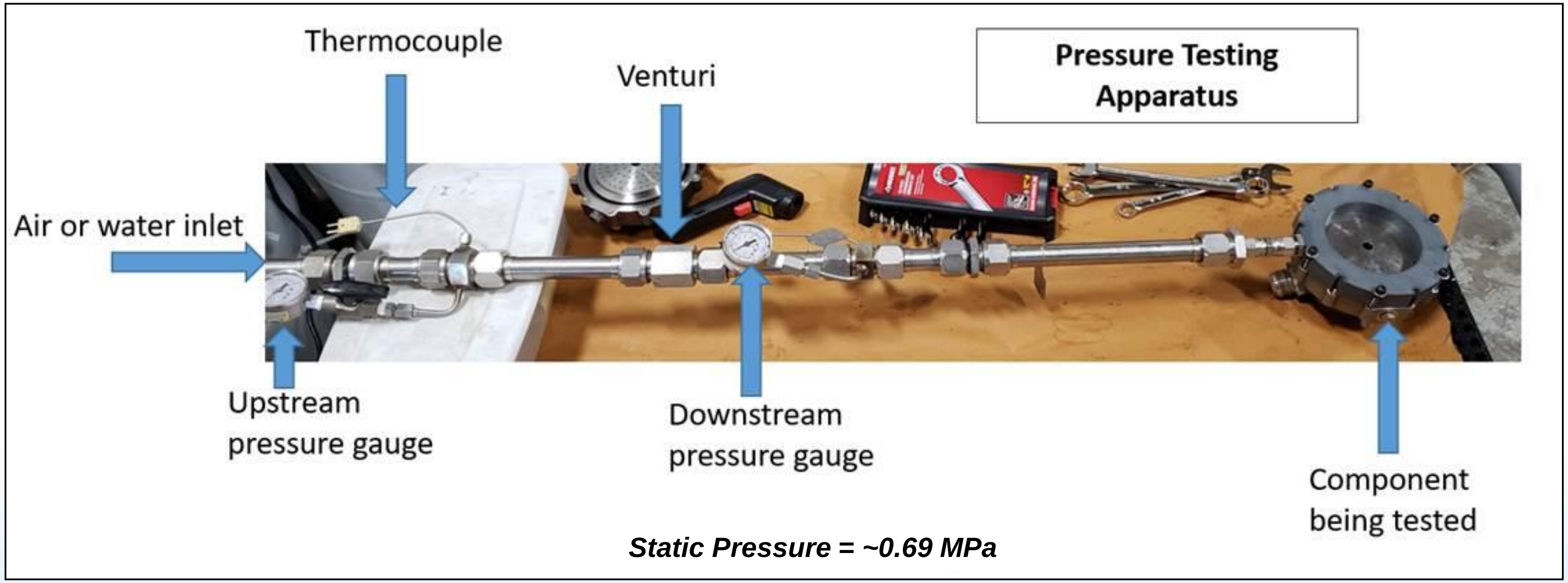
Example Internal Channels

- Pressure Gauge-based Targeting of Chemical Polishing (CP)
  - Specific pressure targets set
  - Component(s) processed to achieve targeted pressure



Static Pressure = ~0.69 MPa

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Images and data courtesy of NASA MSFC

Example Internal Channels

- Pressure Gauge-based Targeting of Chemical Polishing (CP)
  - Specific pressure targets set
  - Component(s) processed to achieve targeted pressure

[redacted] [redacted]

Orifice/ Channel	Port	Upstream (MPa)	Downstream (MPa)
Initial	Fuel	0.42	0.18
	LOX	0.43	0.20

NASA SBIR Phase 2: “Post-Process Optimizing of Additive-Manufactured Nickel-Based Superalloys” (80NSSC19C0211)
NASA SBIR Phase 3: “Surface Enhancement using ISF of Additively Manufactured Hardware” (80NSSC20C0080)
Images and data courtesy of NASA MSFC

Example Internal Channels

- Pressure Gauge-based Targeting of Chemical Polishing (CP)
  - Specific pressure targets set
  - Component(s) processed to achieve targeted pressure

[redacted]

[redacted]

Orifice/ Channel	Port	Upstream (MPa)	Downstream (MPa)
Processed	Fuel	0.47	0.070
	LOX	0.46	0.076

NASA SBIR Phase 2: “Post-Process Optimizing of Additive-Manufactured Nickel-Based Superalloys” (80NSSC19C0211)
NASA SBIR Phase 3: “Surface Enhancement using ISF of Additively Manufactured Hardware” (80NSSC20C0080)
Images and data courtesy of NASA MSFC

Summary

- Roughness and Texture of AM Internal Channels can be modified/reduced via Chemical Polishing
  - >70% pressure drop reductions have been measured in 1.2K Combustion Chamber Cooling Channel testing
- Fuel Injector Performance and Port Geometry can be altered/improved via Chemical Polishing
  - Otherwise scrap and/or poorly performing Fuel Injectors have been successfully salvaged/improve
  - Port “true” geometries have been strongly maintained/remediated
  - Tight material removal tolerance capabilities have been demonstrated

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Metal Additive Manufacturing for Propulsion Applications

Edited by
Paul R. Gradl, Omar R. Mireles,
Christopher S. Protz, and Chance P. Garcia

PROGRESS IN ASTRONAUTICS AND AERONAUTICS

Timothy C. Lieuwen, Editor-in-Chief
Volume 263

CHAPTER 5

Post-Processing of Metal Additively Manufactured Components

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CHAPTER 8

Component Performance and Application Characteristics

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NASA Marshall Space Flight Center, Huntsville, Alabama

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REM Surface Engineering, Southington, Connecticut

National Aeronautics and Space Administration

SPINOFF

2022

Some Engineering Is Only Skin Deep

Ability to finish surfaces of 3D-printed superalloys improves performance for engines, industry

In this hot fire test at Marshall Space Flight Center, a nozzle printed from a NASA-developed superalloy metal is used inside the combustion chamber. The nozzle's surface was polished by Southington, Connecticut-based REM Surface Engineering, with a process and tools developed under SBIR funding from Marshall. *Credit: NASA*

Building rocket parts using 3D printing is less expensive than traditional manufacturing methods and can facilitate complex shapes without joints. But the technique leaves rough surfaces (left) that could cause turbulence, corrosion, and accelerated wear if not perfectly polished (right). *Credit: NASA*

REM Surface Engineering already had experience finishing 3D-printed surfaces but had never worked with certain high-performance superalloys NASA needed for rocket engines. With the help of two SBIR contracts, the company designed and constructed this large-scale chemical polishing cell, where it polished NASA's superalloy nozzles. Today the company is ready to use the equipment for commercial clients. *Credit: REM Surface Engineering*

Recent advances in 3D printing with metals are making it an increasingly attractive option, often offering both cost savings and higher-performing components. The resulting parts, however, have one major drawback that threatens to offset the advantages of metal 3D printing, or additive manufacturing: they have much rougher surfaces than those produced by traditional methods. This can dramatically reduce performance and durability in many applications.

Smoothing these surfaces, especially on strong, high-performance metals, is its own challenge, and it's one NASA has undertaken in hopes of both improving rocket engines and making 3D printing viable across more industries.

Paul Gradl has led several additive manufacturing projects at NASA's Marshall Space Flight Center in Huntsville, Alabama, including efforts to use the technology to build rocket engines. "Additive manufacturing allows us to fabricate parts much quicker, and we see cost savings because of that," he said, adding that 3D printing could reduce engine weight and allow for part reduction, eliminating joints.

Components like combustion chambers, injectors, and nozzles traditionally required multiple parts to be manufactured and then joined or fastened together. Instead, they can be printed as entire units, reducing the number parts and, therefore, the number of seams that can become points of failure. But rough surfaces threaten to reduce fatigue life, speed up corrosion, and cause turbulence in fluid flows, said Gradl.

So he contacted REM Surface Engineering of Southington, Connecticut. Founded by CEO Justin Michaud's grandfather as a decorative plating supply company in the 1960s, REM had since developed a combination of chemical and chemical-mechanical techniques for metal surface finishing.

The company had already successfully finished surfaces of 3D-printed metal parts but did not have viable processes for some metals NASA was interested in, including certain "superalloys." Under two Small Business Innovation Research (SBIR) contracts from Marshall in 2018 and '19, REM developed the ability to surface-finish parts printed from Inconel 625 and 718, popular nickel-based superalloys of interest to the agency and industry. The funding also helped the company develop surface finishing for JBK-75, an iron-nickel-based alloy, and NASA HR-1, a derivative of JBK-75 that's resistant to the high-pressure environment of hydrogen engines.

Gradl said starting with Inconel would both meet NASA's immediate needs and provide a commercial market for the company's work. The ability to process JBK-75 and NASA HR-1, meanwhile, would help the agency advance its Rapid Analysis and Manufacturing Propulsion Technology project, which aims to improve rocket thrust chambers while bringing down their cost, in part through 3D printing with composite materials.

REM's work with superalloys has drawn interest from commercial space companies, the auto racing industry, and producers of turbomachinery such as gas turbines and jet engines. Additional possible markets include radio frequency waveguides and even a potential nuclear fusion reactor, Michaud said.

He noted that the work is also helping NASA quantify the performance of various 3D printing materials, components, and techniques, which will help other companies enter the business. "NASA is taking away the barriers to entry and opening up space for more success across the industry," Michaud said. ●

Additive Manufacturing for the Aerospace Industry
Edited by Francis H. Froes and Rod Boyer

Outline

- Abstract
- Keywords
- 16.1. Introduction
- 16.2. Best practices for surface texture characterization of ...
- 16.3. Surface finishing of additive manufacturing compon...
- 16.4. Additive manufacturing-built components surface-fi...
- 16.5. Conclusions
- 16.6. Corollary
- Acknowledgments
- References

ELSEVIER
Additive Manufacturing for the Aerospace Industry
2019, Pages 341-374

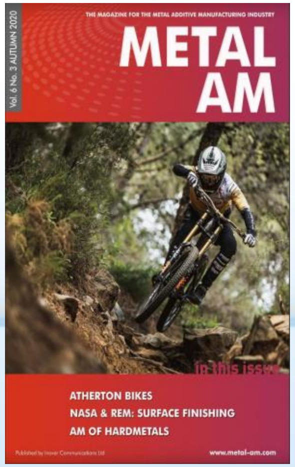
16 - Surface texture characterization and optimization of metal additive manufacturing-produced components for aerospace applications

Agustin Diaz

https://doi.org/10.1016/B978-0-12-814062-8.00018-2

Abstract

The additive manufacturing (AM) field is growing at an accelerated rate, with new printing techniques and modifications of existing technologies coming out every day. Powder bed fusion (PBF) stands out from the many AM technologies as the main technique to employ when building metal components for aerospace applications. The focus of this chapter will be the texture of the surfaces produced by PBF of metal components and their characterization. The surface texture of these components is highly complex and unique; however, the distinctiveness of these surface textures needs to be understood in order to do an accurate characterization of them. Our discussion will include best practices to characterize the surface texture of PBF-built components based on the surface properties of the printed component, the optimization of the surface textures during the building process, and the use of different surface finishing techniques (post-processing) to yield



THE MAGAZINE FOR THE METAL ADDITIVE MANUFACTURING INDUSTRY

METAL AM

Vol. 6 No. 3 AUTUMN 2020

In this issue

ATHERTON BIKES
NASA & REM: SURFACE FINISHING
AM OF HARDMETALS

Published by Inovar Communications Ltd
www.metal-am.com

NASA and REM: Advancing surface finishing

Advancing rocket propulsion through Additive Manufacturing, novel surface finishing technologies and public-private partnerships

Whilst Additive Manufacturing is undoubtedly having a huge impact on the design and manufacture of rocket propulsion systems, most notably combustion chambers and nozzles, the Achilles' heel of all AM process is currently as-built surface finish. Whilst in many AM applications surface finish may be largely irrelevant to a component's function or performance, when it comes to high-cycle fatigue properties, achieving the required level of smoothness is critical to performance. In this article, Justin Michaud, REM Surface Engineering, reports on advancements achieved in this area through a public-private partnership with NASA.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