MATERIALS QUALIFICATION THROUGH NSUF: CASE STUDY ON PM-HIP ALLOYS

Janelle P. Wharry[1], Caleb D. Clement[1], Saquib Bin Habib[1], Wen Jiang[1], Yangyang Zhao[1], Sri Sowmya Panuganti[1], Yu Lu[2,3], Yaqiao Wu[2,3], Donna P. Guillen[4], David W. Gandy[5]

[1] *Purdue University*; [2] *Boise State University*; [3] *Center for Advanced Energy Studies*; [4] *Idaho National Laboratory;* [5] *Electric Power Research Institute*

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Project Team Members at Purdue

Caleb D. Clement
Ph.D. 2023
Now at Westinghouse

Saquib Bin Habib
Ph.D. expected 2026

Sri Sowmya Panuganti
M.S. 2022

Yangyang Zhao
Post-Doc 2019-2021

Wen Jiang
Post-Doc 2023
Now at Xi`an Jiao Tong

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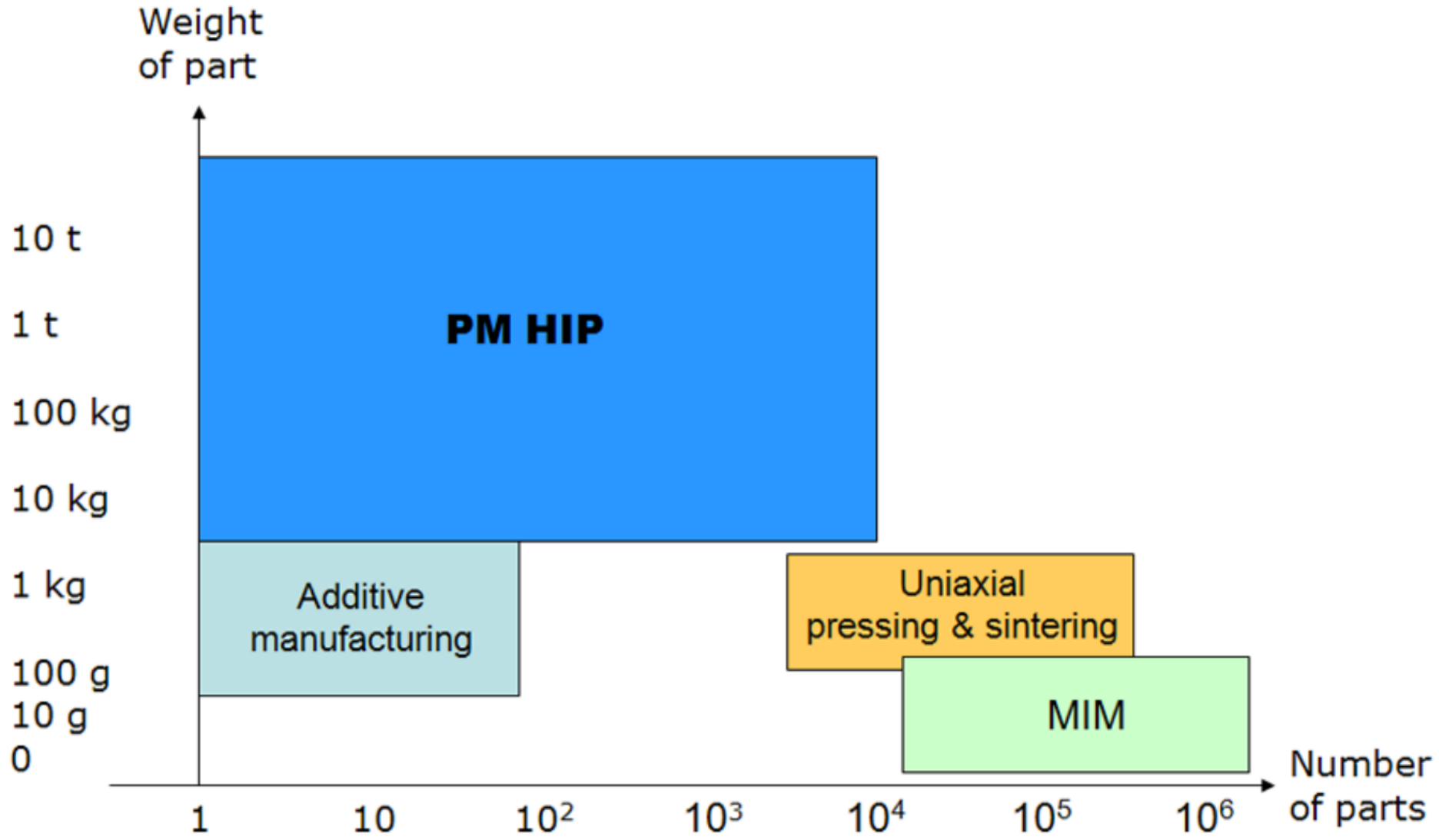
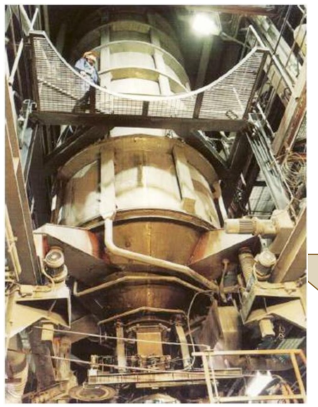
Objective

Demonstrate the use of several NSUF partner facilities and capabilities for an irradiation and post-irradiation examination (PIE) campaign to generate qualification data for alloys fabricated by powder metallurgy with hot isostatic pressing (PM-HIP).

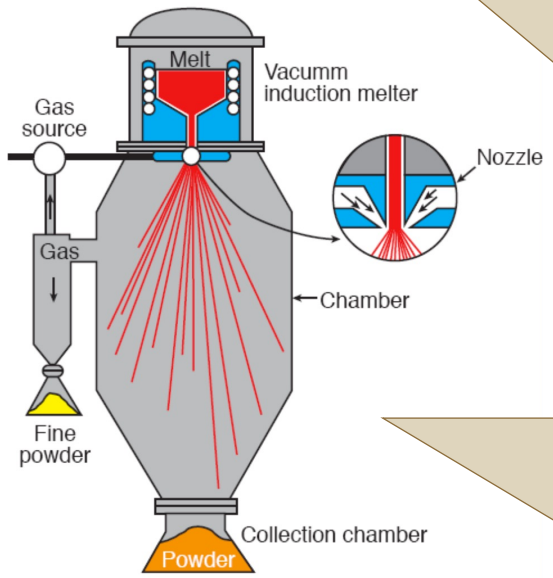
PM-HIP Positioning Compared to Other Fabrication Methods



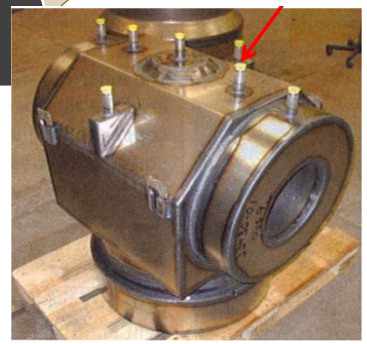
Overview of PM-HIP Process



- Powder atomization
- Sieve
- Blend



- FEM design can
- Form can
- Weld



- Fill can
- Bake out
- Seal
- HIP

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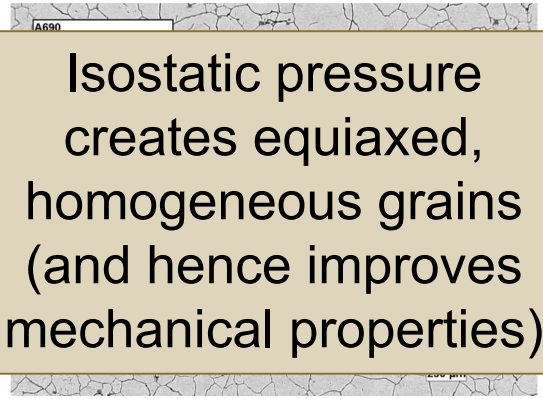
Benefits of PM-HIP

Easier to inspect, fewer quality issues

Poor quality castings

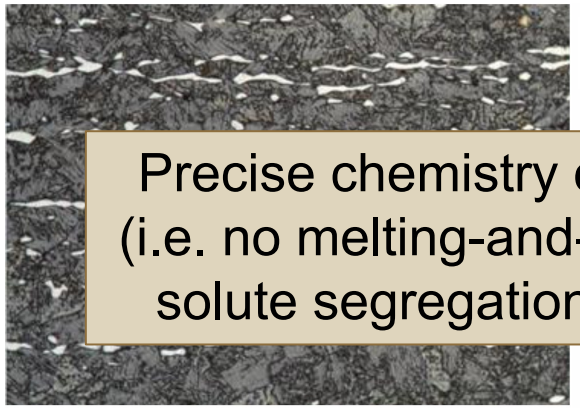
High powder compaction & densification

Voids/porosity in castings

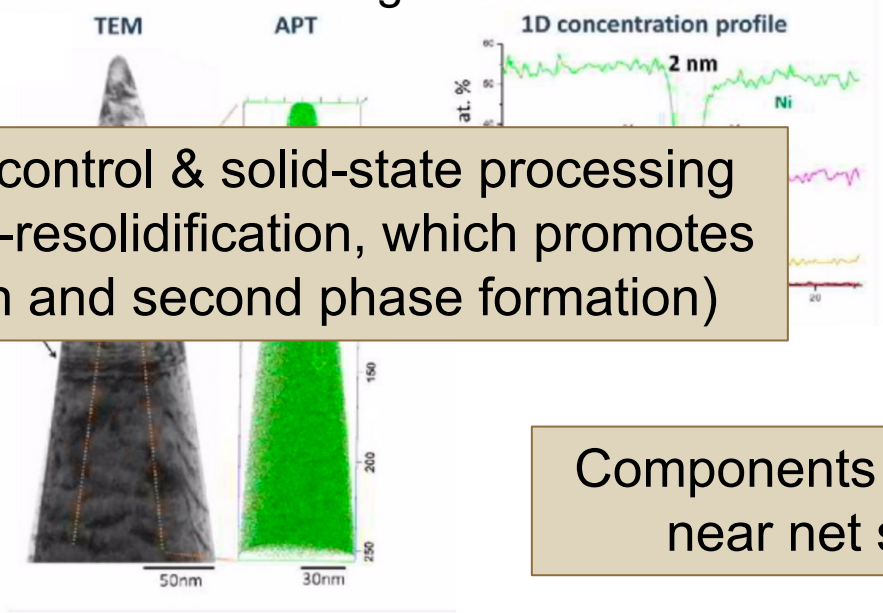


Isostatic pressure creates equiaxed, homogeneous grains (and hence improves mechanical properties)

Grain texture (Alloy 690)



Ferrite stringers in forged stainless steel plate



Precise chemistry control & solid-state processing (i.e. no melting-and-resolidification, which promotes solute segregation and second phase formation)

Solute & impurity pickup; grain boundary segregation

Components produced near net shape

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BSU-8242 Experiment Matrix

Jiang, et al. under revision (also on arXiv)

Clement, et al. MSE A 857 (2022) 144058

Wharry, et al. Data in Brief 48 (2023) 109092

Wharry, et al. Frontiers (2023)

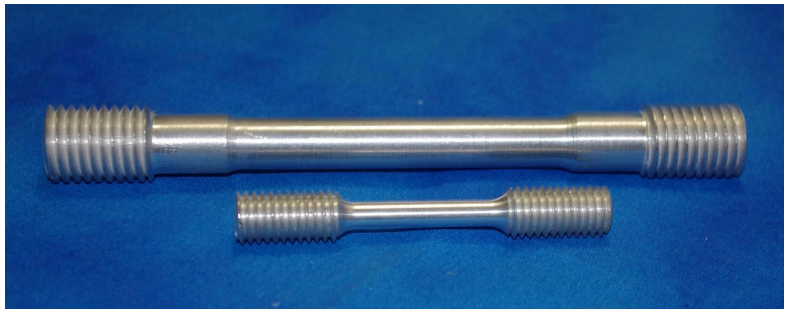
Saquib Bin Habib, March 4, 11:45 am, Regency Q

Alloy	Process	Target Dose [dpa]	Target Temp [ºC]	Micro-structure	Tensile
SA508	PM-HIP, Forged	1	300	✓	✓
		1	400	✓	✓
Grade 91	PM-HIP, Cast	1	400	✓	✓
		3	400	✓	✓
Alloy 625	PM-HIP, Forged	1	400	✓	✓
		3	400	✓	✓
Alloy 690	PM-HIP, Forged	1	400	✓	✓
		3	400	✓	✓
316L SS	PM-HIP, Wrought	1	400	–	–
		3	400	–	✓

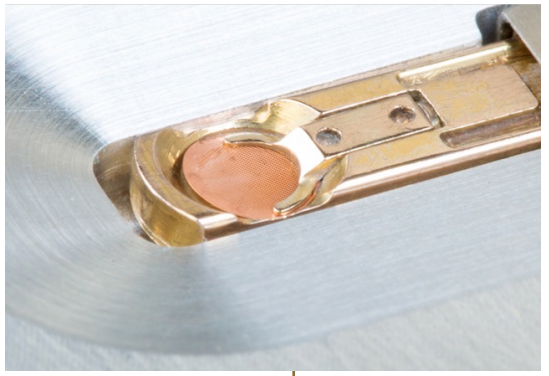
BSU-15-8242 Irradiation Campaign in ATR

NSUF Capability
Neutron Irradiation

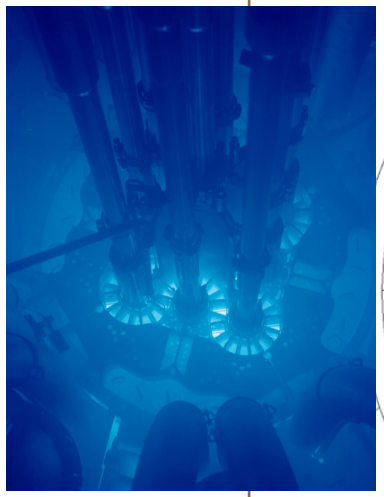
NSUF Facility
Advanced Test Reactor, Idaho National Laboratory

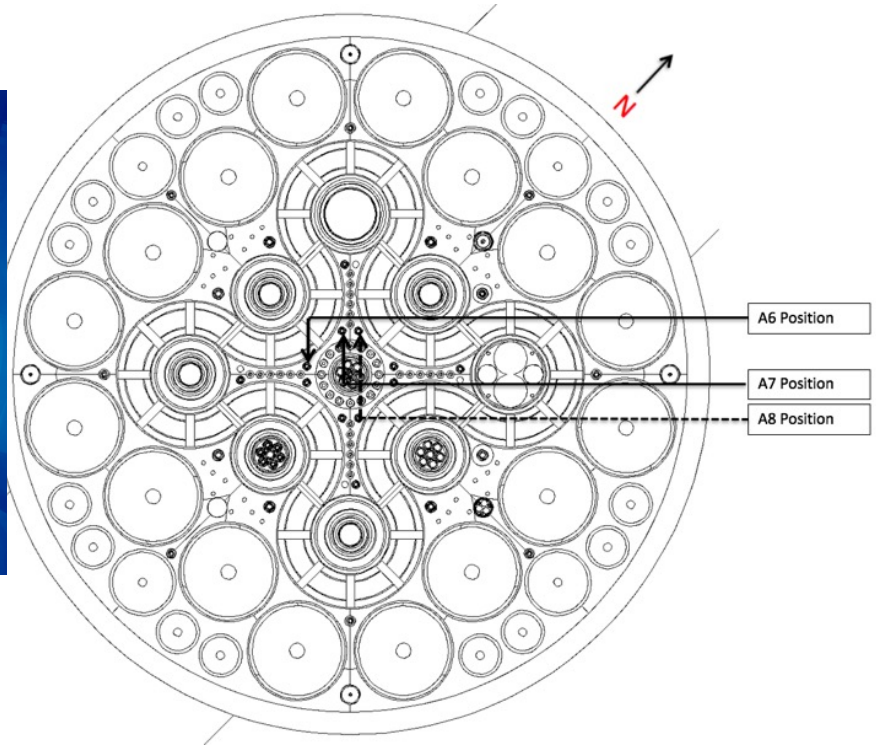


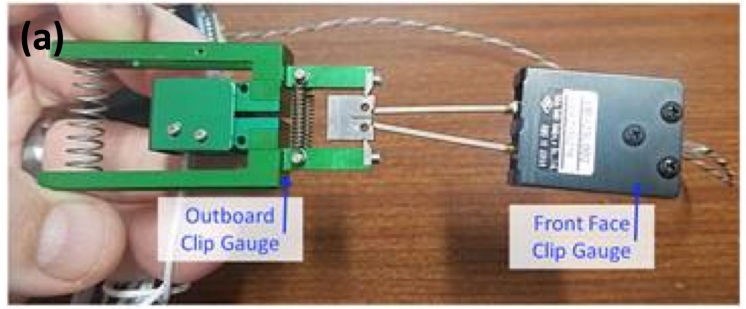
ASTM standard tensile bars: yield strength, modulus, % elongation

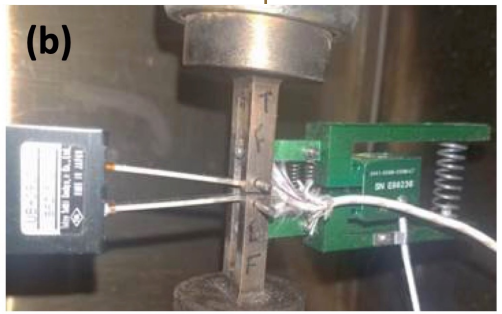


TEM discs: microstructure, nanoindentation







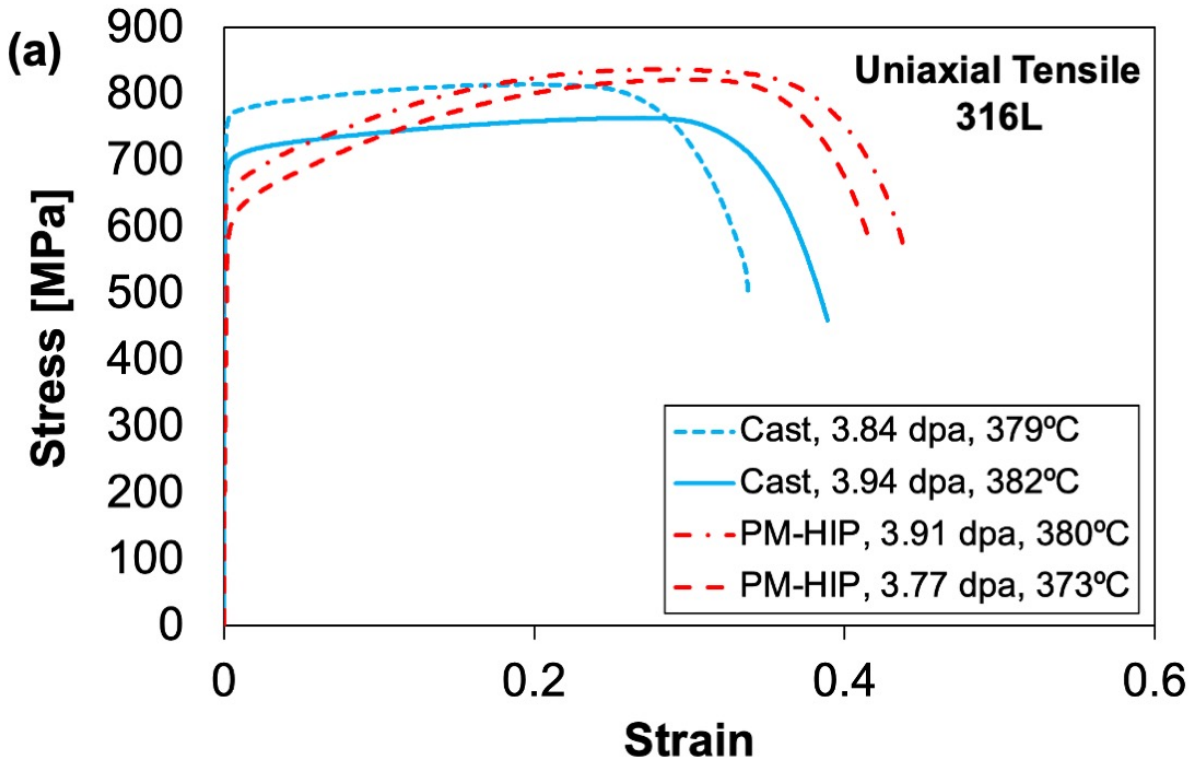


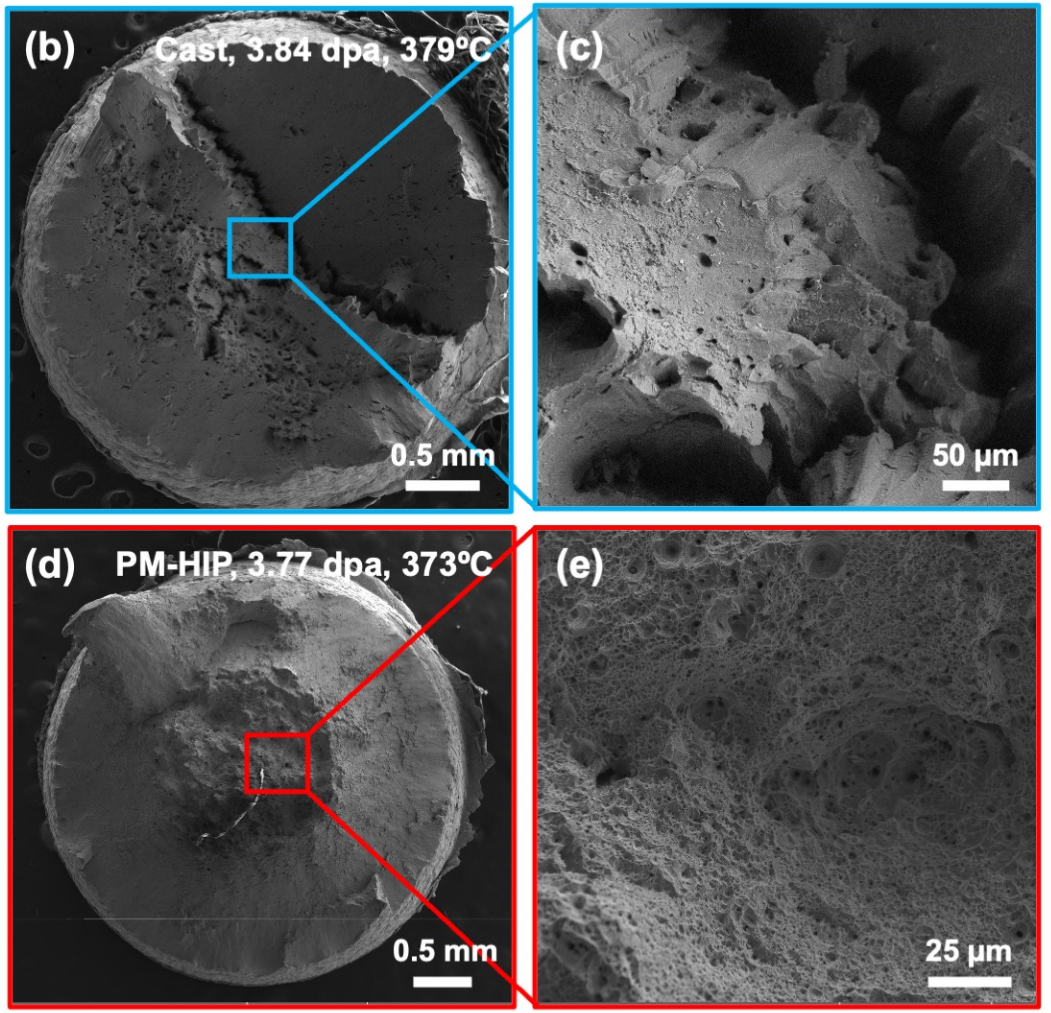
Miniature CTs: fracture toughness

Tensile Testing & Fractography – 316L Stainless Steel

NSUF Capability
13M Instron Load Frame

NSUF Facility
Hot Fuel Examination Facility,
Idaho National Laboratory



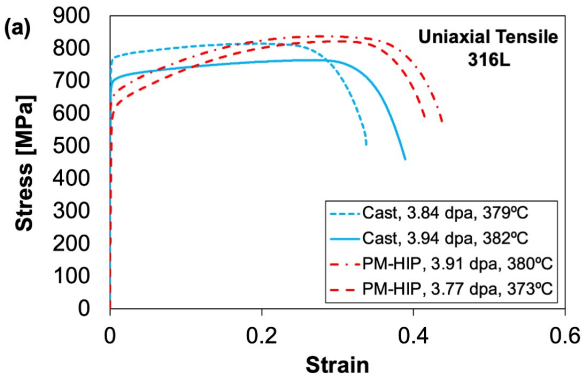


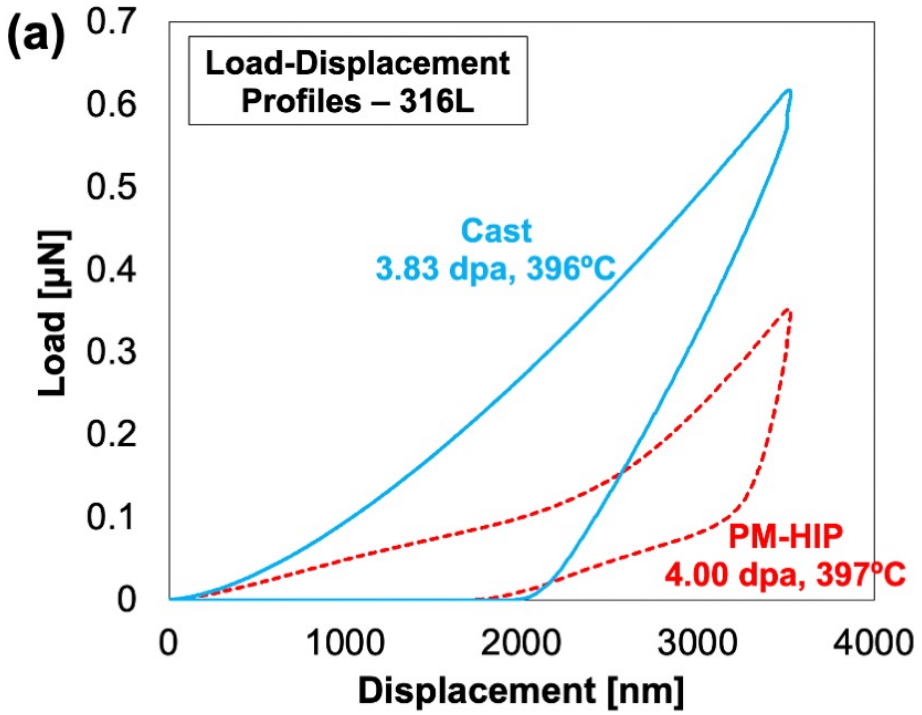
Nanoindentation – 316L Stainless Steel

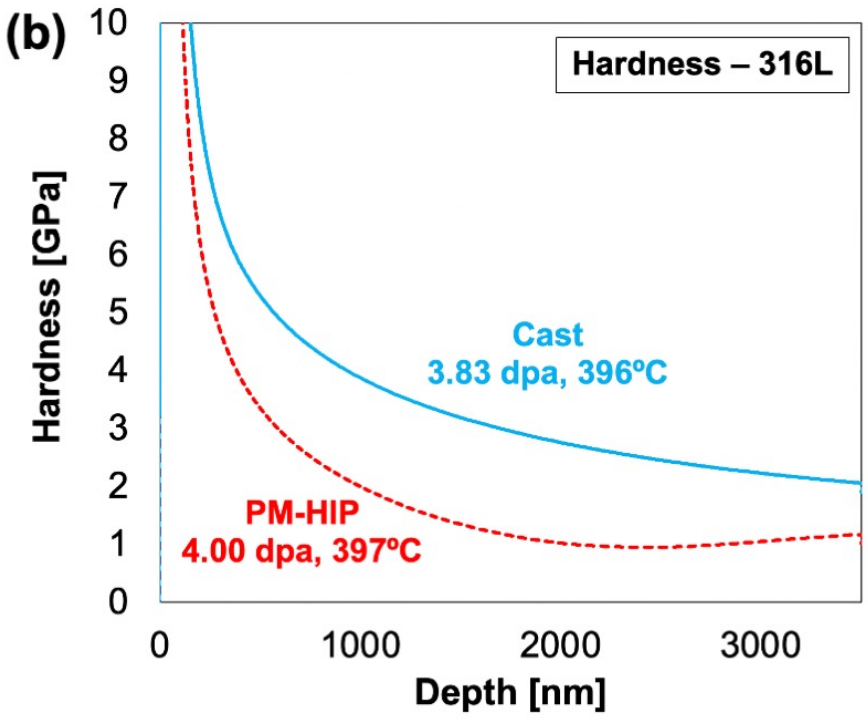
NSUF Capability
Hysitron TI-950 TriboIndenter

NSUF Facility
Microscopy and Characterizaton Suite (MaCS), Center for Advanced Energy Studies (CAES)

Recall stress-strain curves:



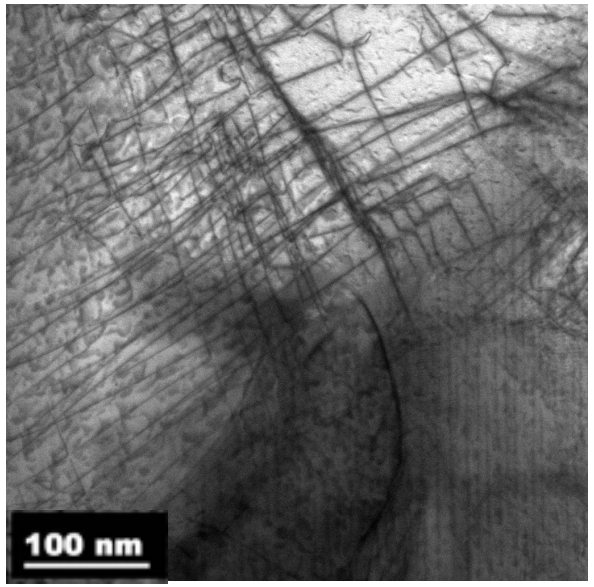
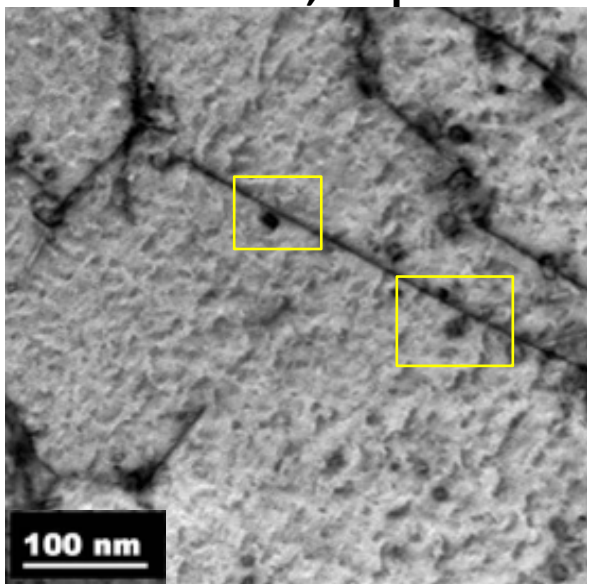
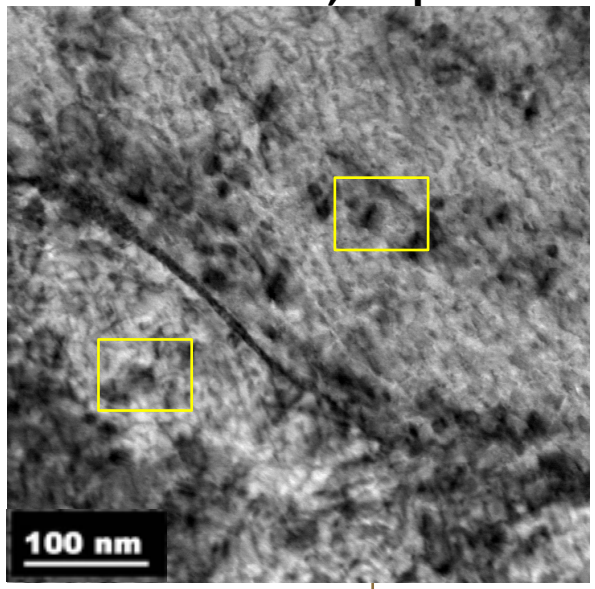
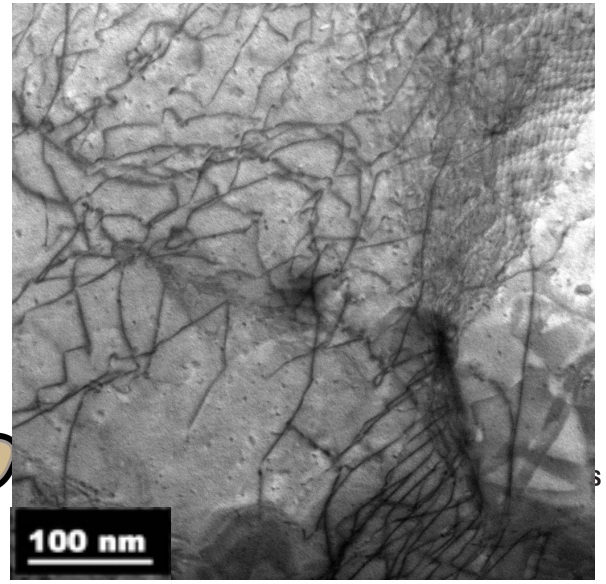
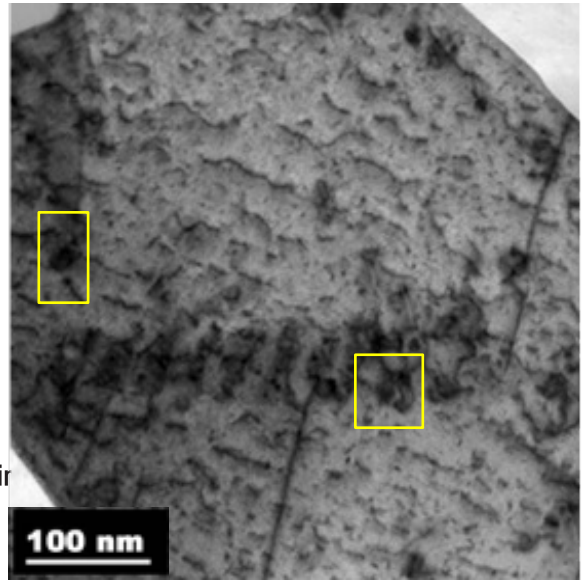
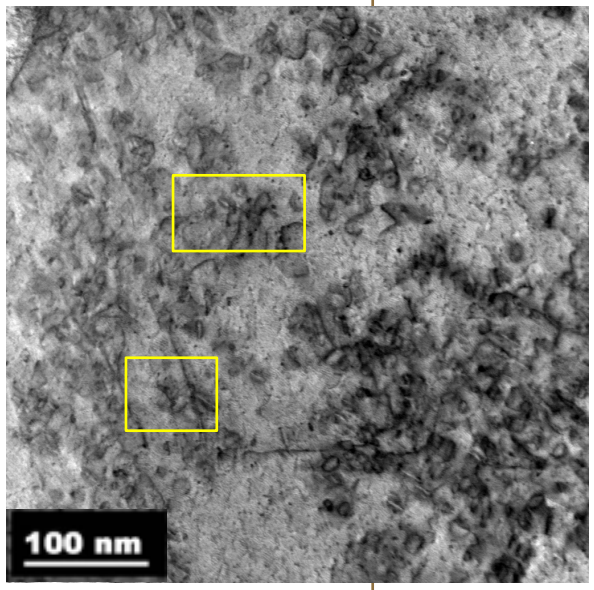




Transmission Electron Microscopy – Grade 91 Ferritic Steel

NSUF Capability
FEI Tecnai TF-30 FEG STwin TEM

NSUF Facility
MaCS, CAES

	Unirradiated	400°C , 1 dpa	400 °C, 3 dpa
Cast			
PM-HIP			

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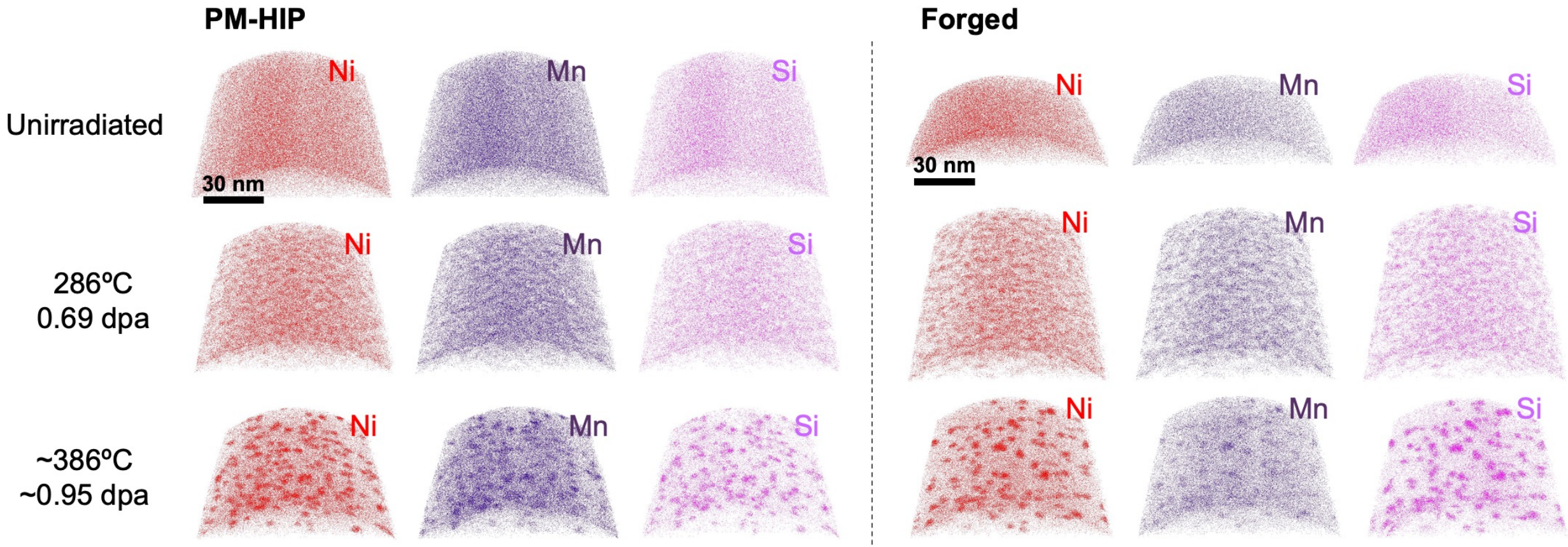
Atom Probe Tomography – SA508 RPV Steel

NSUF Capability
CAMECA LEAP 4000X HR

NSUF Facility
MaCS, CAES



Conclusions

- NSUF has enabled us to generated high-fidelity irradiation performance data on common PM-HIP nuclear structural alloys – microstructure evolution, microchemical evolution, mechanical property evolution.
- Results generated can be used within ASTM and ASME to support code qualification and specifications development for PM-HIP products in the nuclear power industry.