Ultrasonic Additive Manufacturing & other AM Processes for Nuclear Component Manufacture

Sudarsanam Suresh Babu &
Collaborators from Fabrisonic, EPRI, ORNL, OSU and UTK

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U.S. DEPARTMENT OF ENERGY | Advanced Manufacturing

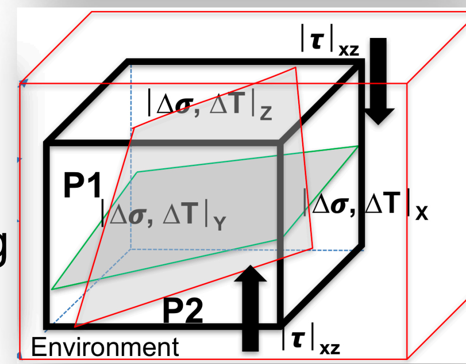
OAK RIDGE National Laboratory

Outline: 17+3 mins Q/A

- Motivation
- Ultrasonic Additive Manufacturing (UAM)
  – Case Study 1: HFIR Control Plates
- Direct Energy Deposition Process
  – Case Study 2: Dissimilar Material Joints
- Future Directions
- Summary

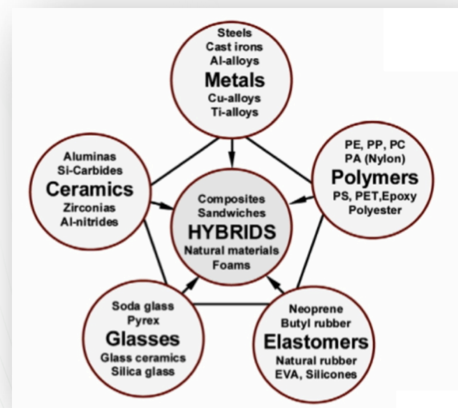
AM Process Flow

Fundamental Understanding Science & Technology



Babu (2017)

New Energy Applications

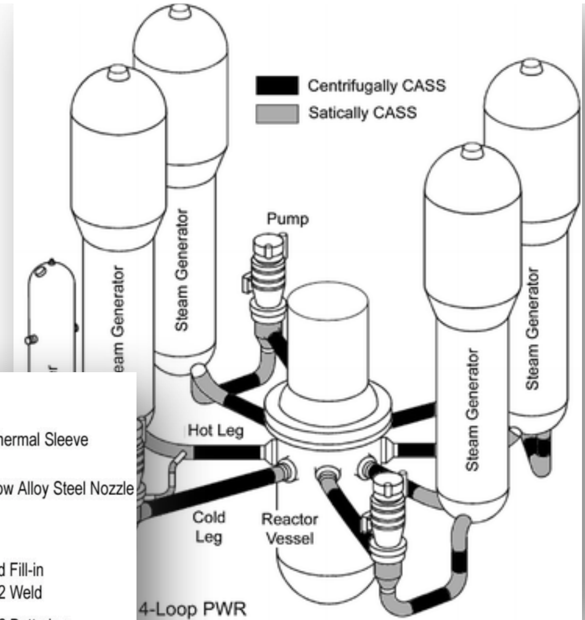


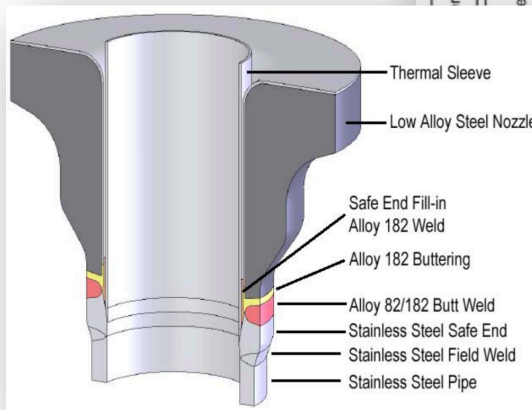
Ashby (2005)

Motivation

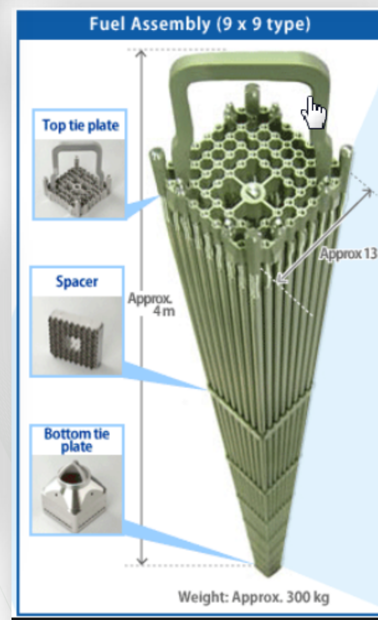
- Additive manufacturing has emerged as potential route for manufacturing nuclear power components with dissimilar materials.
- Other applications
  - Control rods
  - Spray nozzles
  - Cooling channels
  - Instrumentation
- What do we need?
  - Process optimization
  - In-situ and Ex-situ Qualification with and without radiation

Reactor Pressure Vessels – Dissimilar Material Joints



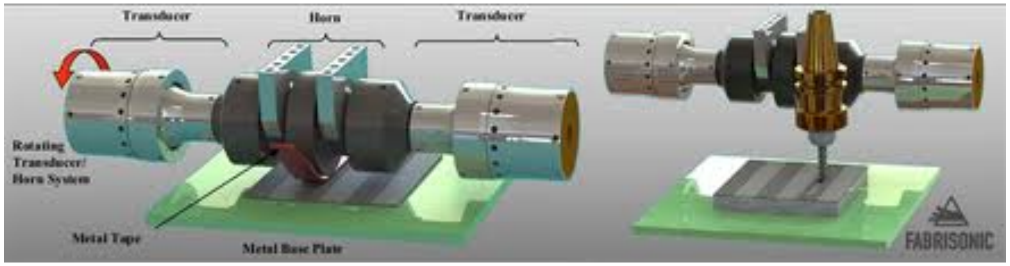


Courtesy: EPRI

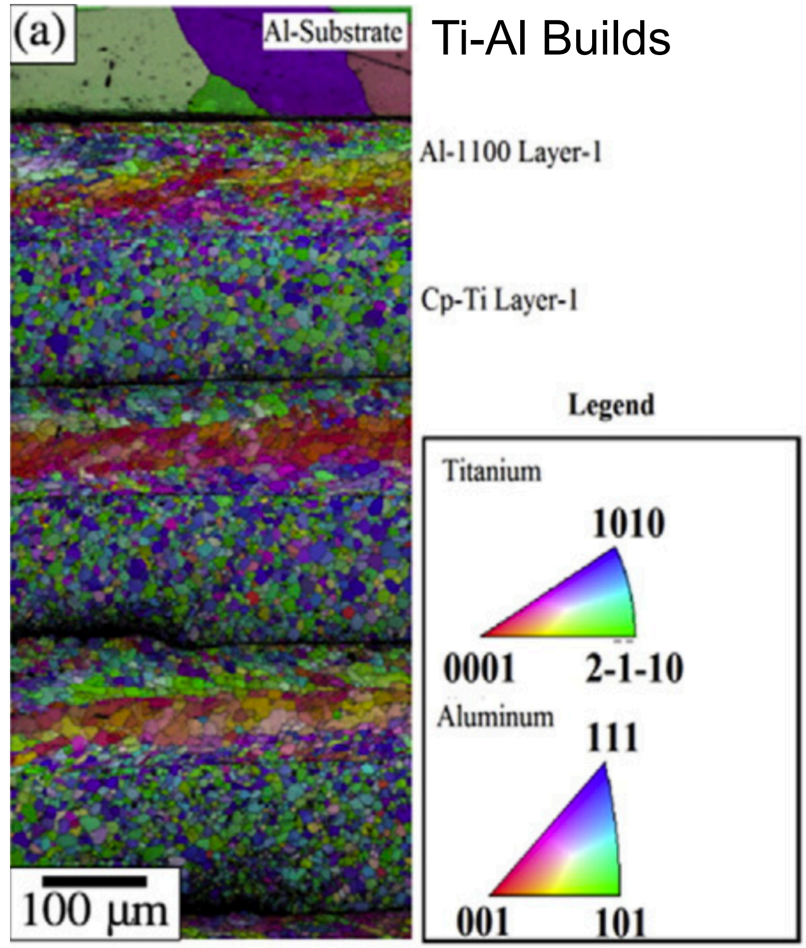


Complex Geometry Fuel Assembly Structures

Ultrasonic additive manufacturing is based on solid-state welding.



Ti-Al Builds



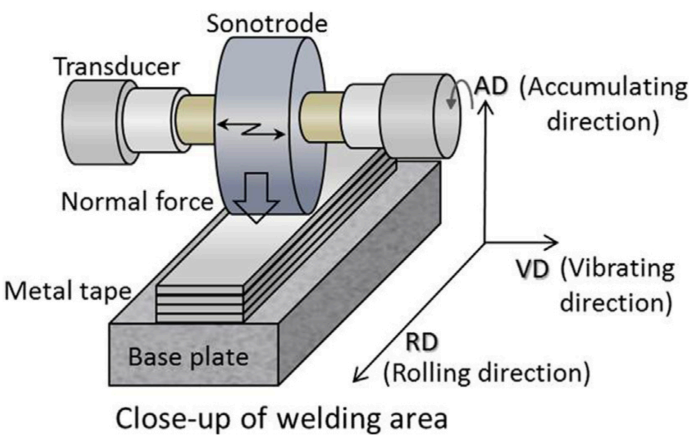
- How can we do In-situ process qualification?

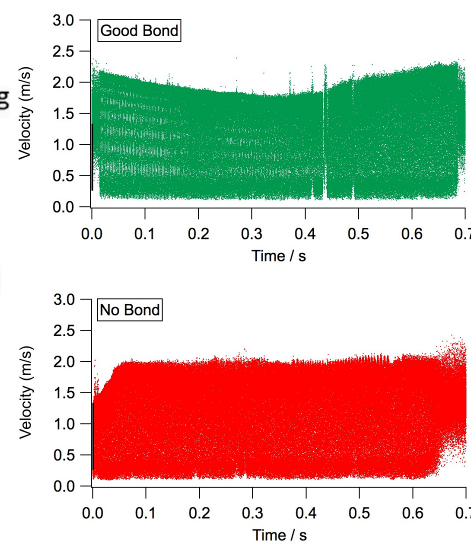
Sridharan et al (2016)

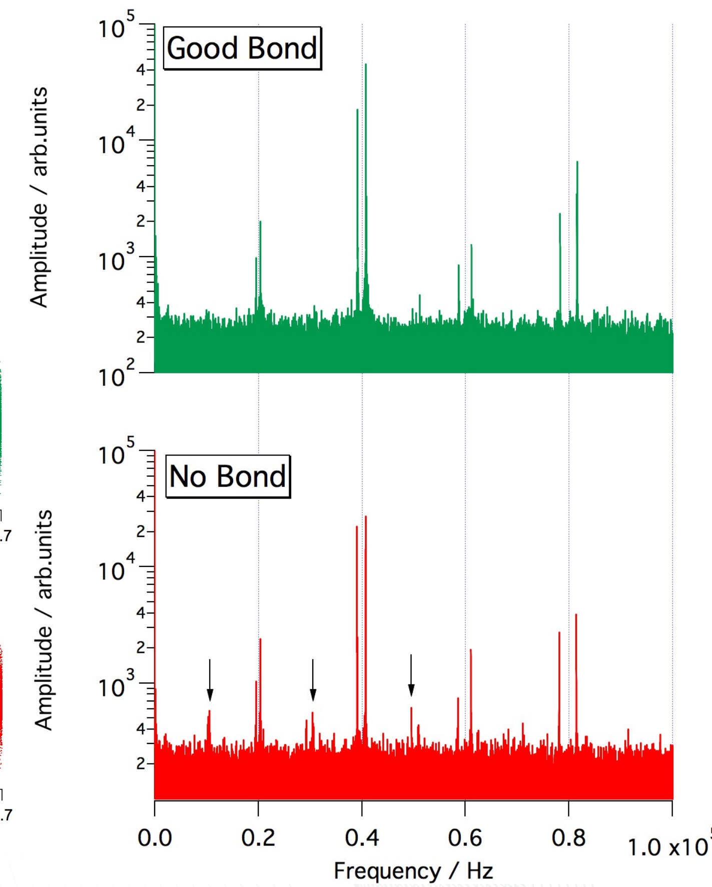
High-frequency (20 kHz) displacement data processes can be used for in-situ process qualification.

In situ velocity measurements of very high power ultrasonic additive manufacturing using a photonic Doppler velocimeter

D. R. Foster*[1], G. A. Taber[1], S. S. Babu[2] and G. S. Daehn[1]







Shimuzu et al (2014)

- Let us consider an application case study:

Ultrasonic additive manufacturing was successfully used to for prototype with embedded neutron absorbers.

Hehr et al (2017)

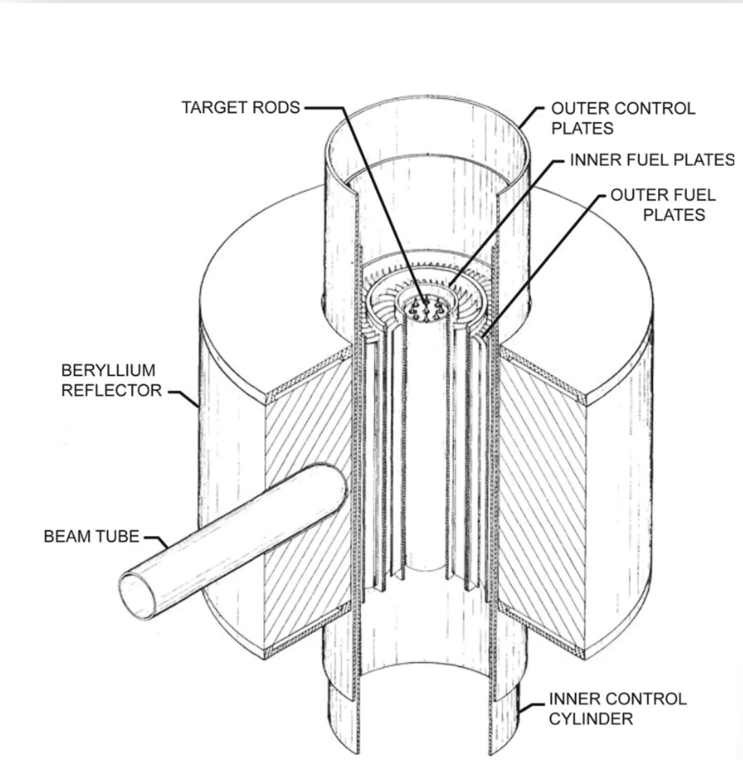
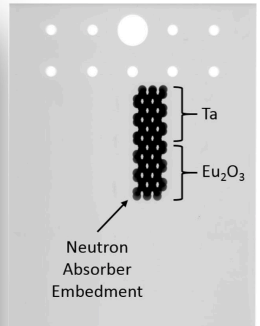
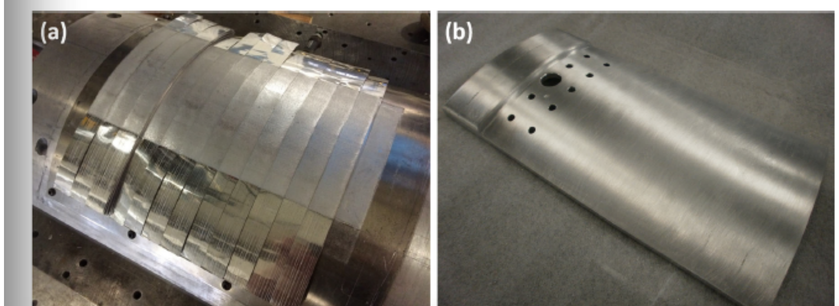


Fig. 1. Simple schematic of HFIR core.



Placement was designed based on neutron-material interaction calculations



UAM Process

- Current work: Ex-situ Qualification after irradiation

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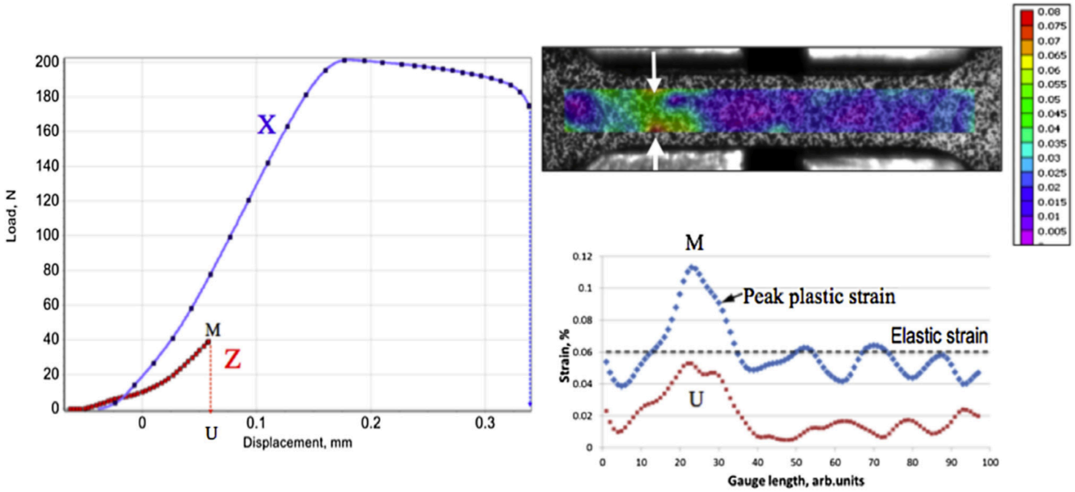
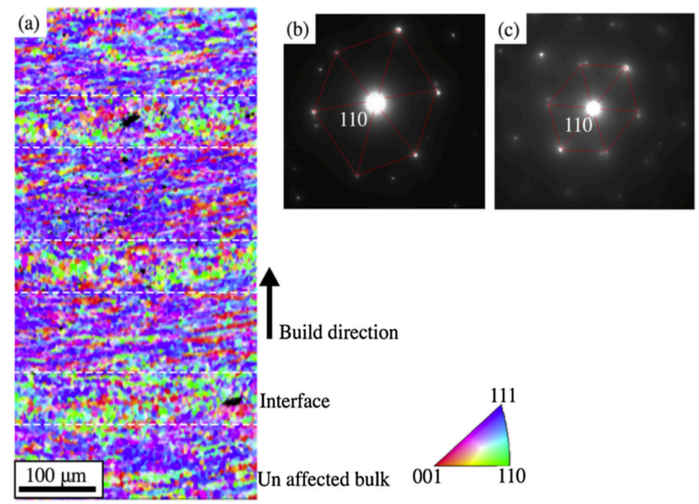
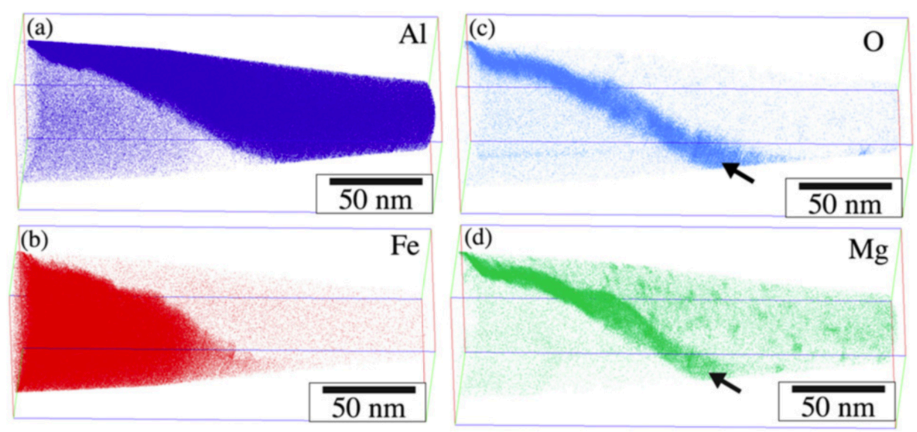
Anisotropic properties in Al-Al and Al-Fe builds are correlated to interface microstructures.



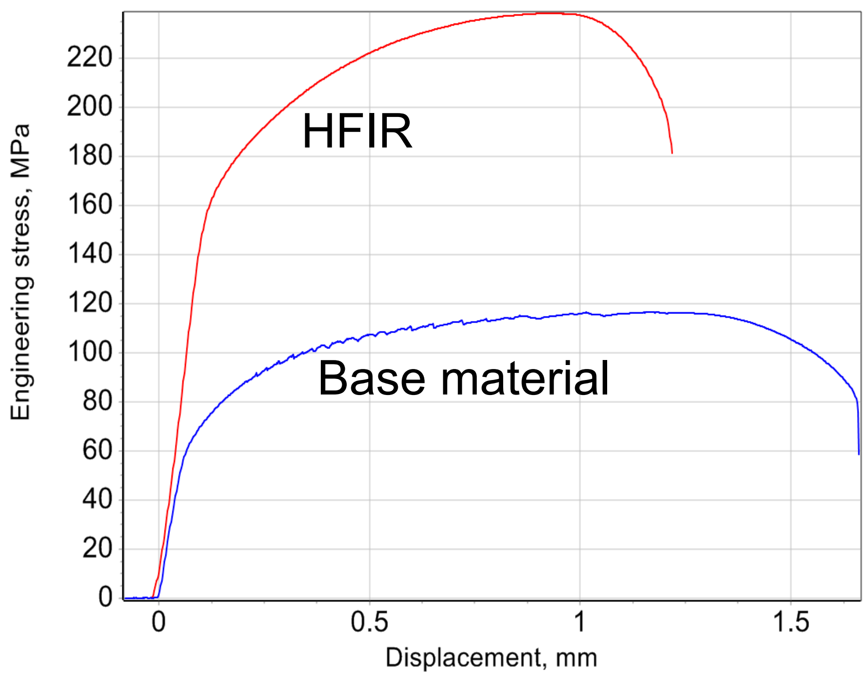


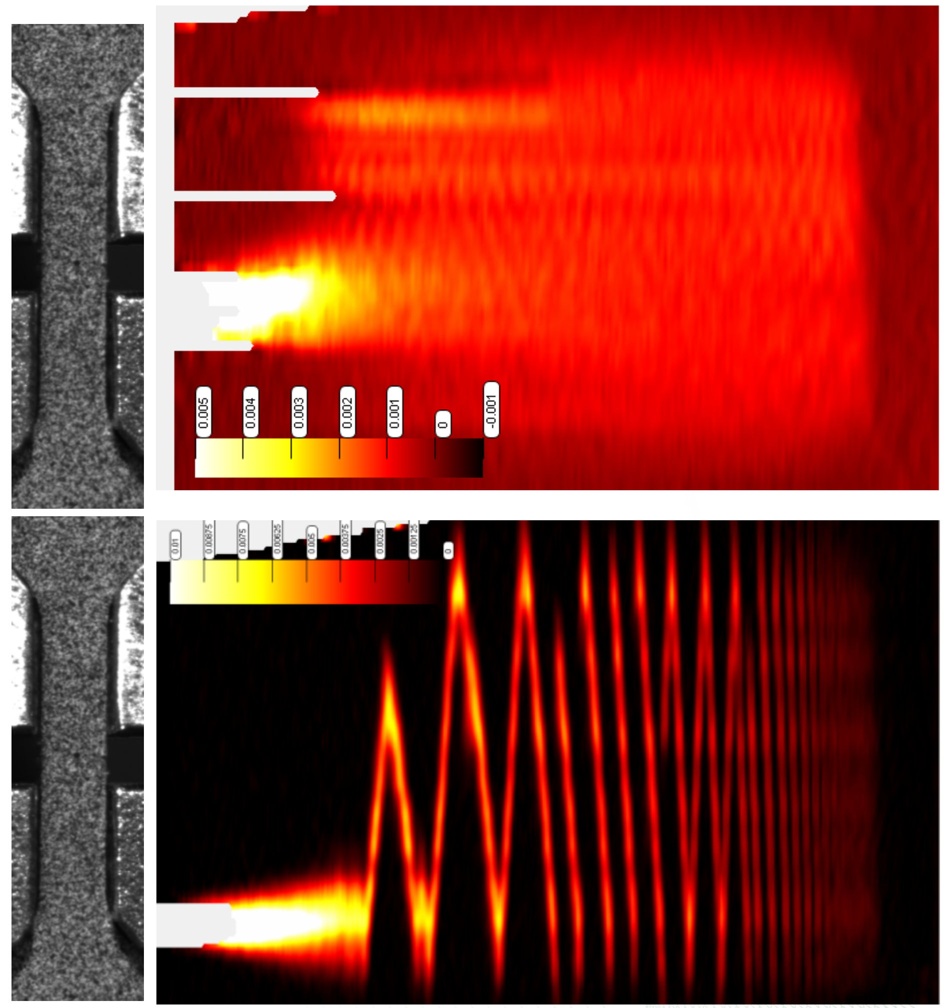
Sridharan et al (2017)



- ORNL's multi-scale ex-situ characterization tools were used to attain these process-structure-property correlations.
- How about after neutron radiation exposure?

Preliminary results: After irradiation campaign (0.913 dpa), base material UAM joints were tested.



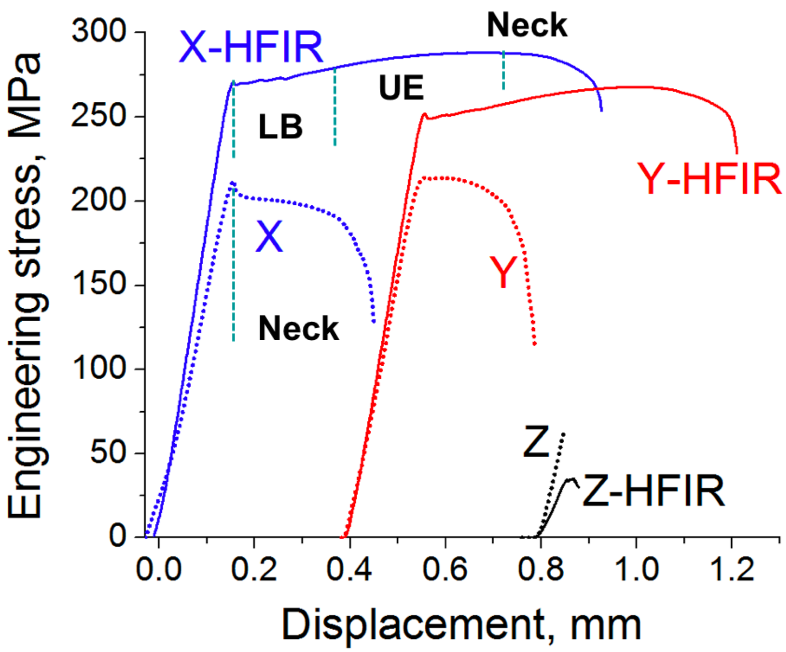


Time, strain->

- Base material shows neutron hardening.
- How about the UAM builds?

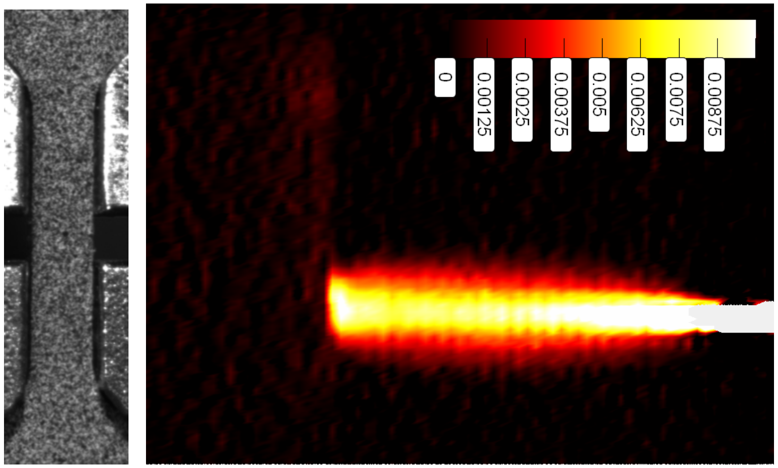
Anisotropic properties still persist, however, neutron irradiation effects can be observed.

Load-displacement Curves

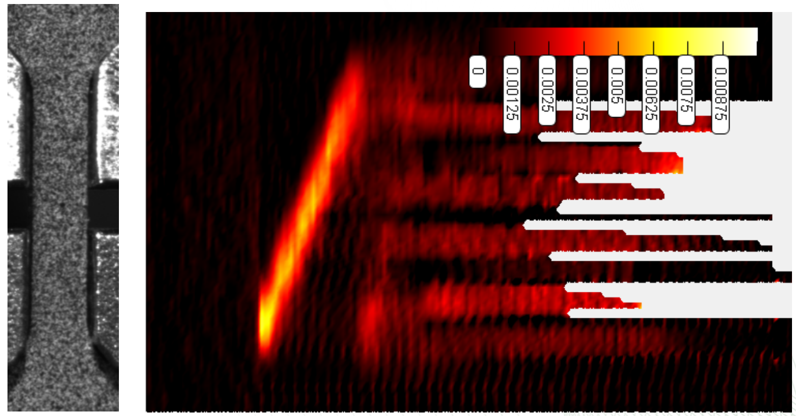


- What is the role of post-process heat treatment (180°C/8h)?

Non-irradiated (x-direction)

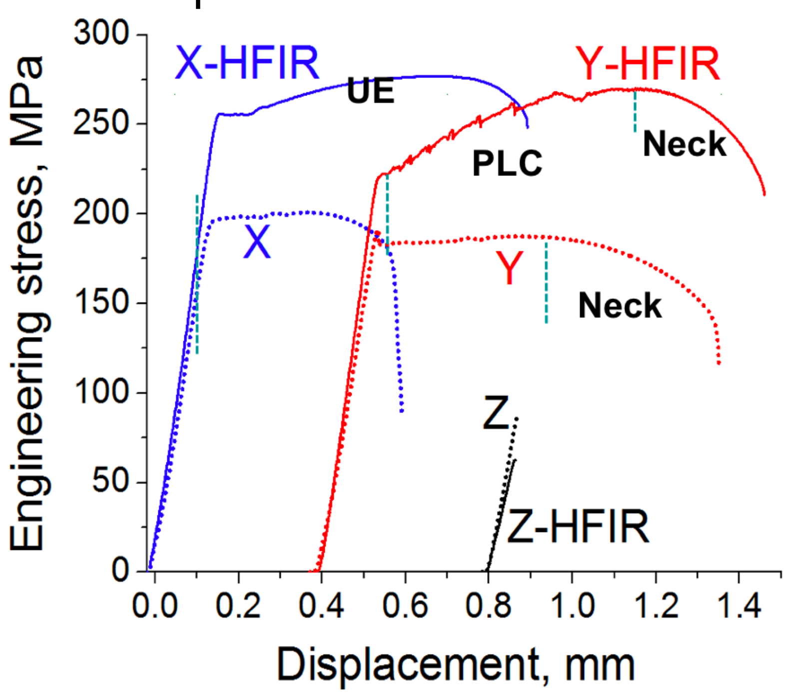


Irradiated (x-direction)



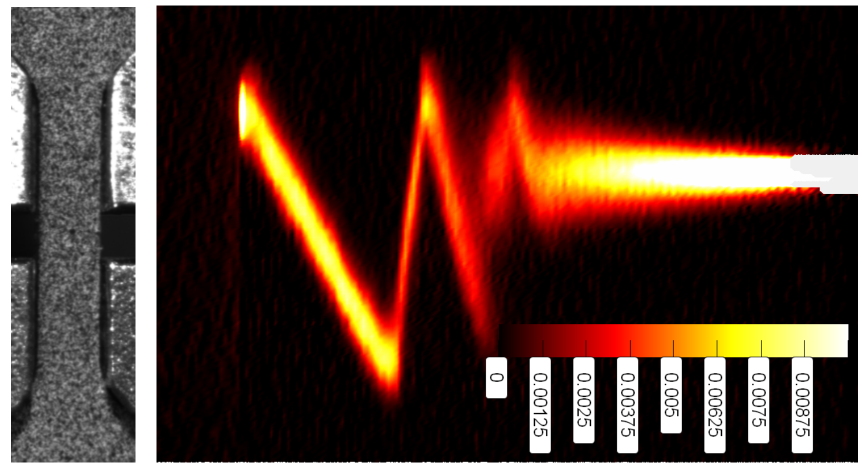
Complex strain transients (Luders band) were observed during tensile testing of aged samples.

Load-displacement Curves

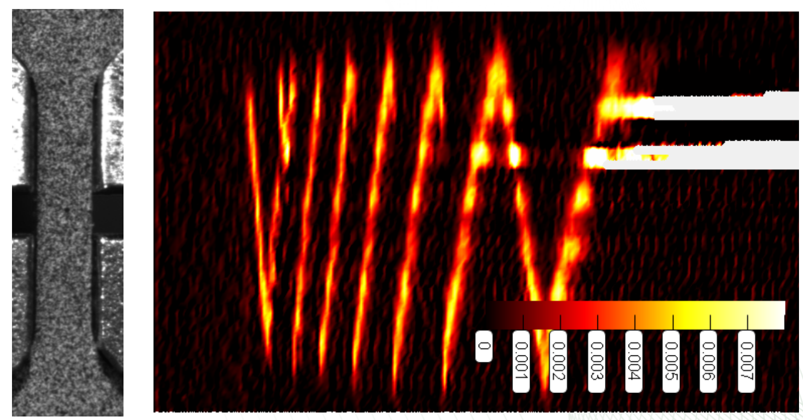


- Interpretation: Crystallographic texture may play a role.
- Data will be used for qualifications of the hybrid parts.

Non-irradiated (y-direction)



Irradiated (y-direction)



Laser Direct Energy Deposition (DED) process is widely used in gas turbine industries for repair.

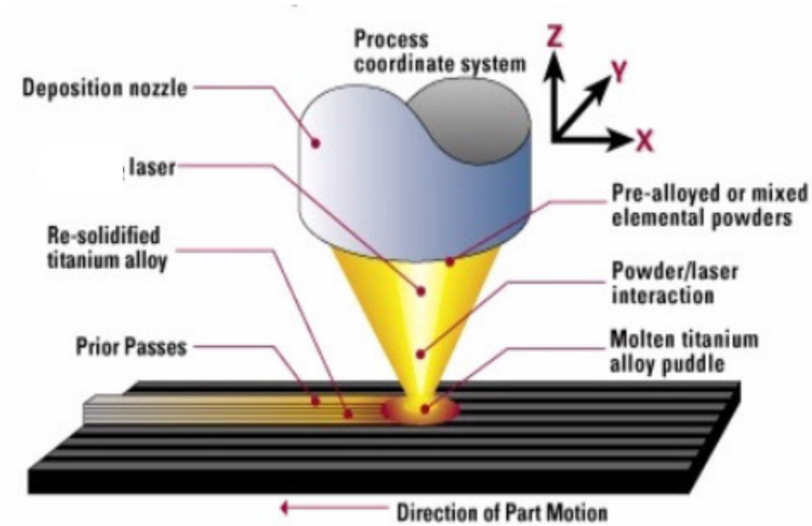
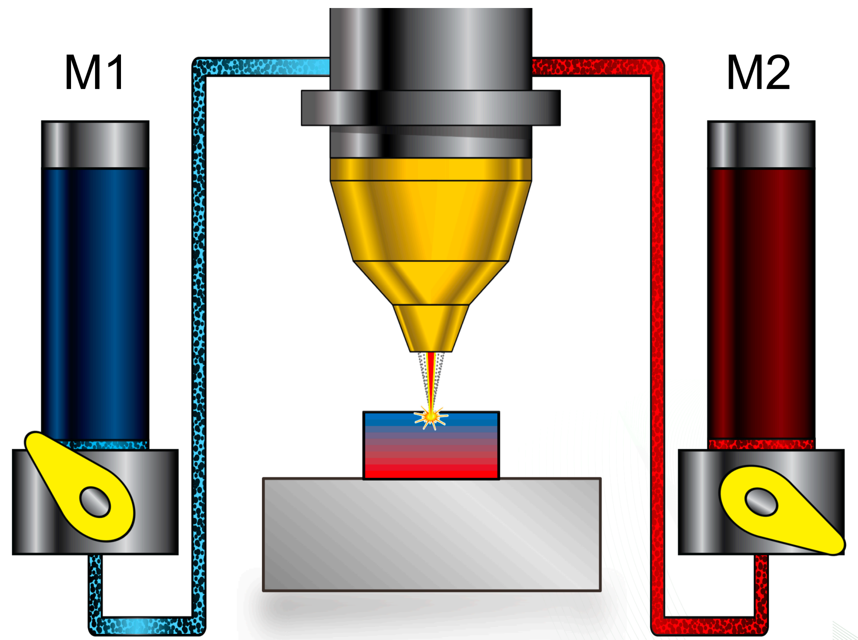


Image courtesy of Kelly, S. (2004). Thermal and Microstructure Modeling of Metal Deposition Processes with Application to Ti-6Al-4V.



Courtesy: Sridharan and Jordon (ORNL)

- Process has ability to transition from one alloy to another easily (up to four). Can we extend this process for designing and fabrication of dissimilar metal transition joints within reactor pressure vessels?

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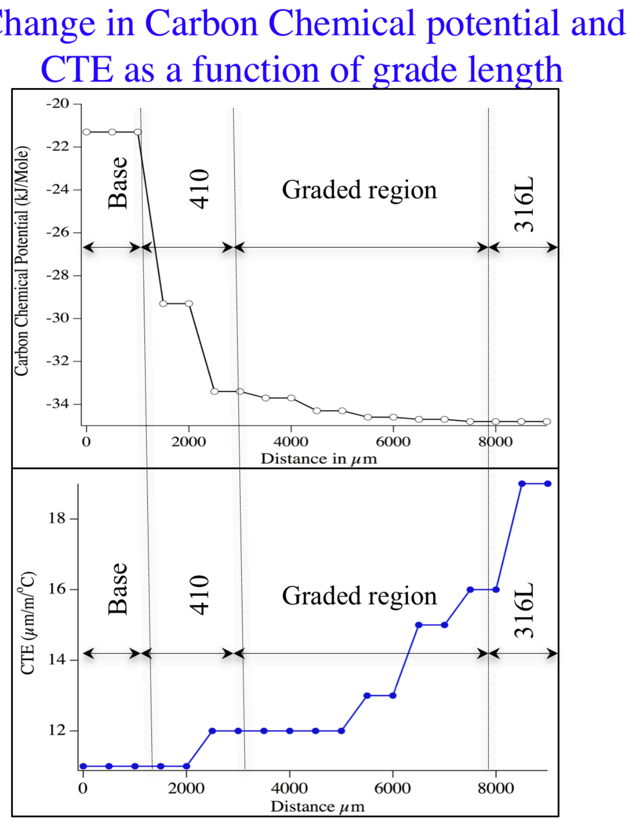
Using computational thermodynamic and kinetic ICME tools, Cr-Mo to 316L transition joint was designed.



Sirdharan et al (2017)

- Transition joint was fabricated using the following parameters
  - Travel speed: 600mm/min
  - Step over 0.5mm
  - Power 400W
  - Powder feed rate: 5g/min
- Preheat maintained at 300°C using a hot plate

- Did we achieve the transition?

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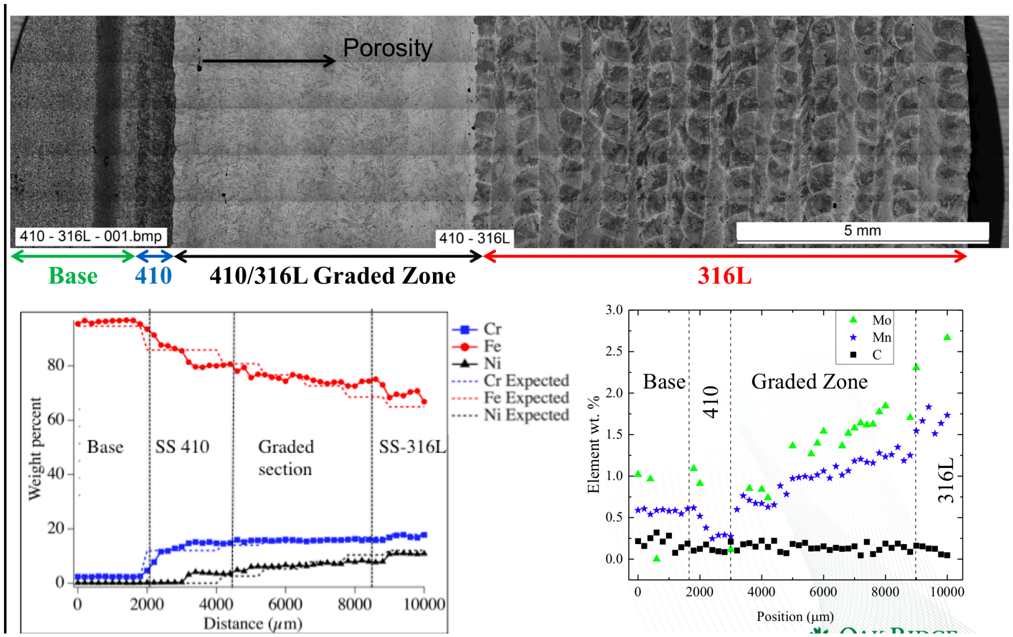
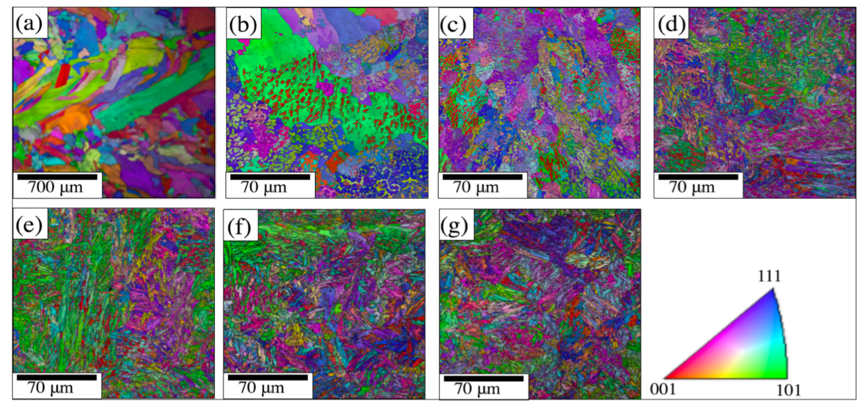
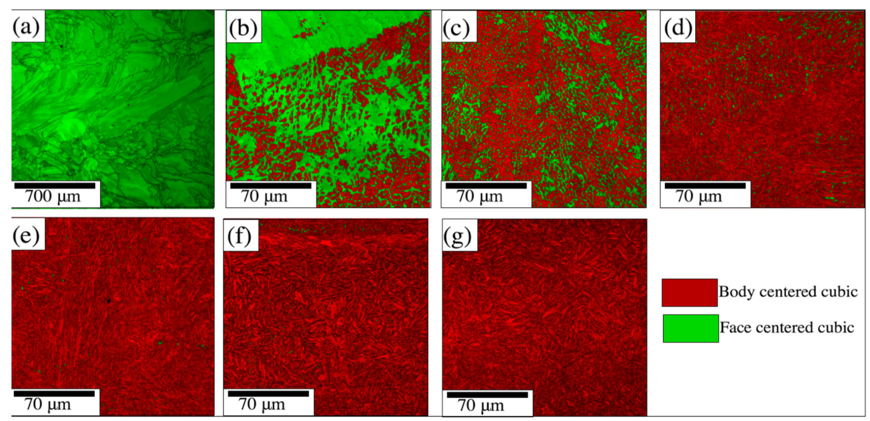
DED process allowed us to fabricate transition joints with controlled compositions and phase variations.

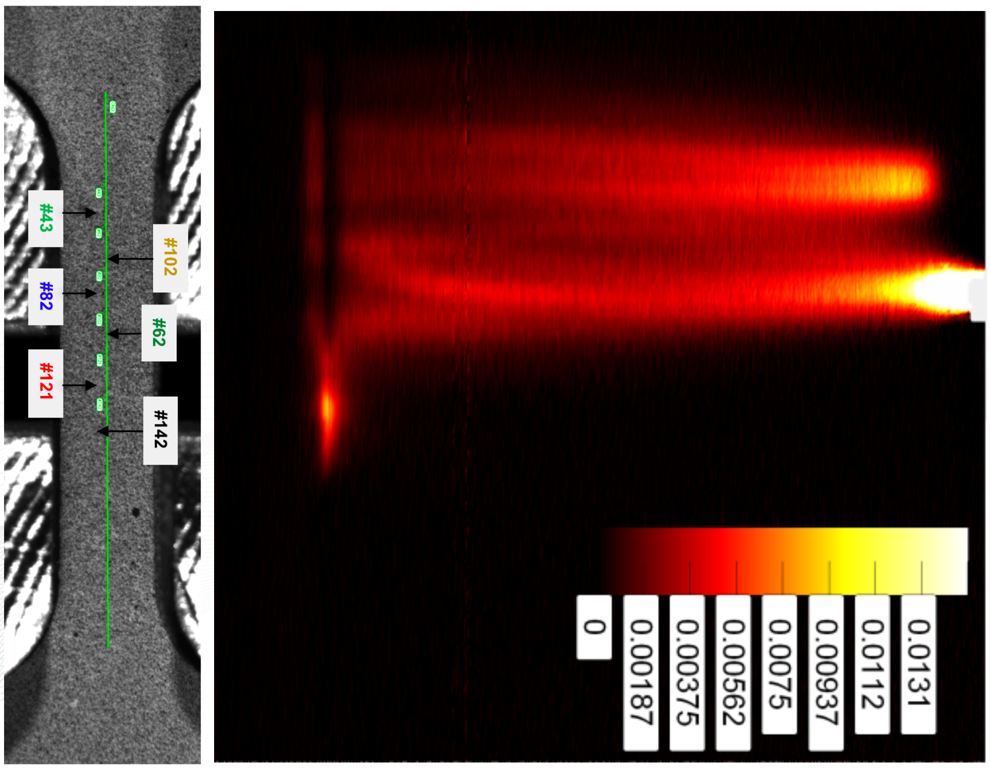


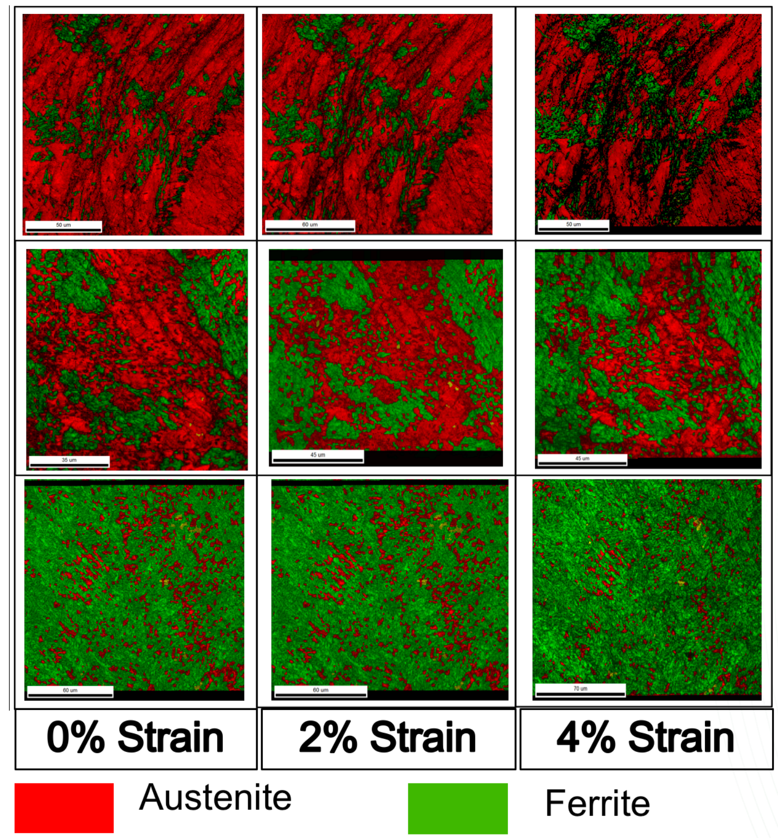




- Gradual transition from BCC to FCC structure was achieved.
- How does this complex microstructure behave under loading conditions?

Transition joint shows typical strain partitioning due to transformation of austenite (FCC) to martensite (BCC/BCT).





- We are using this data to design and test new generation of transition joints.

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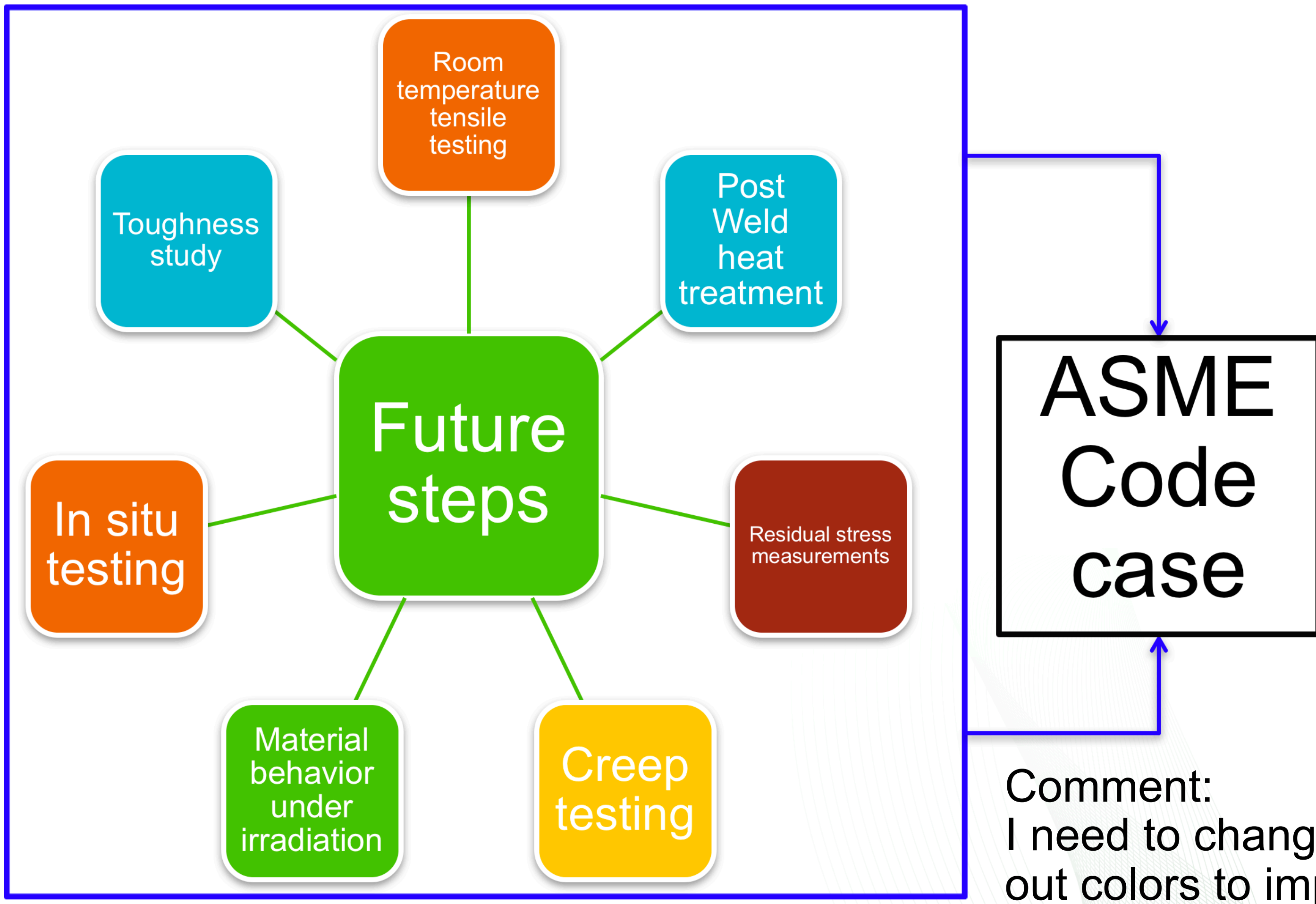
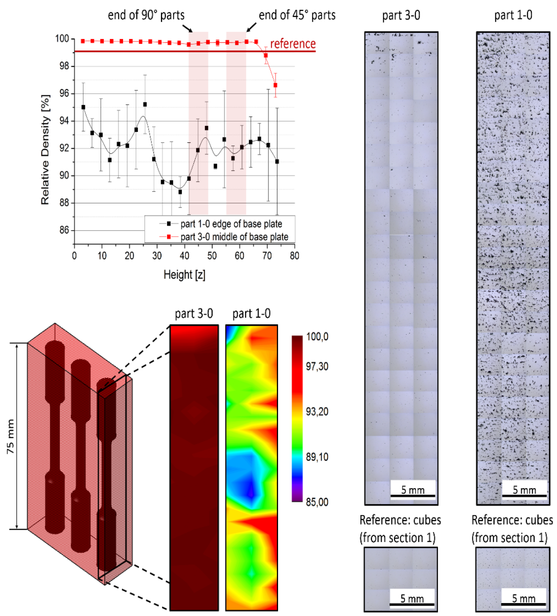
Future Directions (1): Develop datasets for traditional qualifications.



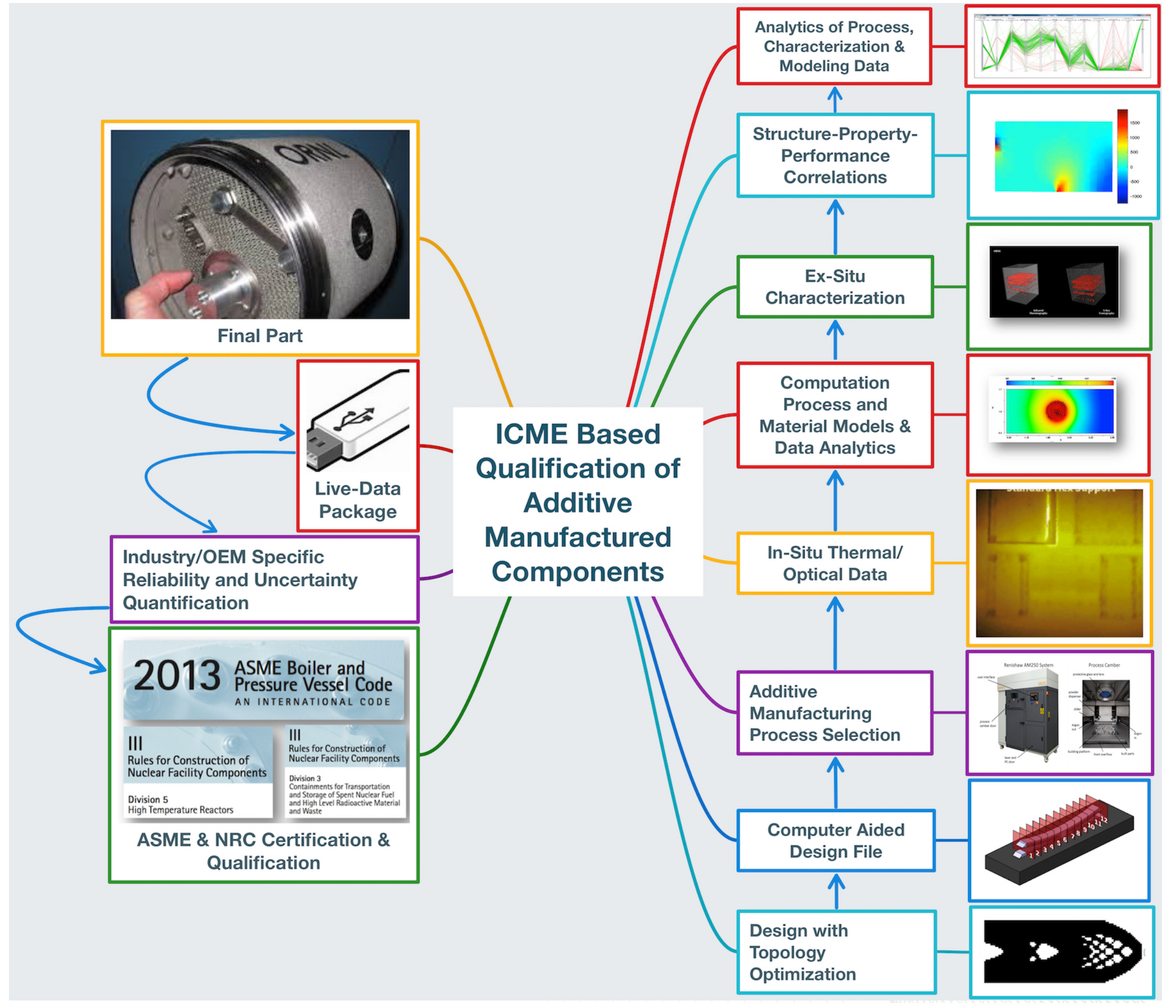
Comment:
I need to change this to with out colors to improve readability

- How about component level qualifications?

Future Directions (2): Develop in-situ monitoring, modeling and process based qualifications



Research by Popp (2015) proved that cubes are not satisfactory qualification artifacts!



Requires integration of tools for modeling, making and measuring.

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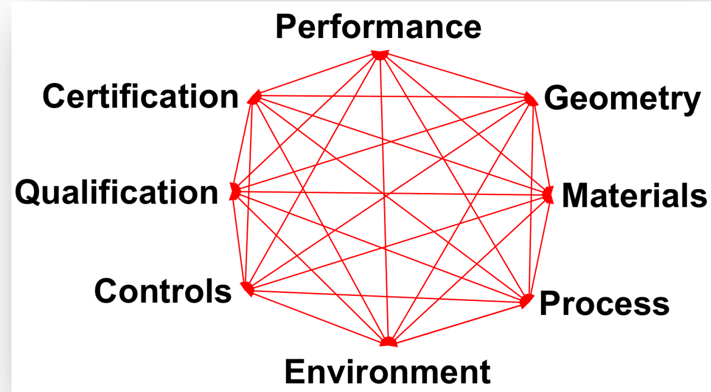
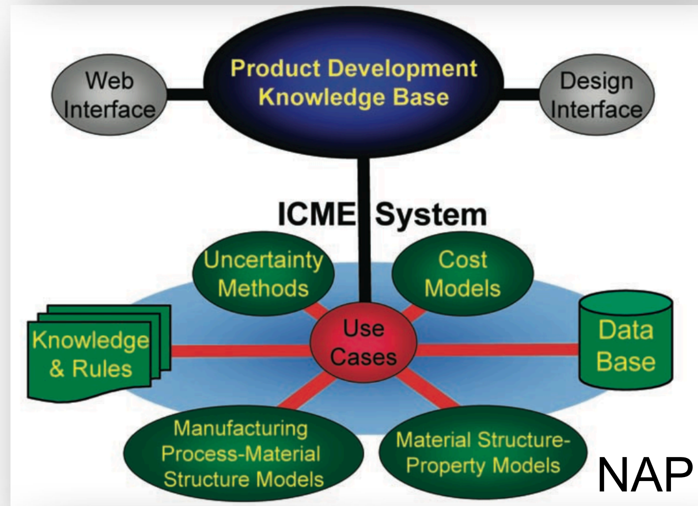
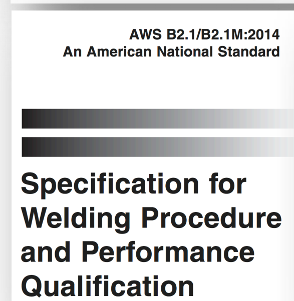
Summary and Conclusions

- Information Infrastructure for AM of complex components: interaction between geometry, materials, processes, controls, qualification, certification and performance under service
- It is possible to ICME models, extend in-situ and ex-situ characterization to develop rapid qualification methodologies for both fusion and solid-state AM processes.
- Case studies were presented in support of the same notion.

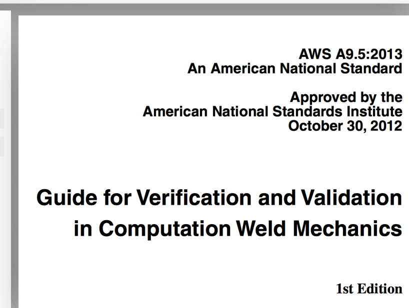






AWS B2.1/B2.1M:2014
An American National Standard

Specification for Welding Procedure and Performance Qualification



AWS A9.5:2013
An American National Standard

Approved by the
American National Standards Institute
October 30, 2012

Guide for Verification and Validation in Computation Weld Mechanics

1st Edition