3D Printing of Components and Coating Applications at Westinghouse

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Outline

• Additive Manufacturing (AM) / 3D Printing
• Metals Additive Manufacturing Technologies
• Westinghouse Fuel Manufactured Products
• Status of Nuclear Fuel Development Efforts
• Development in Support of Advanced Reactors
• Coated Cladding – Key Requirements
• CHF Testing With and Without CRUD Deposit, Oxide and Coatings
• Summary
Additive Manufacturing (AM) / 3D Printing

- Develop and test critical nuclear materials: 316L, Alloy 718, and Zirconium
- Produce a reactor ready test component
- Exploit the benefits of Additive Manufacturing
  - Producing components with: Powder Bed Fusion, Binder Jetting, and Directed Energy Deposition AM technologies
  - Obsolete and high value / lead time components
  - Next gen plant components - SMR, LFR, …
  - Prototypes, mockups, jigs / fixture, tooling, etc.
- Support the development of codes and standards
  - Participating on ASTM F42 subcommittees
  - DOE funded project: Qualification of AM for Nuclear
- Development Needs:
  - Additional material development and testing to support the development of code & standards
  - Cost effective, large scale equipment
  - AM suppliers with Nuclear programs
Metals Additive Manufacturing Technologies

- **Direct Energy Deposition** (Sciaky, Optomec)
  - Automated welding systems using electron beam (EB) or laser energy sources
  - **Opportunities**: Component repairs, cladding, weld buildup

- **Powder Bed Fusion** (EOS, etc.)
  - Powder bed systems using laser or EB melting
  - **Opportunities**: Small, complex components

- **Binder Jetting** (ExOne)
  - Metals, ceramics or casting sand molds
  - **Opportunities**: Large replacement components, castings and prototypes at low cost / lead-time
Westinghouse Fuel Manufactured Products

Pressurized Water Reactors (PWRs)
- W-PWR
- CE-PWR
- KWU/Siemens PWR
- NFI PWR

Boiling Water Reactors (BWRs)
- W-BWR
- NFI BWR

VVER (PWR)
- VVER-1000
- VVER-440

Advanced Gas Reactors (AGRs)
- AGR Fuel
Status of Nuclear Fuel Development Efforts

OVERVIEW

- Design of Advanced Debris Filtering Bottom Nozzle
- Spacer grids optimized utilizing design freedom
- Advanced tubular grid (“Flower Grid”)
- Evaluating available AM metal powders for use in fuel components
- Radiation exposure testing of two alloy systems

BENEFITS

- Better fuel margins
  - Lower fuel assembly pressure drop
  - Better flow mixing and greater heat transfer ability
- Extended fuel cycles
- Customizable fuel assemblies
- Reduced time from concept to market
Development in Support of Advanced Reactors

OVERVIEW

• Prototype components for SMR, advanced reactors and AM manufacturing / design demonstration
• Material development for next generation applications
• Support the development of codes and standards (ASTM & ASME)

BENEFITS

• Design freedom: complex geometries, internal passageways, etc.
• Reduced design time: fast prototyping & mold production
  – Little to no tooling required
  – Design complexity at minimal cost
• Near net shape: reduced material, machining & welding
• Reduced lead-time / reduced supply chain
Development of Accident Tolerant Fuel

• Accident tolerant fuel being developed to improve safety for severe accidents and economics

• Exploring cladding concepts
  – Coated cladding concepts can deliver significant loss of coolant accident (LOCA) margins as well as modest improvements in accident tolerance
Coated Cladding – Key Requirements

• Reduced oxidation and hydrogen pickup in the base material during normal operation (250 to 350°C)
• Resistance to high temperature steam and air corrosion during LOCA and beyond design basis conditions (>1200°C)
• Reasonably low absorption of thermal neutrons (<5 barns)
• No cracking or spalling when strained
  – No cracking during normal operation
  – No spalling during transients
• Cost effective manufacturing at an industrial scale
• Crud deposition comparable to current fuel
• Enhanced resistance to wear (debris, grid-to-rod or rod-to-grid)
• Possible improvement in Critical Heat Flux
Cold Spray Coating Process

• Cr, FeCrAl and Mo deposited on Zirconium Cladding
## CHF Testing With and Without CRUD Deposit, Oxide and Coatings

### Single Heater Rod WALT Loop Test Facility – at reactor conditions

<table>
<thead>
<tr>
<th>Rod</th>
<th>Condition</th>
<th>CHF (W/cm²)</th>
<th>Coolant T (°C)</th>
<th>Pressure (MPa)</th>
<th>Flow Velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>167</td>
<td>No Deposit</td>
<td>459</td>
<td>338.0</td>
<td>15.44</td>
<td>2.4</td>
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<tr>
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<td>No Deposit</td>
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<td>333.8</td>
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<tr>
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<td>No Deposit</td>
<td>455</td>
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<tr>
<td>171</td>
<td>Deposit, 21 microns</td>
<td>451</td>
<td>338.6</td>
<td>15.60</td>
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<tr>
<td>165</td>
<td>Thermal Oxide Layer applied by MIT</td>
<td>503</td>
<td>334.5</td>
<td>15.58</td>
<td>2.4</td>
</tr>
<tr>
<td>177</td>
<td>TiO₂ coating applied by MIT</td>
<td>510</td>
<td>337.5</td>
<td>15.58</td>
<td>2.4</td>
</tr>
</tbody>
</table>

**CHF Impact due to CRUD Deposit appeared to be within repeatability of clean rod tests, thermal oxide layer showed a noticeable difference and TiO₂ showed an increase over the oxide layer**
Summary

• Westinghouse is working to develop additive manufacturing technologies and associated materials, for use in the nuclear industry.
• This R&D is enabling new complex designs, for both the WSMR, next generation reactor designs and for current fuel.
• These technologies are also being used to reduce component manufacturing lead-time and cost for prototype and demonstration components, as well as existing critical and obsolete components.
• Coatings can help make fuel more accident tolerant and improve fuel performance (CHF, reduced corrosion and fretting, etc)