U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

Clean. Reliable. Nuclear.

DOE Microreactor Program

Structural Materials: Progress, Plans, and Priorities

Technology Maturation Panel

GAIN-EPRI-NEI Microreactor Program Workshop

August 18, 2020

John Carpenter

LANL

Background: Material Advances Drive Design and Performance

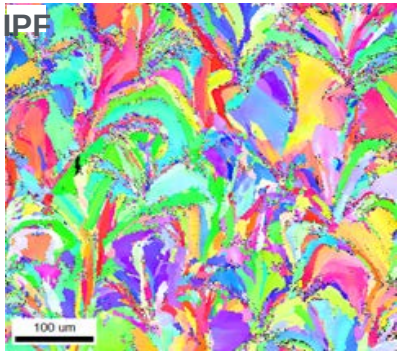
- Material characteristics needed:
  - Assure that the core geometry is coolable during normal, abnormal and accident regimes (including for example during conduction assisted passive cool-down);
  - Act as barriers to fission products to retain them within the core 'vessel' at all times; and
  - Assure that geometry influenced reactivity temperature coefficient (RTC) is repeatable and predictable.
- Current options are all imperfect and include steels, refractories, and ceramics

Material	Operating Temperature	Corrosion Resistance	Ductility
Steel	Low	Medium	High
Refractory Metals (TZM)	High	Low	Medium
Ceramics (Graphite)	High	High	Low

- Other properties such as weight, microstructural stability, creep resistance, etc. are important, too.

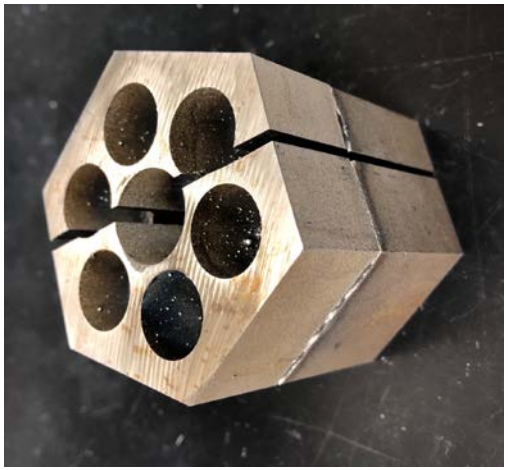
Program Activities and Accomplishments

- 316 SS (powder metallurgy (PM) [3] / additive manufacturing (AM) [3])
  - Purpose: Applicability of current code requirements to new manufacturing processes
- Grade 91 (wrought [5] / AM [2])
  - Purpose: Provide material option with enhanced high temperature strength / higher creep strength (thinner ligaments)
- Process-**Structure**-Property Relationships
- Fabrication / **Joining** / Design Interactions
- **Rapid Material Qualification**
- Grade 91 Core Block Code Case



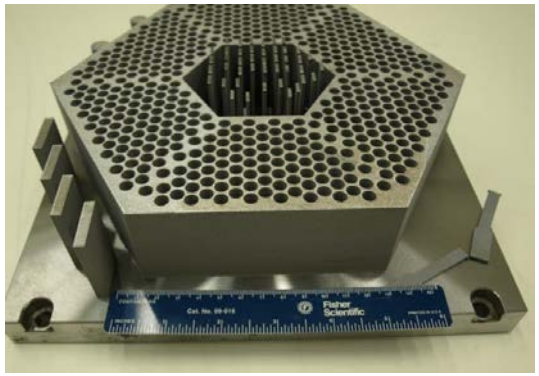
EBSD Image of AM Gr 91 in as deposited state (left)

Interaction of welds with design lead to tier welding trials (below).

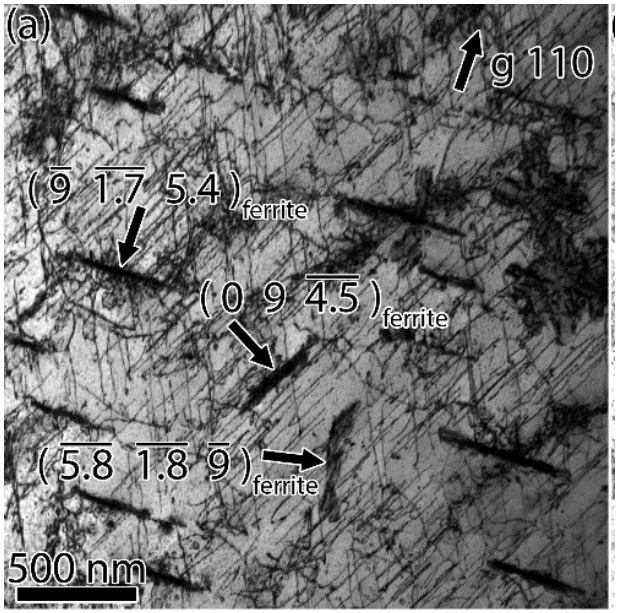


New test methods to minimize experiments and mature materials faster (left).

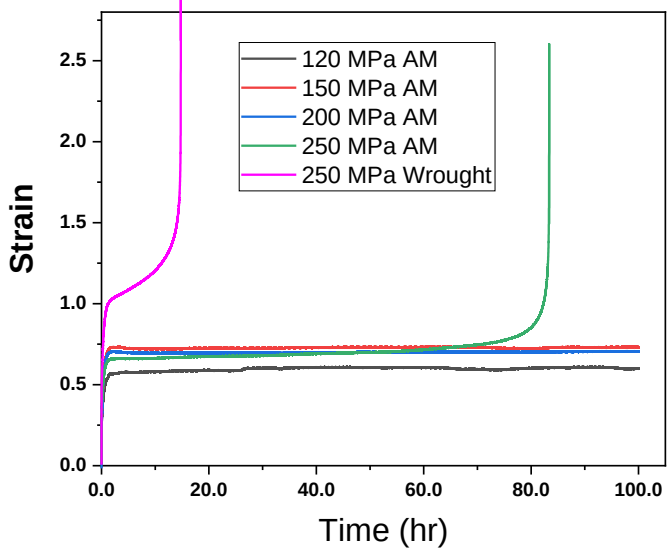
Novel Microstructure Creates Enhanced Property Combinations in Grade 91

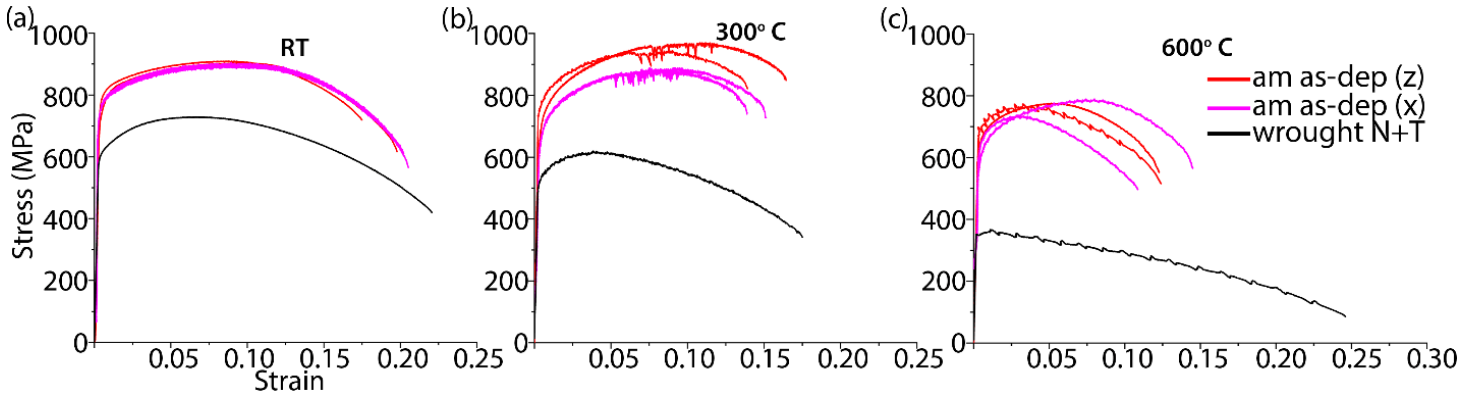


Grade 91 fabricated into complex architectures using AM (above). Theta precipitates or black stripes create unique semi-bainitic microstructure (near right).



AM material shows outstanding properties far surpassing Grade 91



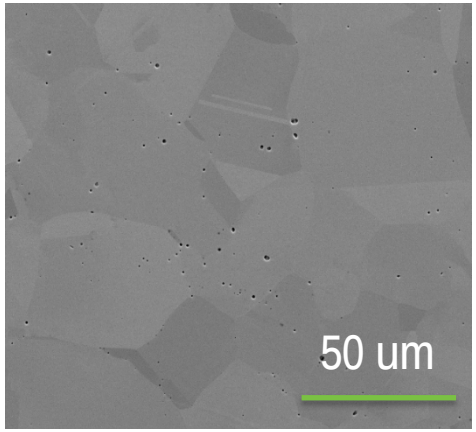


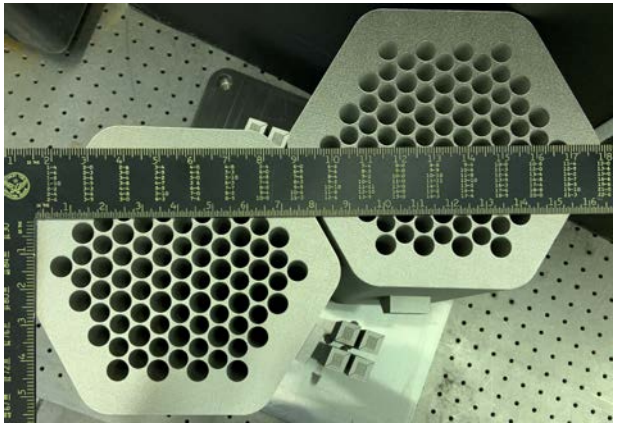
Semi-bainitic microstructure coupled with outstanding thermal stability / strength means this is a new material not yet explored for use in microreactors

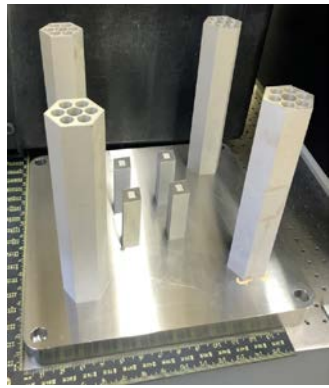
Recent Results Point to Importance of Process-Structure-Property Relationships Even in 'Well-Understood' Materials

Microstructure of 316L SS using powder metallurgy with post-processing meets requirements.

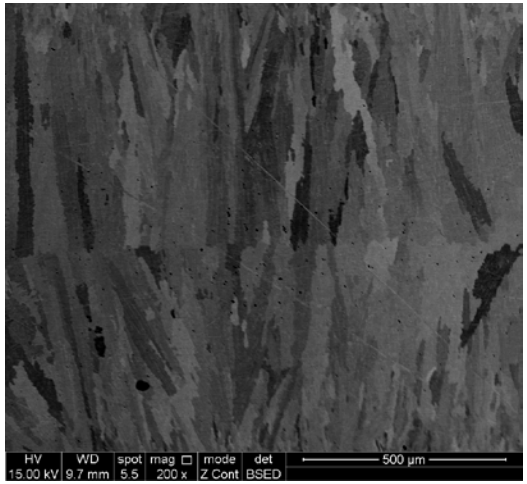
However, creep-fatigue test results indicate significant effect of manufacturing technique.

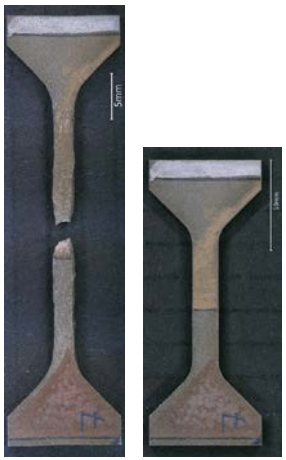






Tier weld line and affected micro-structure (left). Diffusion bonding tensile testing results (right) show reasonable ductility. Joinability is a key consideration.





Additive Manufacturing presents an alternative for complex designs. Material and manufacturing challenges still exist! right image shows parts 10" tall. Bottom image shows parts of similar height but 9" in diameter!

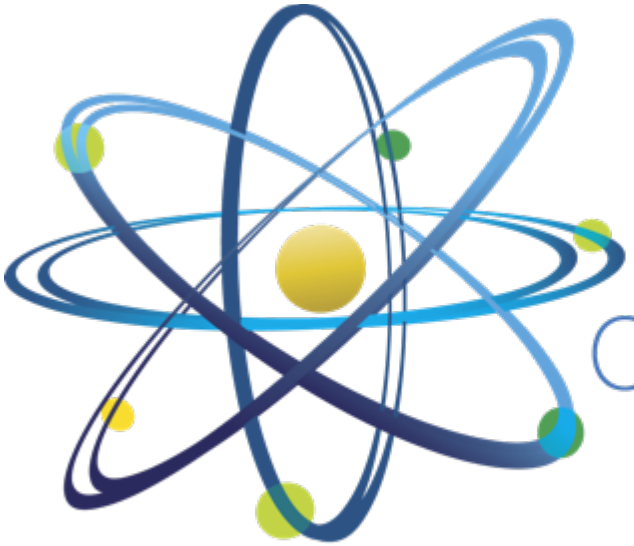
Bottom Line: Novel processing to obtain unique geometries leads to material challenges

Future Work Plans and Priorities – Expand Beyond Steels and Mature Material Streams To Fill Gaps

- Increasing Priority
  - Graphite (AM [1])
    - Goal: Identify and mature fabrication and joining technologies
  - Grade 91 (wrought [5])
    - Goal: Finish Core Block Code Case
  - Molybdenum Alloys (AM [2])
    - Goal: Identify and mature fabrication and joining technologies
- Decreasing Priority
  - 316 SS (PM [3] / AM [3])
    - Purpose: Applicability of current code requirements to new manufacturing processes
  - Grade 91 (AM [2])
    - Purpose: Provide material option with enhanced high temperature strength / higher creep strength (thinner ligaments)

Material	Operating Temperature	Corrosion Resistance	Ductility
Steel	Low	Medium	High
Refractory Metals (TZM)	High	Low	Medium
Ceramics (Graphite)	High	High	Low

<u>Overall Purpose:</u> Provide new design space through identification of materials with enhanced high temperature properties and feasible manufacturing routes



Clean. **Reliable. Nuclear.**