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MRP: Qualification of Powder Metallurgy Hot Isostatic Pressed (PM HIP) Materials for Elevated-Temperature Nuclear Construction

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Changing the World's Energy Future

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MRP: Qualification of Powder Metallurgy Hot Isostatic Pressed (PM HIP) Materials for Elevated-Temperature Nuclear Construction

Advanced Reactor Technologies Program
Advanced Materials R&D Program Review
June 7 and 8, 2022

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Contributors

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- Richard Wright (Structural Alloys, LLC)

Fiscal Year 2022 (FY-22) Work Packages

- AT-22IN080410, Structural Materials – INL

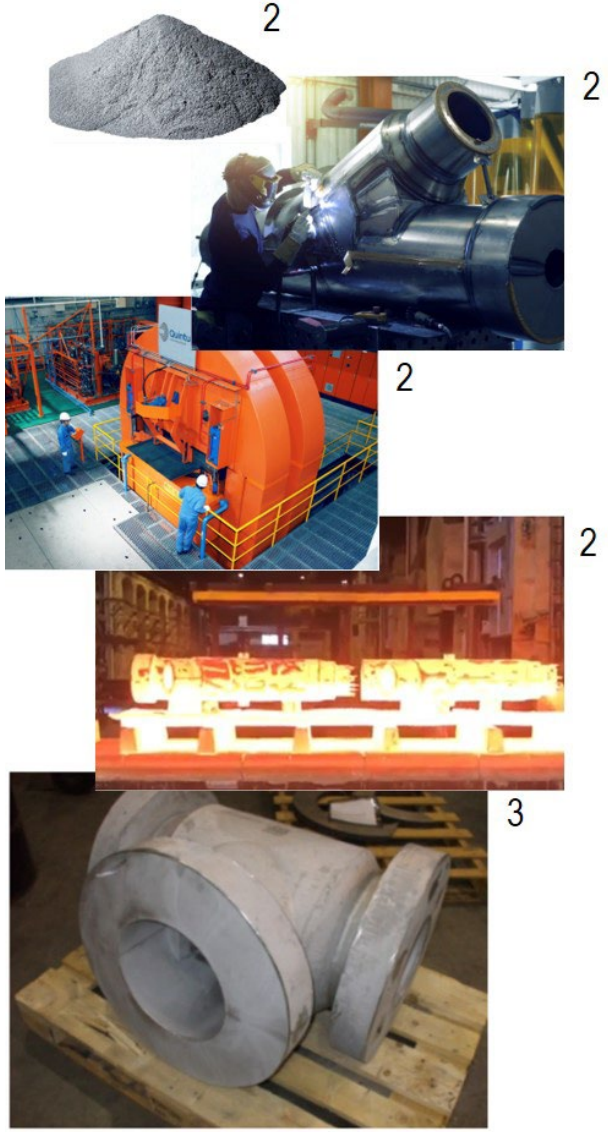
Outline

- Motivation
- Research and Development (R&D) Progress To Date
- Planned FY-22 R&D

Motivation

Process and Advantages

- PM HIP is a mature advanced manufacturing method that is used by many non-nuclear industries to fabricate structural components[1]
  - Elimination of inspectability issues and concerns
  - Production of homogenous microstructures
  - Enabling components using near-net shape (NNS) technologies
  - Enabling new alloys systems & targeted chemistries
  - Enhancing weldability through stringent “tramp” element controls
  - Alternate supply route for long-lead time components
  - Elimination of re-work or repair of large cast components
  - Production of smaller, individual heats (lots) of material as opposed to several ton heats in near-net shape form or as ingots
- PM HIP attributes are also attractive for fabricating reactor components
  - **Particularly timely for microreactors due to smaller component size**



[1] From background file for RC 11-1826 associated with Code Case N-834
[2] MTC Powder Solutions AB. (downloaded 2021, June 27). Technology. https://mtcpowdersolutions.com/technology
[3] Gandy, D., Siefert, J., Lherbier, L., & Novotnak, D. (2014, April). PM-HIP Research for pressure retaining applications within the electric power industry (SMR2014-3305). In ASME 2014 Small Modular Reactors Symposium. American Society of Mechanical Engineers Digital Collection.

Components Fabricated by PM HIP Relevant to Microreactors

1

Valve Body
316L Stainless Steel
780 kg (1,716 lbs)

2

Steam Plenum Access Port
A508
544 kg (1,200 lbs)
(still in HIP canister)

3

Upper Head
A508 Class 1, Grade 3
1,650 kg (3,650 lbs)
1,270 mm (50 inches) diameter

[1] Gandy, D., Siefert, J., Lherbier, L., & Novotnak, D. (2014, April). PM-HIP Research for pressure retaining applications within the electric power industry (SMR2014-3305). In ASME 2014 Small Modular Reactors Symposium. American Society of Mechanical Engineers Digital Collection.
[2] Gandy, D. W., Stover, C., Bridger, K., Lawler, S., Cusworth, M., Samarov, V., & Barre, C. (2019). Small Modular Reactor Vessel Manufacture/Fabrication Using PM-HIP and Electron Beam Welding Technologies. Hot Isostatic Pressing: HIP'17, 10, 224.
[3] Gandy, D. (2020, Mayl). Powder Metallurgy- HIP for SMRs and Advanced Reactors. Presented to the American Society of Mechanical Engineers Boiler and Pressure Vessel Code Task Group on Division 5 Advanced Manufactured Components.

Approach to PM HIP technology adoption proposed in DOE Microreactor Program

Goals of the Microreactor Program PM HIP R&D

- Demonstrate that the elevated-temperature mechanical properties required by structural design of microreactors are comparable to, or better than, those from wrought products.
  - Through a combination of microstructural characterization and targeted elevated-temperature mechanical properties testing to reduce demonstration timeline.
- Develop specifications and acceptance criteria for PM HIP components based on allowable materials characteristics instead of solely by testing of witness specimens.
  - Providing assurance that the PM HIP components accepted for reactor construction will perform as designed throughout the design lifetime.
  - Important for the adoption of the PM HIP technology for high temperature reactor construction.

Examples of microreactor applications

- Reactor vessel, nozzle, reactor head, valve body, pump impeller, etc.

Approach to PM HIP technology adoption proposed in DOE Microreactor Program

Approach

- Leverage understanding of microstructures and high temperature mechanical properties for components fabricated by PM HIP and by traditional wrought product forms to qualify similar classes of alloys, e.g., solid-solution alloys, fabricated by PM HIP with minimal additional testing.

Scope

- PM HIP of 316H stainless steel (SS) 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)

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R&D Progress To Date

Procured 316H SS PM HIP bar

Chemistry , in wt.%

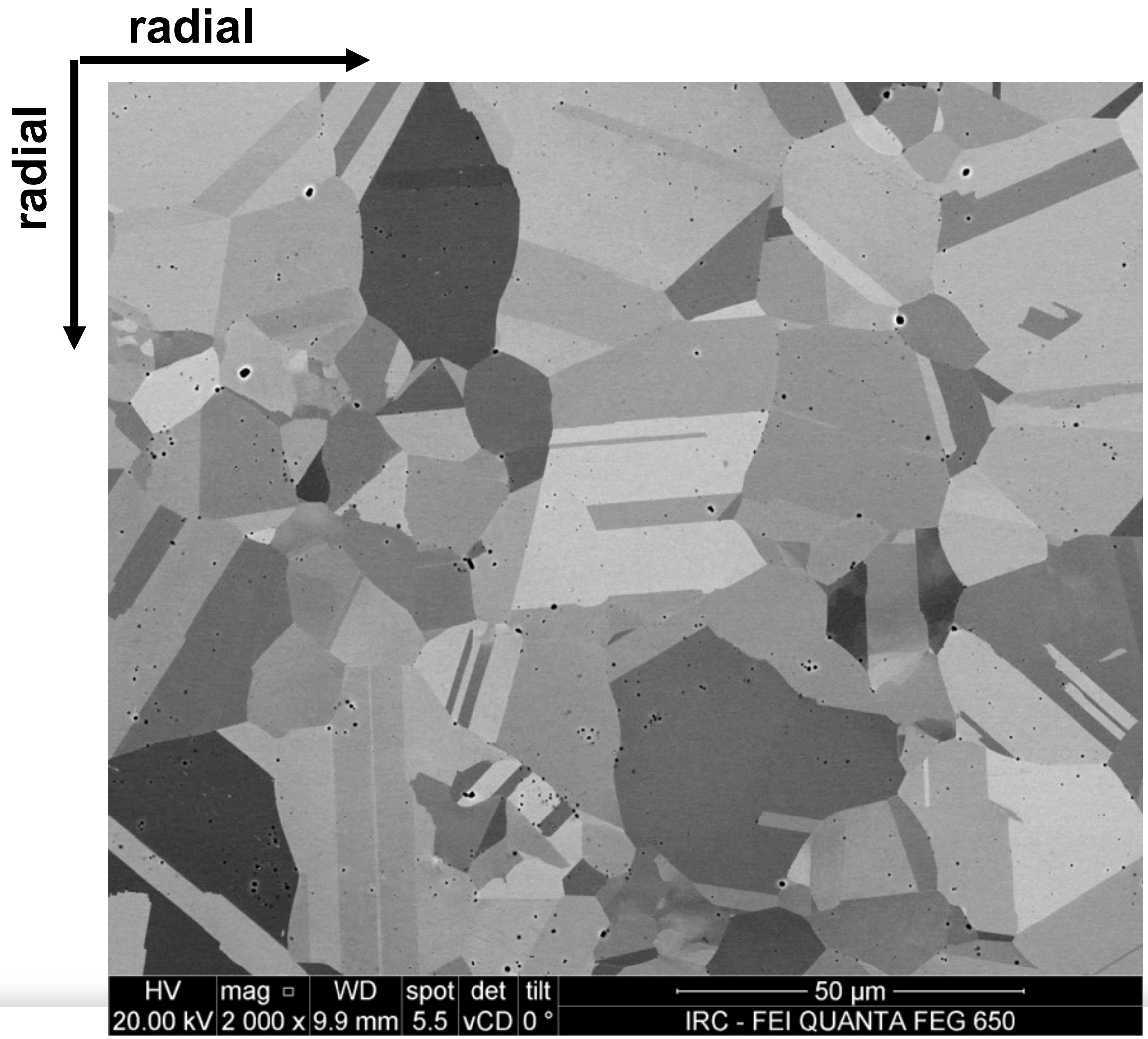
	C	Si	Mn	P	S	Cr	Ni	Mo	Al	Ti	N
Bar	0.040	0.17	0.21	0.002	0.003	16.44	11.95	2.48	0.007	0.005	0.147
Min	0.04					16.0	10.0	2.00			0.05
Max	0.1	0.75	2.00	0.045	0.030	18.0	14.0	3.00	0.03	0.04	

	B	Co	Cu	Nb	Ta	V	Fe	O	Ta+Co
Bar	0.0003	0.011	0.012	< 0.005	0.006	< 0.005	68.47	0.0202	0.017

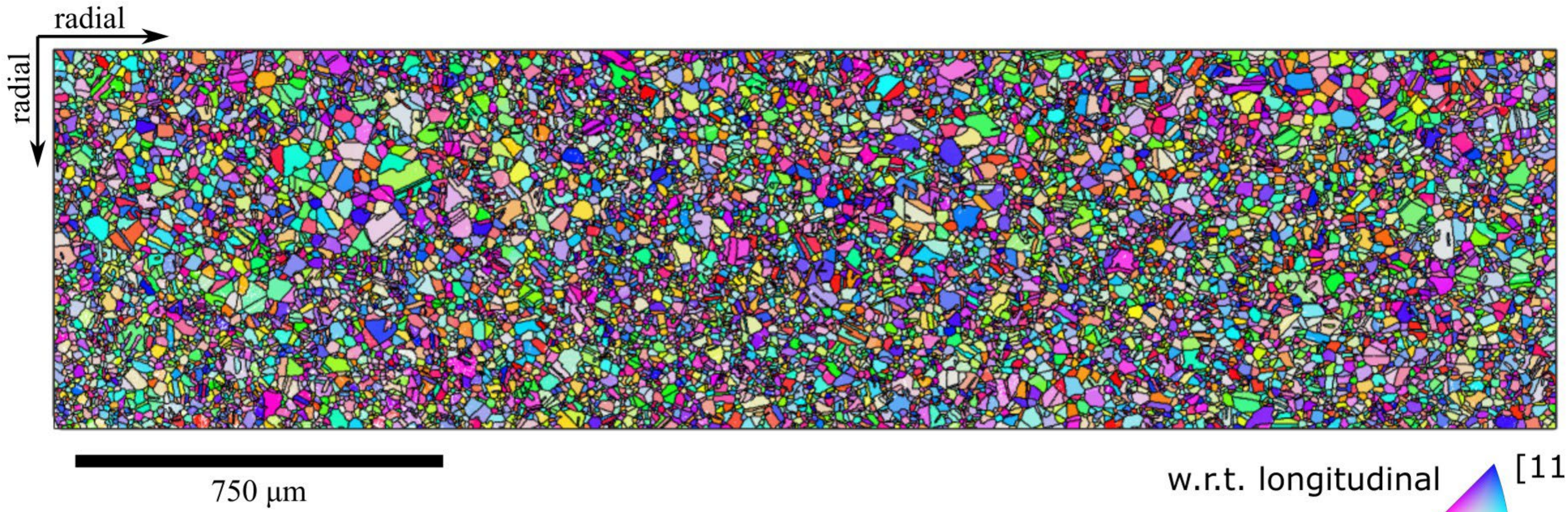
Mechanical and microstructural properties

	Tensile Strength MPa	Yield Strength MPa	Elongation %	Hardness HRB	Grain size
Bar	671	370	50	89	7
Requirement	≥ 515	≥ 207	40	≤ 95	≤ 7

As-received microstructure



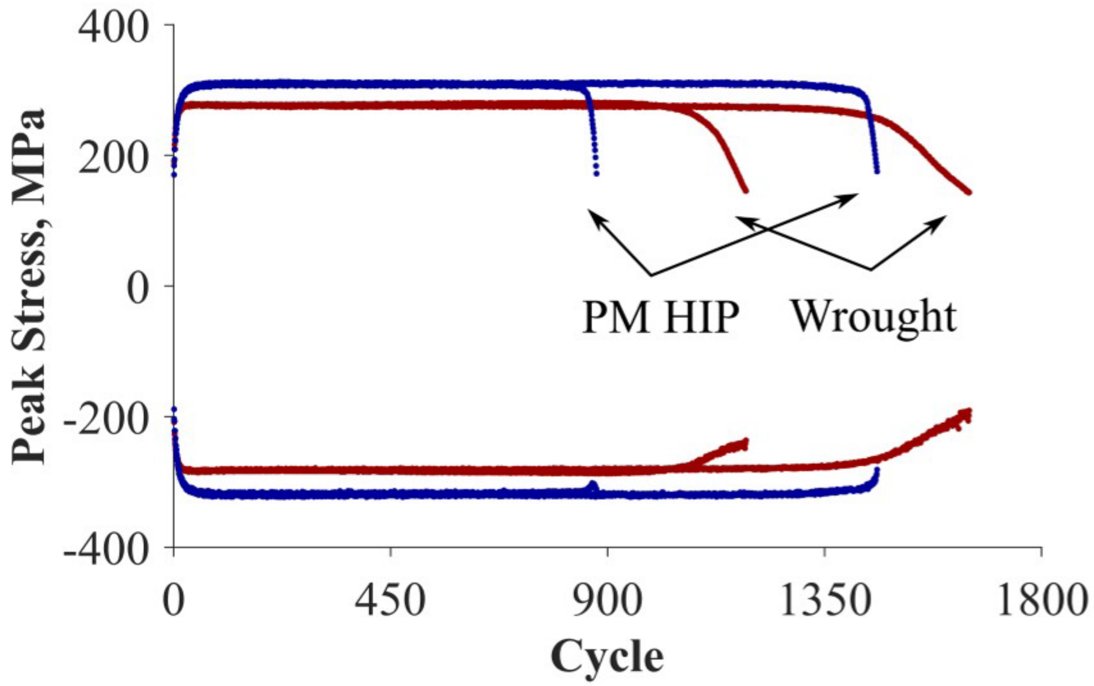
As-received microstructure



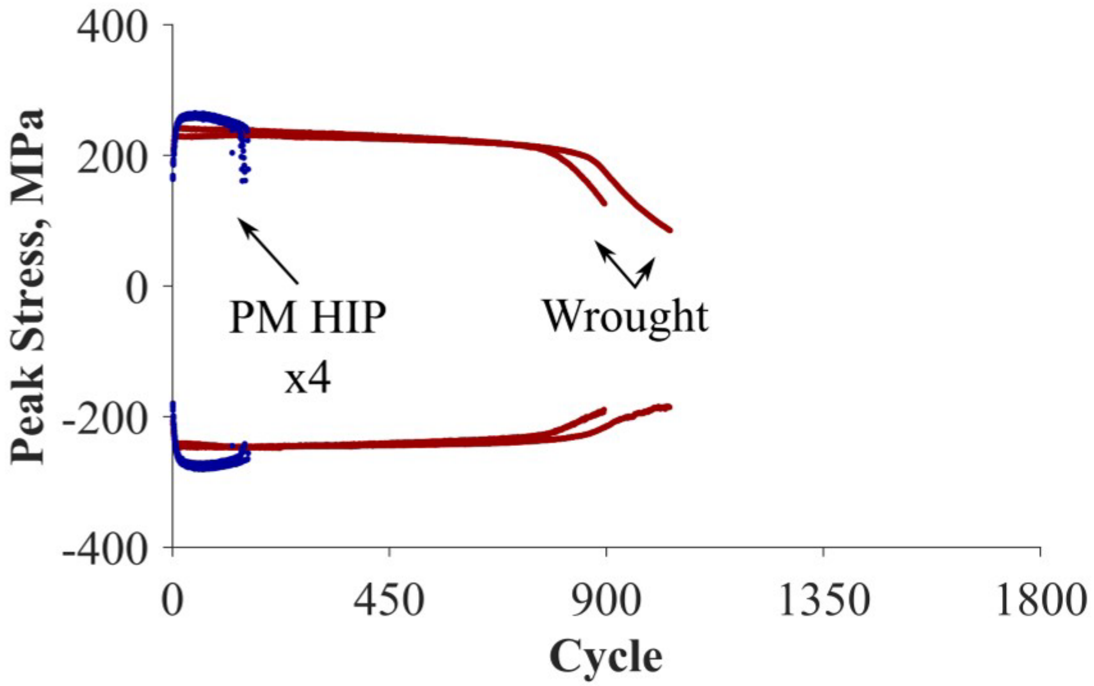
Elevated-temperature cyclic properties

Alloy 316H
T = 650°C
$\Delta\varepsilon = 1\%$
R = -1
$\dot{\varepsilon} = 0.001\ s^{-1}$

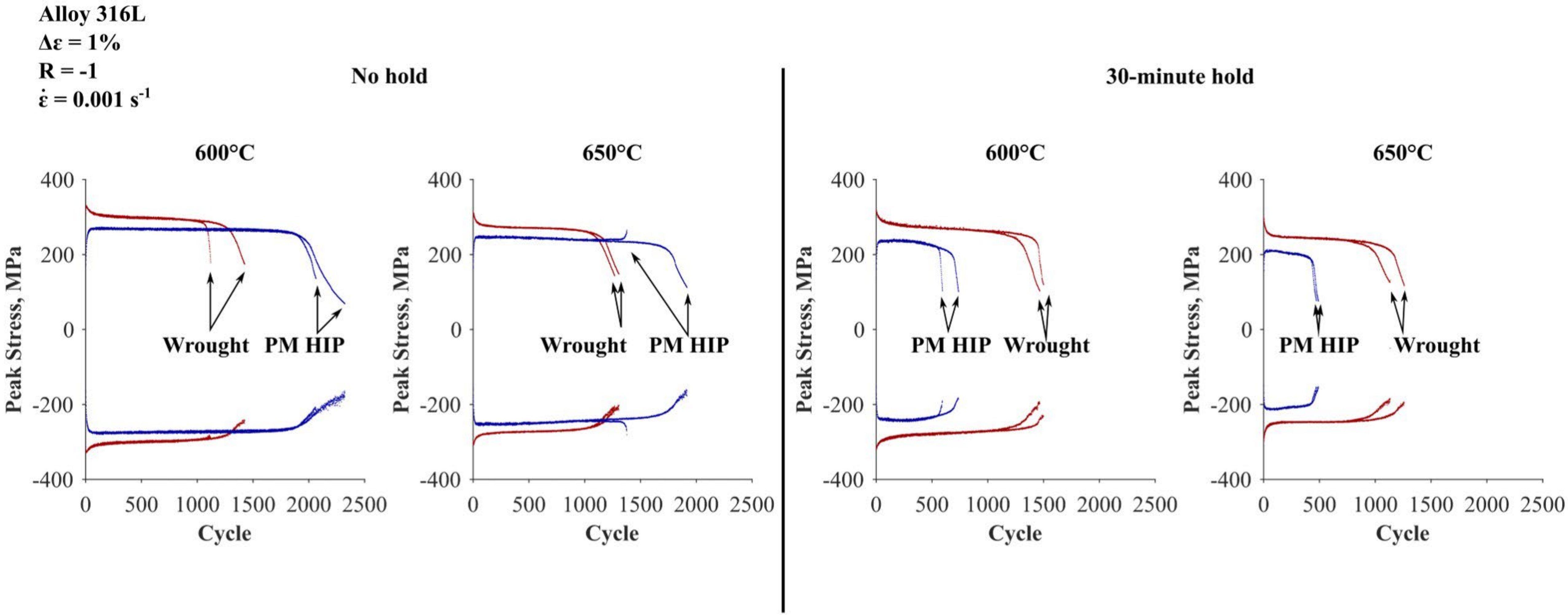
No hold



30-minute hold



Comparison with PM HIP 316L SS



Summary

- The PM HIP 316H SS bar exceeded the minimum room-temperature tensile property requirements.
- The elevated-temperature creep-fatigue properties of the PM HIP 316H SS bar are reduced compared to the wrought material.
- Room-temperature tensile data from witness specimens are not representative of, and do not predict, creep-fatigue properties.
- The mechanisms responsible for the observed behavior need to be identified.
- Current PM HIP practices are not able to fabricate elevated-temperature nuclear components that have similar or more superior creep-fatigue properties compared with components fabricated from traditional wrought product.

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Planned FY-22 R&D

Scope

1. Identify mechanisms responsible for the cyclic performance of PM HIP 316H SS material procured in FY-21 to resolve issues.
2. Confirmatory testing of optimized material to demonstrate long term PM-HIP properties comparable to wrought 316H SS.
3. Initiate procurement of PM-HIP Alloy 800H and conduct initial mechanical properties testing.

Plan

In order to identify mechanisms responsible for the cyclic performance, PM HIP 316H SS bars with the following characteristics will be characterized:

1. The oxygen concentration of the powder shall be lower than 130 ppm.
2. The processing parameters shall be optimized in addition to powder requirements specified in 1. above.

Summary

- PM HIP is a mature technology that offers many advantages that are attractive to the microreactor industry.
- The elevated-temperature creep-fatigue properties of the PM HIP 316H SS bar that has been characterized are reduced compared to the wrought material.
- Work will be carried out in FY-22 to identify the mechanisms responsible for the reduced creep-fatigue properties.
- Confirmatory testing of optimized material will be conducted to demonstrate long-term PM HIP properties comparable to wrought-product form.
- The lessons learned for PM HIP 316H SS will be applied to the procurement and confirmatory testing of PM HIP Alloy 800H.

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