Structural Materials – INL

ASME PM-HIP 316H Code Cases in Support of Microreactors

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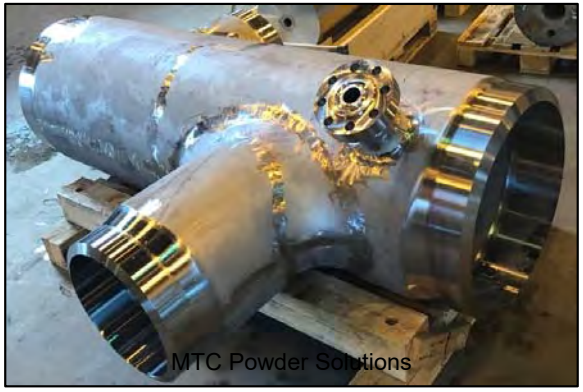
Background

- Powder metallurgy hot isostatic pressing (PM-HIP) is a manufacturing technique that can produce metallic components by consolidating powder into complex geometric shapes
  - Minimizes additional fabrication steps such as welding/machining
  - Eliminates solidification structures compared to castings
  - Eliminates directional grain elongation compared to rolling/forging



- Microreactor construction can greatly benefit from PM-HIP components which can allow for optimized designs, reduced construction time, reduced waste, and better component/material availability

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PM-HIP Adoption for Microreactors

Goals

- Demonstrate high temperature mechanical properties of PM-HIP materials are comparable to, or better than, wrought materials
- Develop specifications and acceptance criteria for PM-HIP components based on allowable materials characteristics
- Leverage understanding of microstructure and high temperature mechanical properties for components fabricated by PM-HIP and by traditional methods to qualify similar classes of alloys, e.g., solid solution alloys, fabricated by PM-HIP with minimal additional testing

Scope

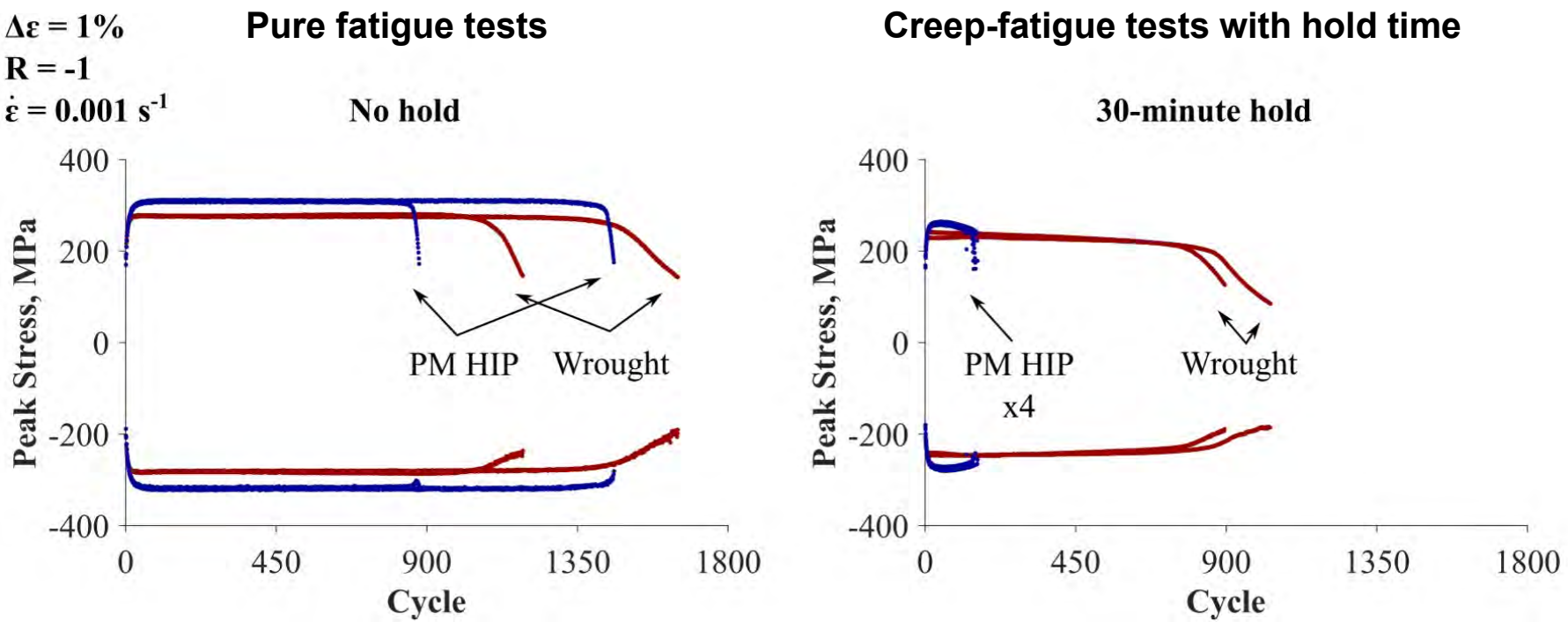
- PM-HIP 316H stainless steel is first addressed to support multiple advanced reactor designs
- Followed by other solid solution alloys
  - e.g., PM-HIP Alloy 800H, a reference construction material for high-temperature gas-cooled reactors (HTGRs)

Major Milestones

- Complete development of PM-HIP 316H code cases for the American Society of Mechanical Engineers (ASME) Section III, Division 5, Class A applications by 2025
  - Low temperature PM-HIP 316H code case (up to 371°C)
  - High temperature PM-HIP 316H code case (371°C<T<816°C)

Previous Results

- Cyclic (fatigue and creep-fatigue) test data of 316H PM-HIP material and wrought product at 650°C and 1% total strain
  - Fatigue performances were similar
  - Creep-fatigue performance of PM-HIP 316H was sub-par



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Properties and Process Optimization

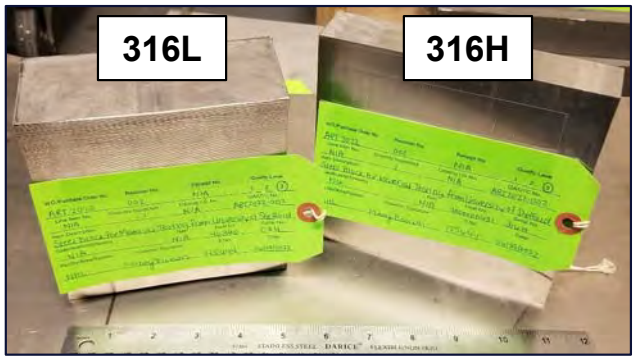
A possible cause for poor creep-fatigue performance was the oxygen content within the powder

- A deeper understanding is needed to determine how the composition and microstructure influence PM-HIP mechanical properties
  - Overall oxygen concentration
    - Prior data has shown that >130 ppm oxygen content in PM-HIP SS may be deleterious to elevated temperature properties
  - Oxide size and distribution
  - Grain size and grain size distribution

Recent Progress

- Analyzed 316H PM-HIP material produced by MTC Powder Solutions (316H - MTC Heat 1)
- Procured 316H and 316L stainless steel produced via the PM-HIP process by the United Kingdom (UK) Nuclear Advanced Materials Research Center (NAMRC)

NUCLEAR AMRC
ADVANCED MANUFACTURING RESEARCH CENTRE



- Submitted procurement of 316H PM-HIP – 190 mm Ø bars
  1) Oxygen concentration below 0.0130 wt% (same heat treatment as previous 316H bar with 0.0190 wt% O)
  2) 0.0130 wt% O with *optimized* heat treatment
- Procured wrought 316H stainless steel

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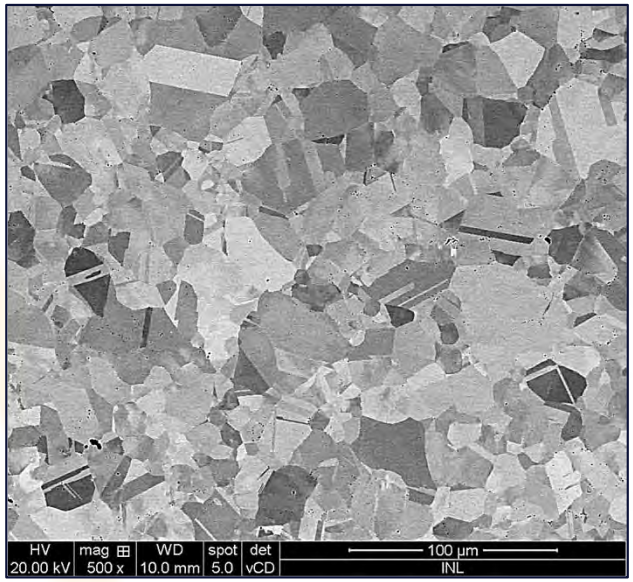
Materials

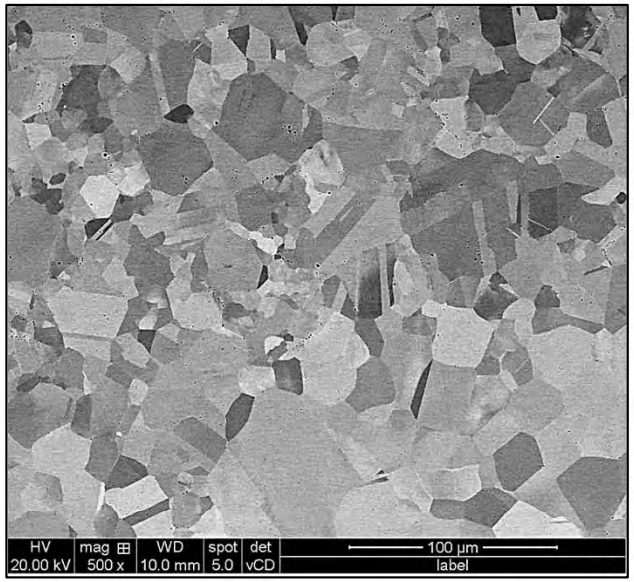
Consolidated Product Chemical Compositions (wt%)										
	Ni	Cr	Mo	C	Si	Mn	S	P	O	N
316H – MTC Heat 1	12.0	16.2	2.53	0.05	0.17	0.21	0.01	0.003	0.0190	0.141
316H – UK-NAMRC	11.8	17.3	2.53	0.04	0.17	0.18	<0.003	<0.005	0.015	0.069
316L – UK-NAMRC	11.9	17.7	2.44	0.015	0.83	1.88	0.008	0.008	0.0117	0.06

316H – MTC Heat 1



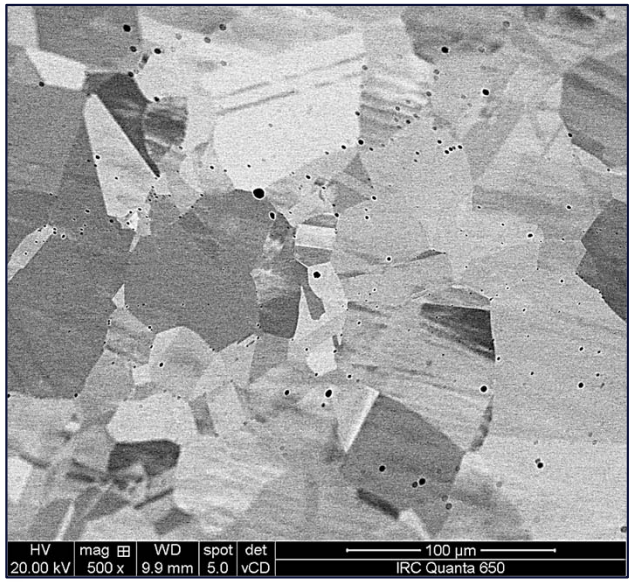
224 $HV_{0.3}$

316H – UK-NAMRC



194 $HV_{0.3}$

316L – UK-NAMRC



173 $HV_{0.3}$

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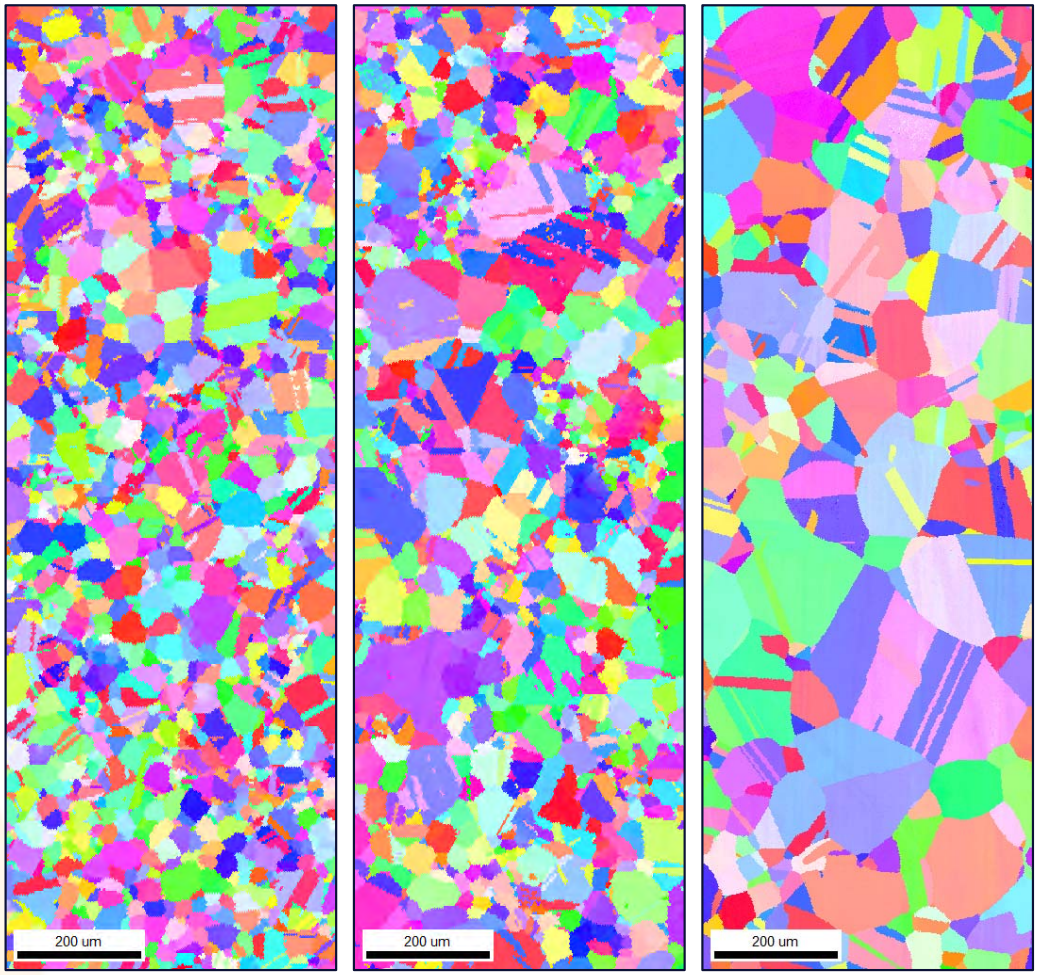
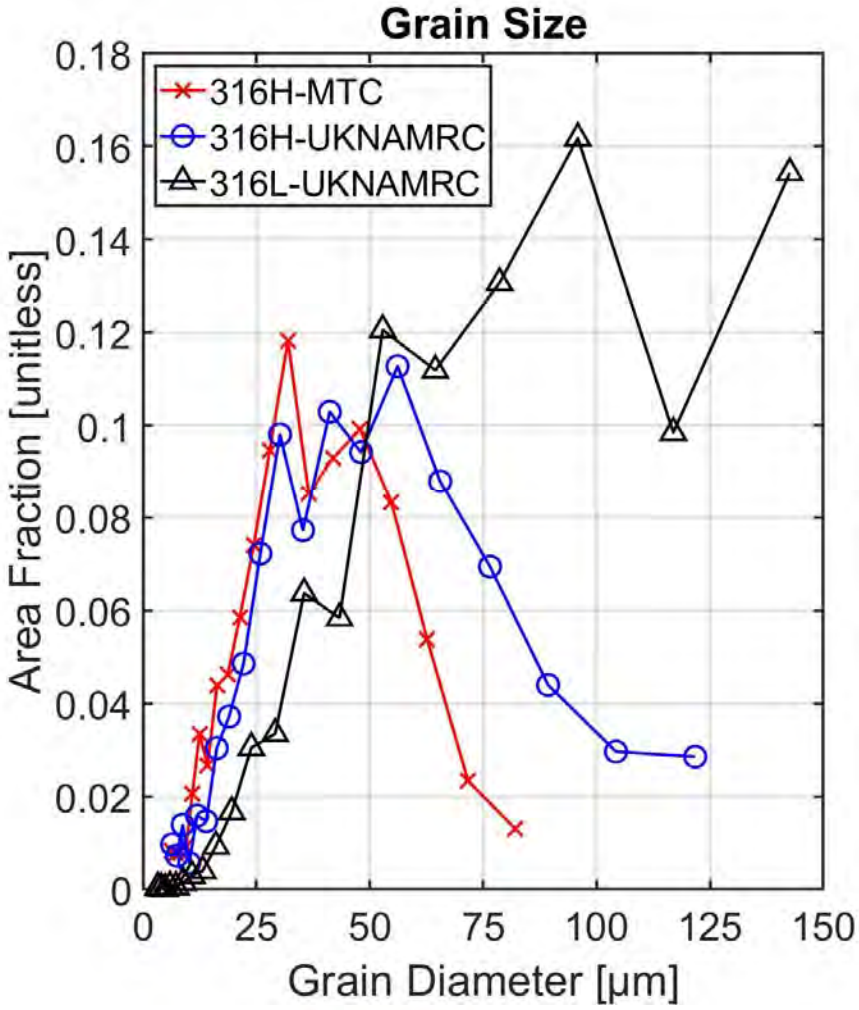
Results – Grain Size

316H MTC Heat 1	316H UK-NAMRC	316L UK-NAMRC



d_{avg}= 35 µm d_{avg}= 47 µm d_{avg} = 80 µm



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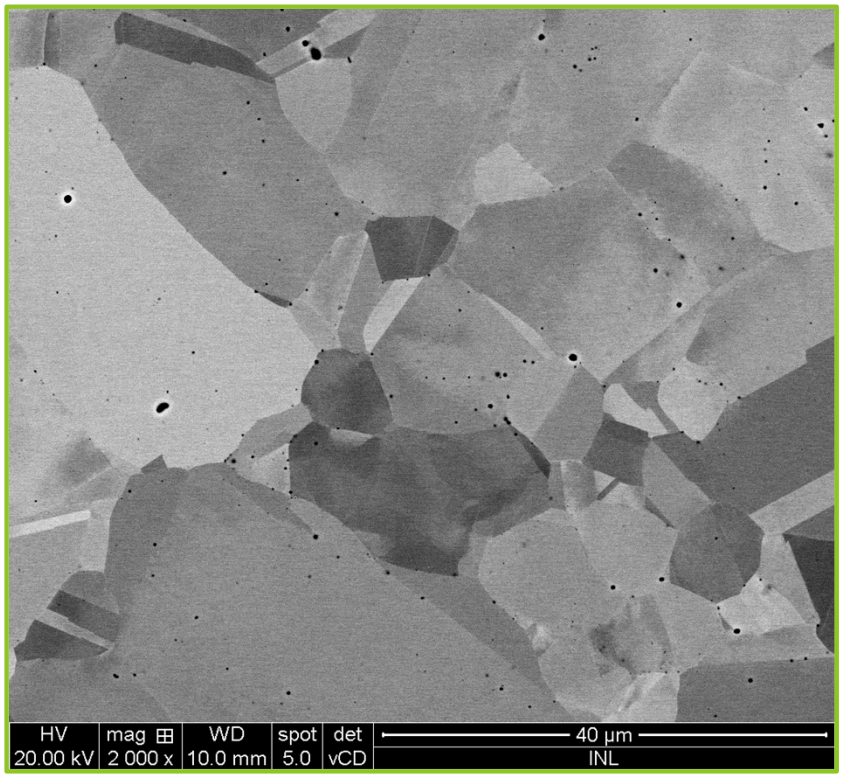
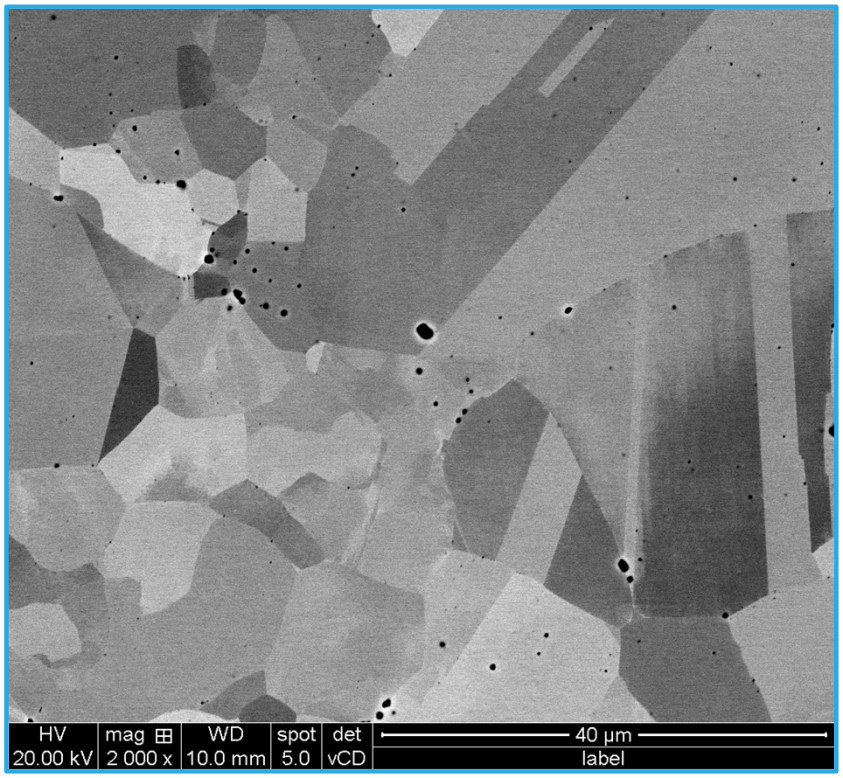
Results – Oxides

316H – MTC Heat 1



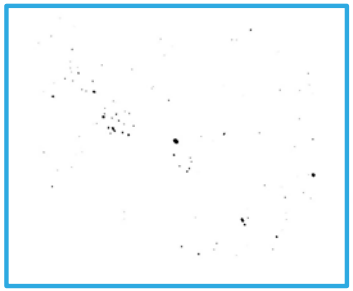
Oxide Area Fraction = 0.0004%

316H – UK-NAMRC



Oxide Area Fraction = 0.0007%

Image Thresholds →



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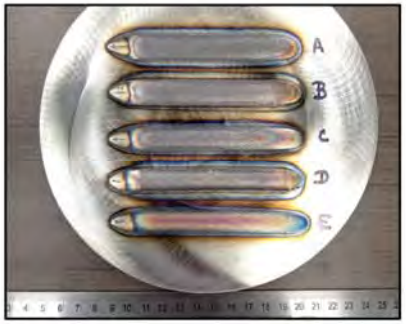
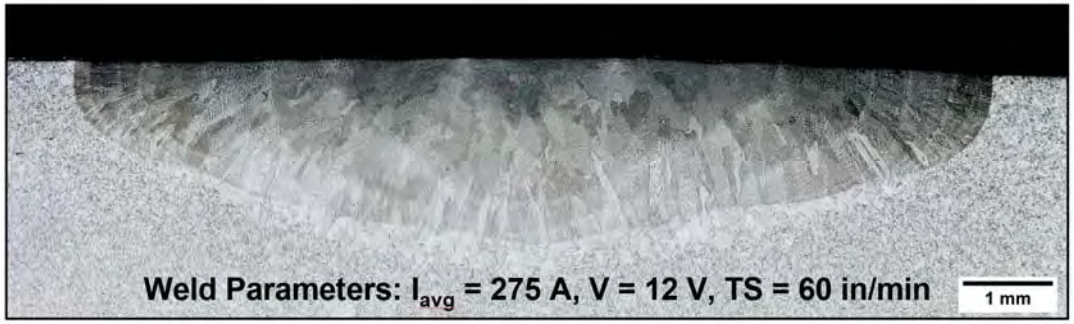
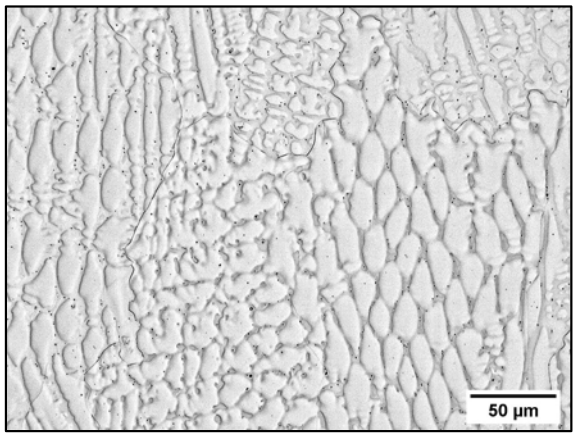
Results – Fusion Welding

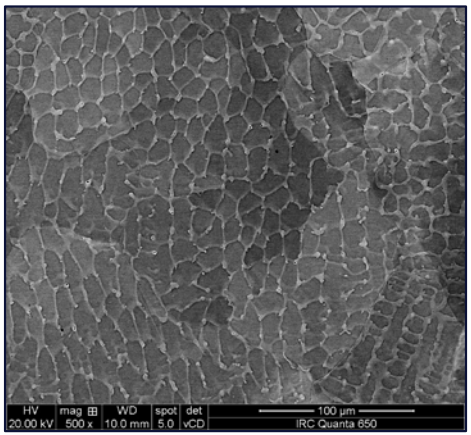
- Performed a scoping weldability analysis on 316H – MTC Heat 1
  - No major gas tungsten arc welding (GTAW) weldability issues, i.e., porosity or solidification cracking

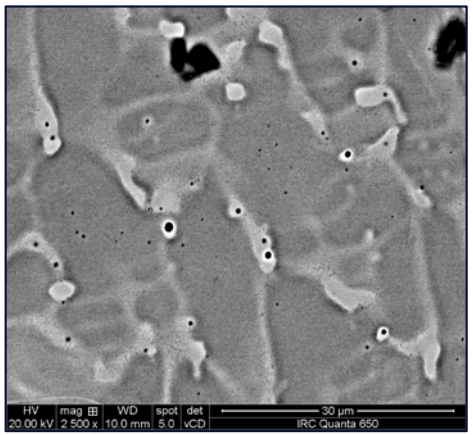




  - Presence of precipitates, likely oxides, are segregated to the interdendritic regions of the weld metal







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Conclusions

- Grain size variations between the materials procured
- Varying oxide size and distributions between the 316 SS alloys
- PM-HIP 316H showed no major weldability issues
- Oxides remained in the weld metal

Future Work

- Conduct elevated temperature mechanical testing on the UK-NAMRC 316 SS alloys
- Evaluate and perform elevated temperature testing on the PM-HIP 316H with 130 ppm or lower oxygen content fabricated by MTC Powder Solutions

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FY23 Milestone

M3AT-23IN0804091, 9/15/2023

- Complete an initial evaluation of the elevated-temperature cyclic properties of optimized Alloy 316H fabricated by powder metallurgy hot isostatic pressing
- On schedule