Mechanical Characterization of As-built and Post-processed In-situ Alloyed Additively Manufactured GRCop-42

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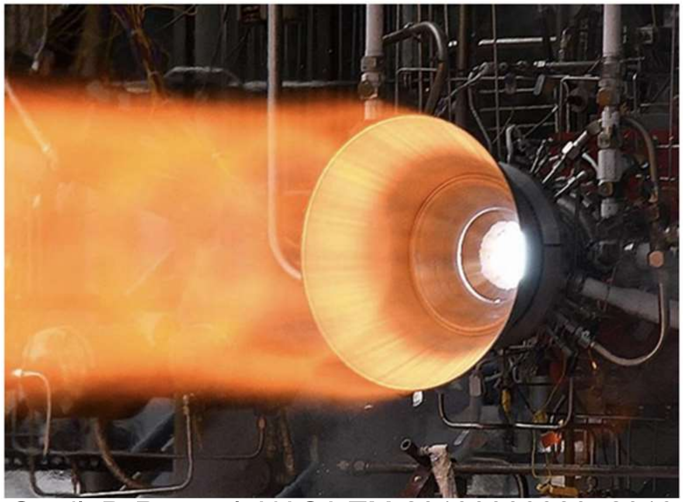
Overview

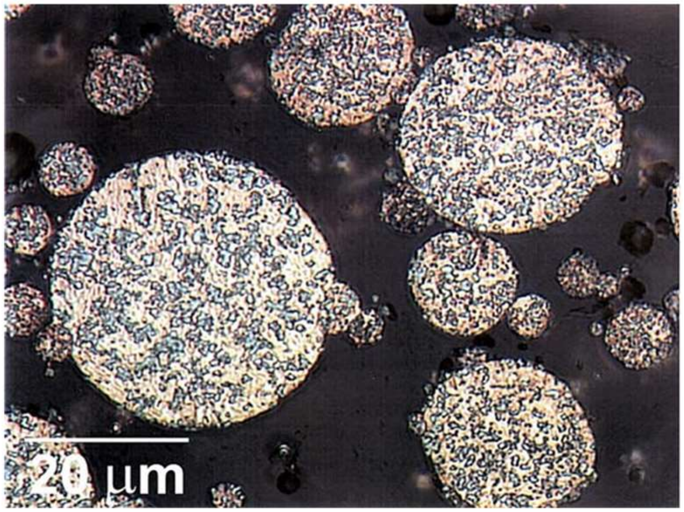
- Background and Motivation
- Sample Manufacturing
- Chemical Composition
- Porosity Analysis
- Mechanical Characterization
  - Tensile testing
  - Creep testing
- Fractography
- Conclusions

Background: GRCop

- GRCop are a family of Cu-Cr-Nb alloys
  - Cu matrix and Cr2Nb dispersoids
  - GRCop-42 is 4 at% Cr and 2 at% Nb
- These alloys were developed for:
  - High temperature mechanical properties
  - High Thermal conductivity



Gradl, P. R. et. al. NASA TM-20190033380, 2019



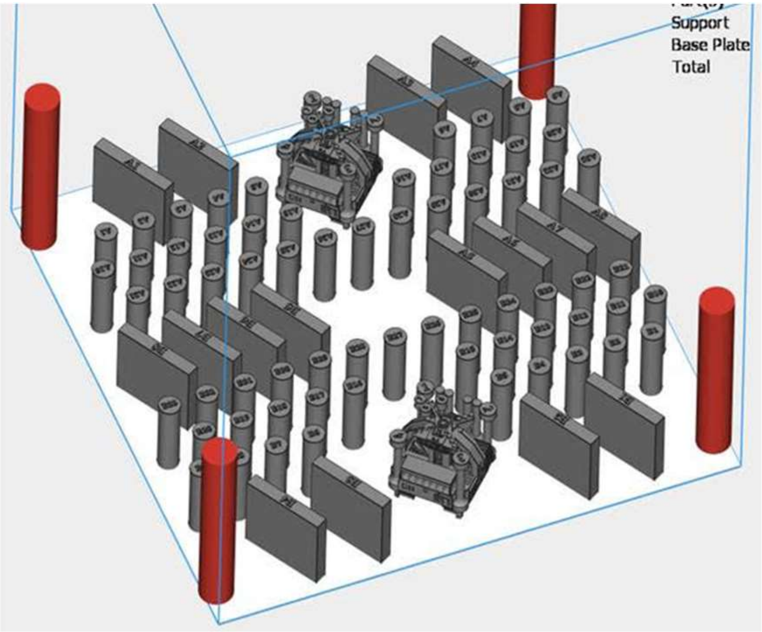
D. L. Ellis, NASA TM - 2005-213566, 2005.

Background: In-Situ Alloying during AM

- Current Literature:
  - Binary or ternary intermetallics
  - All elements participate in the reaction
  - Post-processing can be used to complete alloying reaction
- This work:
  - Dispersion strengthened alloy
  - Only minor alloying elements reacting

Sample Manufacturing

- Material was manufactured with EOS M290 LPBF system
- Two different builds
  - B → single low energy laser scan
  - D → double low energy laser scan
- Hot Isostatic Pressing done at MSFC
  - 954℃ at 150 Mpa
- As built samples → AB
- Hot Isostatic Presses samples → HIP



Chemical Characterization

B	Single laser scan
D	Double laser scan
AB	As-built
HIP	Hot isostatic pressed

- Inductively Coupled Plasma –Optical Emission Spectroscopy (ICP-OES) unit used to determine metals between H and U

- Cr and Nb content low
- Al content higher than allowed

- Incorrect Cr and Nb content

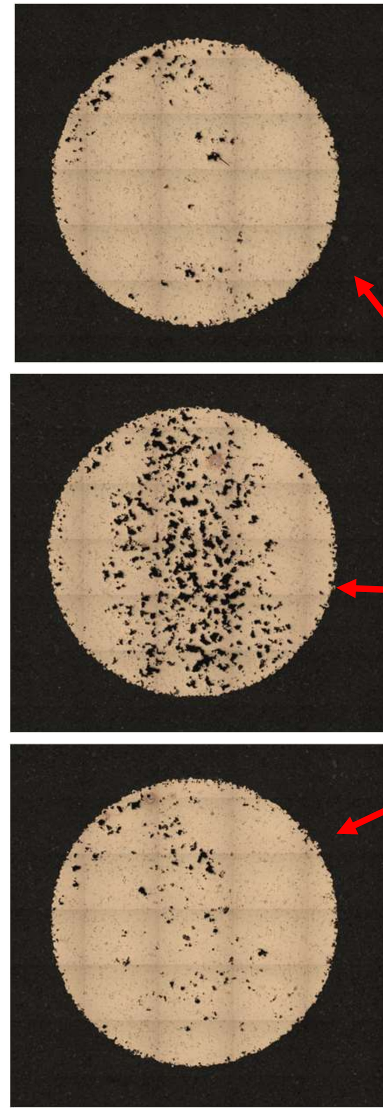
Determined to be from

	Specification[1]	In-Situ AM GRCop-42			
Element	GRCop-42 Wt%	B-AB Wt%	B-HIP Wt%	D-AB Wt%	D-HIP Wt%
Cr	3.1 - 3.4	2.06	1.7	1.75	1.73
Nb	2.7 - 3.0	2.09	1.81	1.77	1.71
Fe	<50 ppm	42 ppm	35 ppm	36 ppm	36 ppm
O	<400 ppm	413 ppm	385 ppm	338 ppm	327 ppm
Al	<50 ppm	111 ppm	73 ppm	86 ppm	72 ppm
Si	<50 ppm	10 ppm	20 ppm	10 ppm	10 ppm
Cu	Balance	Balance	Balance	Balance	Balance
Cr:Nb	1.12 - 1.15	0.99	0.94	0.99	1.01

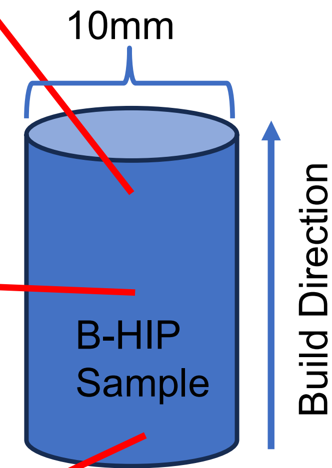
[1]Gradl, P. R. et. al. NASA TM-20190030461, 2019

Porosity Measurements

- Porosity was measured using metallographic images through sample
  - Automated using RoboMet system from UES
- Sample was cut from a printed cylinder to be approx. 3mm tall
- Approximately 63um of material were removed between each image



B	Single laser scan
D	Double laser scan
AB	As-built
HIP	Hot isostatic pressed

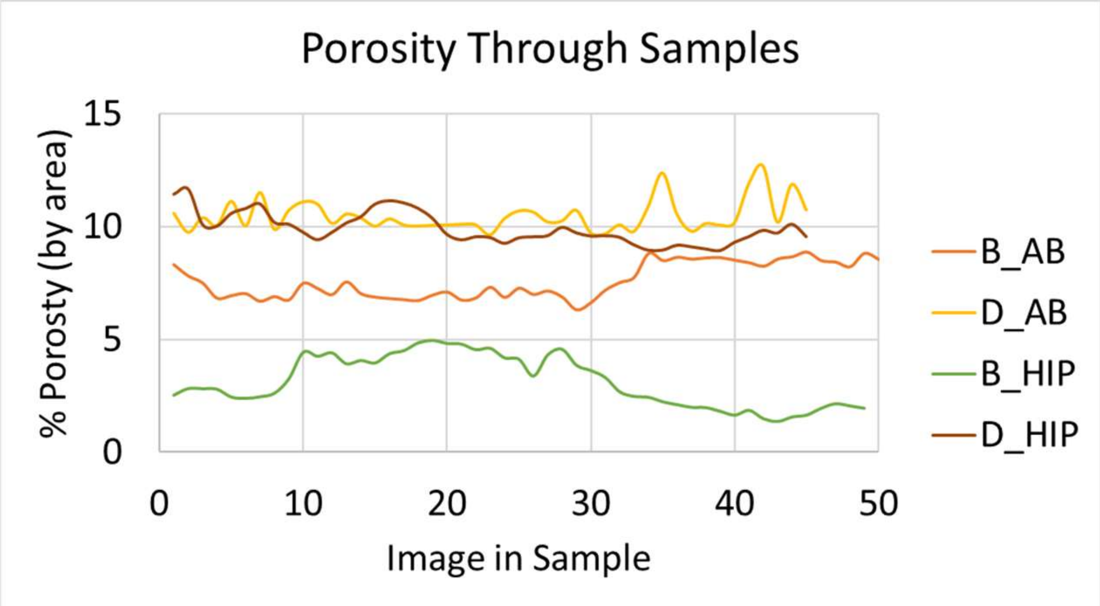


Comparison of Porosity

B	Single laser scan
D	Double laser scan
AB	As-built
HIP	Hot isostatic pressed

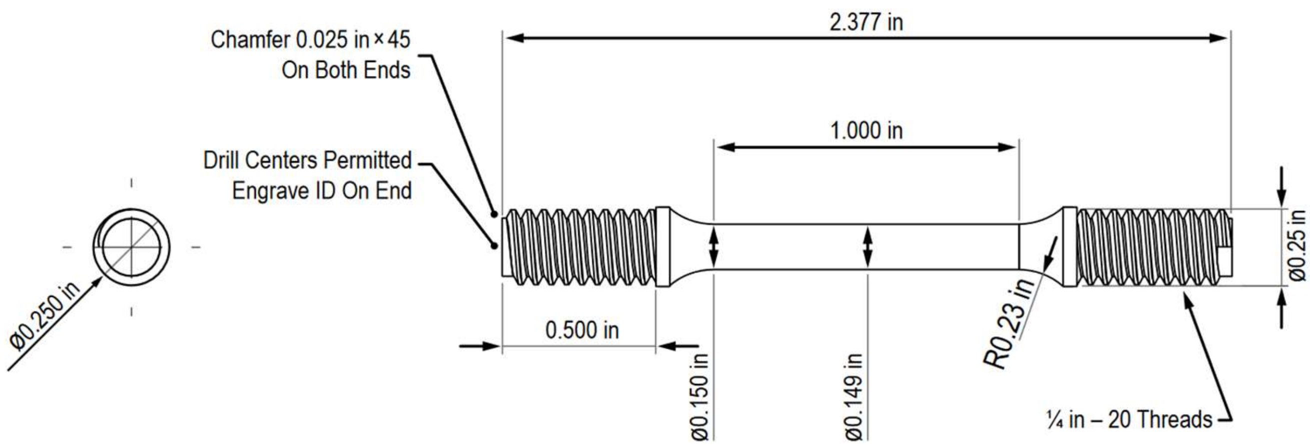
- Comparison of different samples porosity
- D samples have higher porosity than B samples
- B samples have more variation throughout

Sample	B_AB	D_AB	B_HIP	D_HIP
Avg % Porosity	7.6	10.5	3.2	9.9



Tensile Testing

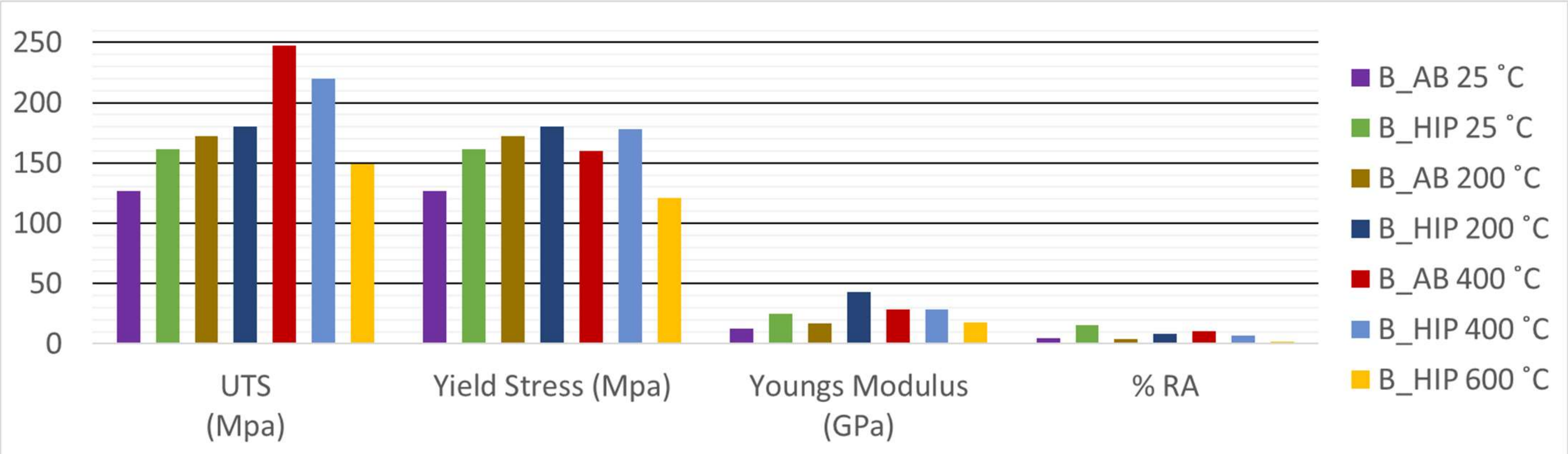
- Samples machined into ASTM E8-style round tensile specimens
- Tested in displacement control at crosshead rate of 0.635 mm/min
- Tested at temperatures of 25℃, 200℃, 400℃, and 600℃



Tensile Properties Results for B Samples

B	Single laser scan
D	Double laser scan
AB	As-built
HIP	Hot isostatic pressed

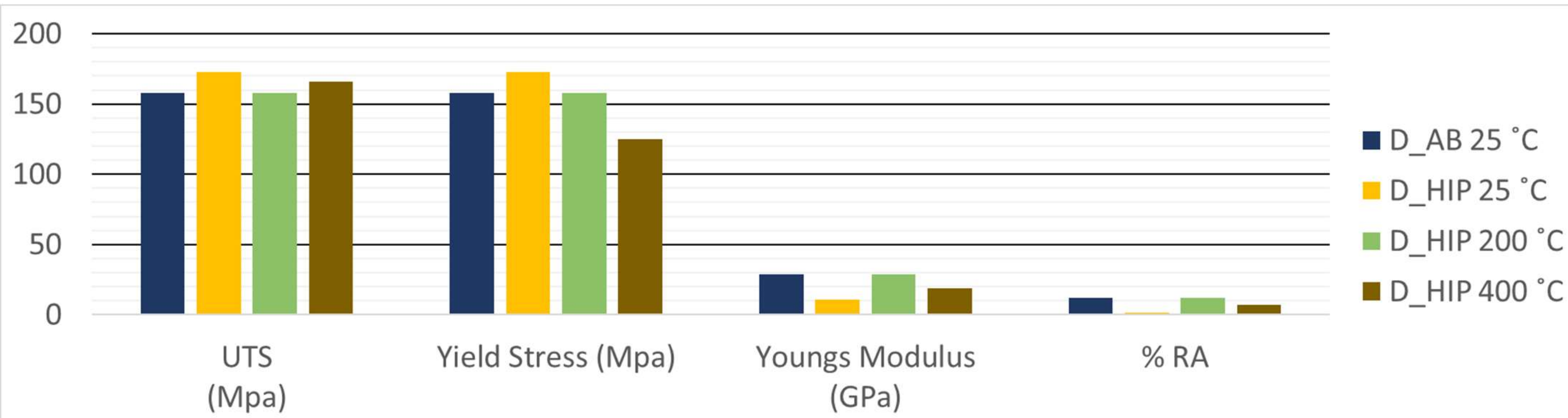
- UTS and YS increase with temperature up to 400˚C then decreases
- B-AB had higher YS and UTS than B-HIP but lower % area reduction



Tensile Properties Results for D Samples

B	Single laser scan
D	Double laser scan
AB	As-built
HIP	Hot isostatic pressed

- More limited data due to limited material available
- D-HIP had higher UTS and YS at room temperature than D-AB

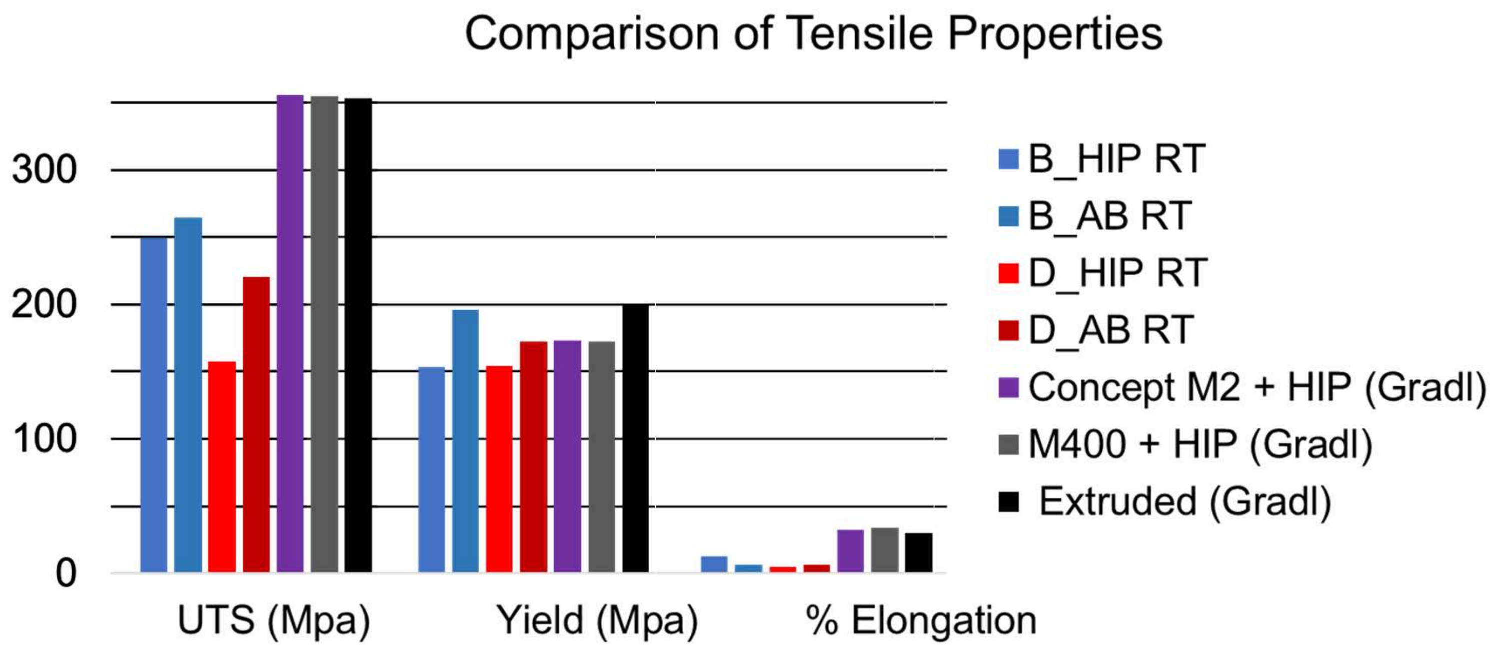


Comparison of Tensile Properties to Literature

B	Single laser scan
D	Double laser scan
AB	As-built
HIP	Hot isostatic pressed

- UTS lower than literature
- Yield Comparable
- Elongation lower

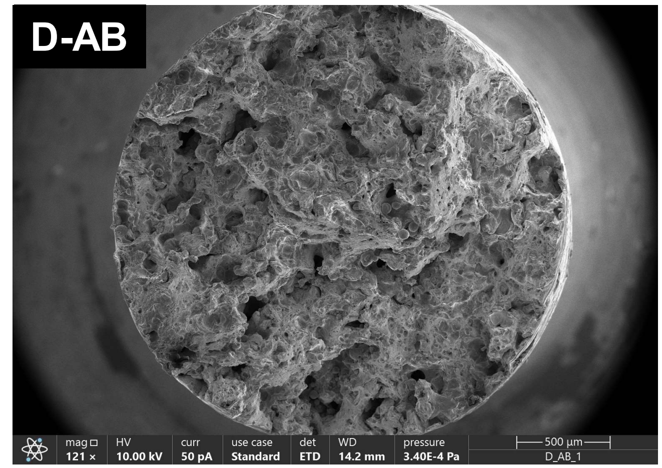
Sample geometry from literature identical to testing done in this work

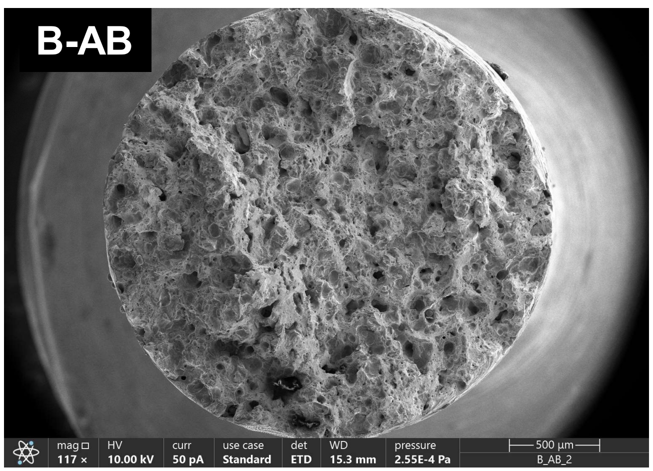


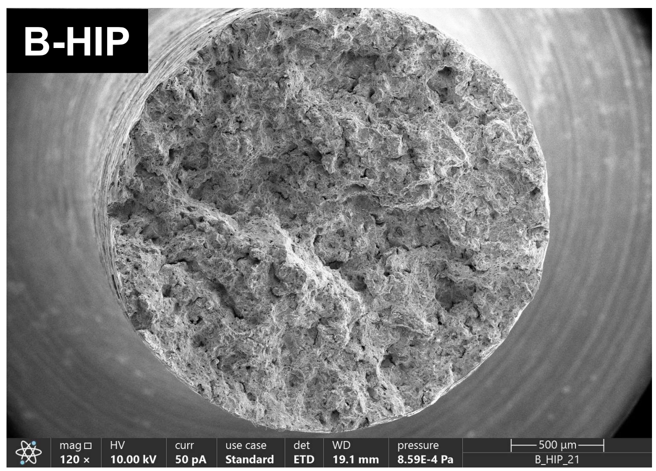
Gradl, P. R. et. al. NASA TM-20190030461, 2019

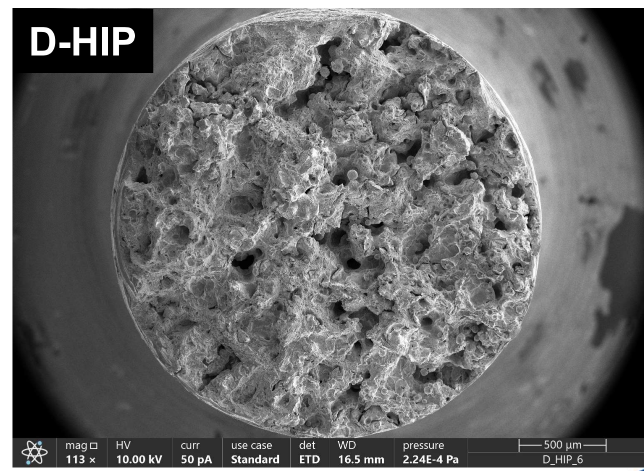
Tensile Test Fractography

- Fracture surfaces from all temperatures
  - Ductile fracture
  - High porosity
  - Unmelted powder/lack of fusion
- D samples show more porosity and defects







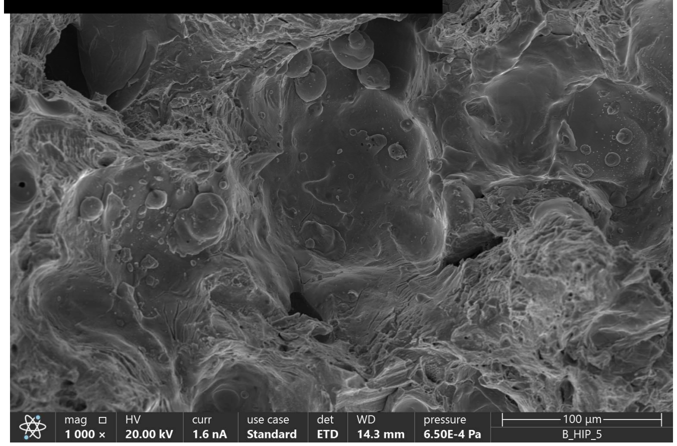


Tensile Test Fractography

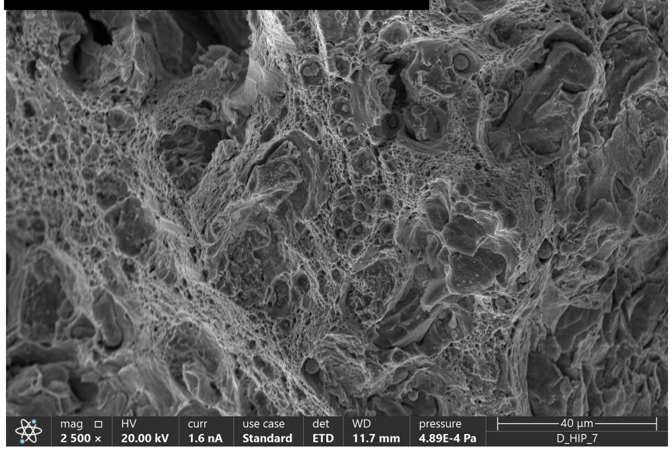
B	Single laser scan
D	Double laser scan
AB	As-built
HIP	Hot isostatic pressed

- No significant difference in fracture surfaces for as-built and HIPed material
  - Printing parameters for both B and D were not optimal leading to significant defects in both

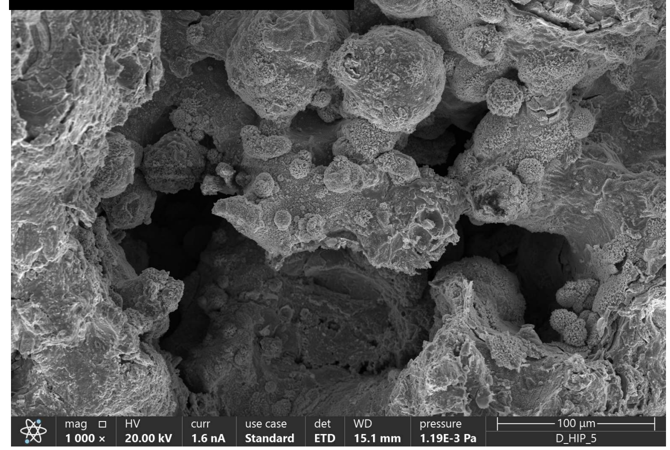
Lack of Fusion Defects
B-HIP



Voids around particles
D-HIP



Unmelted powder
D-HIP



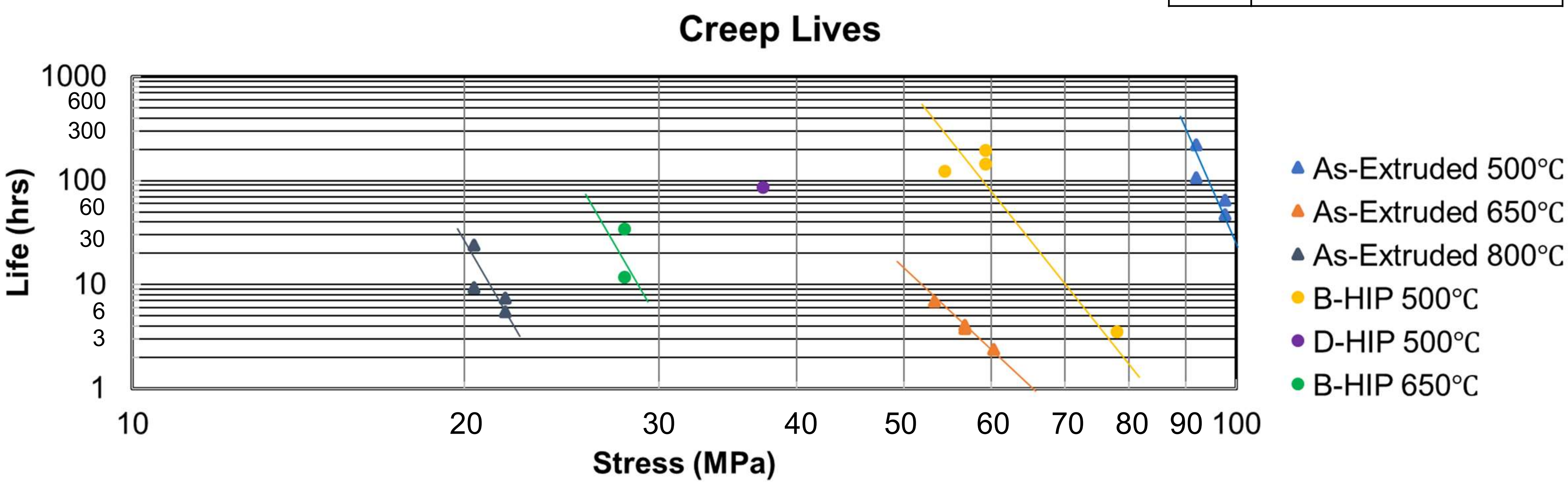
Vacuum Creep Testing

B	Single laser scan
D	Double laser scan
AB	As-built
HIP	Hot isostatic pressed

- Only completed testing of B-HIP material
- Sample dimensions the same as for tensile testing
- Tested at temperatures of 500℃, 650 ℃, and 800 ℃
- Displacement measured two ways
  - Movement of the load train
  - Camera system to measure the distance between two fiduciary marks

Creep Testing Results

B	Single laser scan
D	Double laser scan
AB	As-built
HIP	Hot isostatic pressed



- Creep life higher for B-HIP than extruded conventionally manufactured GRCop-42

Extruded material data provided by David L. Ellis

B	Single laser scan
D	Double laser scan
AB	As-built
HIP	Hot isostatic pressed

Conclusions

- Both B-HIP and D-HIP compositions are outside alloy specification
- HIP did not close-up all porosity as it was too large
  - Porosity may contain trapped gas
- Creep lives for B-HIP were better than extruded GRCop-42
- In-situ alloying was demonstrated to produce GRCop with acceptable mechanical properties but needs additional work to overcome noted deficiencies

Future Work

- Complete additional creep testing on material
- Test fatigue properties
- Look at grain structure and crystallographic texture

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Questions?

ICP Details

- Ametek Arcos Inductively Coupled Plasma –Optical Emission Spectroscopy (ICP-OES) unit used to determine metals between H and U
  - Necessary for discovery of unknown trace elements
  - Analyzes spectra between 130 nm and 770 nm wavelengths
- LECO 844 Series Combustion Analyzer used for C and S detection
- LECO 736 Series Inert Gas Fusion unit used for N and O detection
  - C, S, and O detected with non-dispersive infrared (NDIR) cells
  - N detected by the change in thermal conductivity of the gas relative to the carrier gas

Additional Creep Data