Advanced Manufacturing to Enable the Next Generation of Nuclear Plants

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Molten Salt Reactor Workshop 2018—Creating a Self-Sustaining Environment for MSR Success
October 3-4, 2018
Outline

- Background
- Development/Demonstration of 4 Advanced Manufacturing/Fabrication Technologies
- 2/3-Scale SMR Manufacturing/Fabrication – Phase 1
- Component Assembly
- Applicability to Advanced Reactors -- Summary
What if it only took 12 months to produce a reactor pressure vessel?
What if you could perform an entire SMR RPV girth weld in less than 60 minutes?
What if you could manufacture an entire SMR head in < 3 months with no vessel dissimilar metal welds?
What if you could eliminate the need for in-service examinations of girth welds?
What if you could perform vertical welds to join rolled plates without subsequent embrittlement concerns?
Enabling the Next Generation of Nuclear Plants

- Scope

  - Manufacture Major Critical Components to Assemble a 2/3-Scale SMR Reactor Pressure Vessel

  - Jointly Funded Collaboration
    - EPRI, Nuclear AMRC, DOE, NuScale Power

  - Others
    - Synertech-PM, Sheffield Forgemasters, Sperko Engineering, Carpenter, ORNL, etc.

DOE Project: DE-NE0008629

What Once Took Weeks, We Can Now Do In Hours…
Advanced Manufacturing 
- Objectives

- Rapidly Accelerate the Deployment of SMRs
- Develop/Demonstrate New Methods for Manufacture/ Fabrication of a Reactor Pressure Vessel (RPV) in <12 months
- **Eliminate 40%** from the cost of an SMR RPV, while reducing the Schedule by **18 Months**

200mm Electron Beam Weld
Electron Beam (EB) Welding

Why EBW?
- One-pass welding!
- No filler metal required.
- EBW can produce welds w/ minimal HAZ
- Nuclear-AMRC, TWI, Rolls-Royce & EPRI have demonstrated in-chamber and/or local vacuum on thick section alloys
  - Enables field/shop welding!
- RPV girth welds (110mm thick) in <60 min

Inspection, Costs?
- Huge savings in welding costs (again, one pass welding)
- Potential to eliminate in-service inspection!
Powder Metallurgy-Hot Isostatic Pressing (PM-HIP)

Why PM-HIP?
- Near-net shape and complex components (reduces materials cost and machining)
- Alternate supply route, shorter turn-around
- Considerable EPRI/Industry development over last 7 years.
- Ideal for multiple penetration applications (RPV or CNV head) vs expensive forgings

Inspection, Costs?
- Homogeneous-Excellent inspection characteristics
- Costs roughly equivalent to forging
- Eliminates need for welds in some applications.
Elimination of Welds via Heat Treatment --Resetting the Clock

How?
- Perform chamber EB weld of sub-assemblies
- Localized Solution HT, quench; normalize; temper
- Resulting microstructure is same as base metal
- Fracture toughness comparable to base material

Inspection, Costs?
- Perform fabrication inspection prior to and following initial solution HT, plus N&T
- Following HT, no weld is visible
- Potentially no weld inspection required at 10 year intervals
Diode Laser Cladding

Why DLC?
- Robotic machine welding
- High deposition rates
- Significantly reduces cladding thickness required (~4mm)

Inspection, Costs?
- Lbs. (or kg) of material required is significantly reduced since thinner layers can be applied.
- No machining after cladding required
Project Tasks

1. Lower Reactor Assembly
2. Upper Reactor Assembly
3A. Thick Section EBW Development
3B. Local Vacuum EBW Development
4. Diode Laser Cladding Development
5. Elimination of DMWs—for Nozzle Applications
6. Elimination of In-Service Inspection via Solution Heat Treatment
7. ASME BPVC Code Development
8. ORNL Mechanical and Metallurgical Testing
2/3rds Scale Small Modular Reactor Manufacture/Fabrication

- EPRI
- Nuclear-AMRC
- US DOE
- NuScale Power
2017-18 Scope/Schedule

Fabrication

- EB Welding Development (Task 3A)
- Diode Laser Cladding Development (Task 4--partial)
- Lower RPV Assembly (Task 1)

Manufacturing & Fabrication

- Lower Head (Synertech PM-HIP)
- Lower RPV Flange Shell (SFEL forged)
- Two Flanges (SFEL forged)
- Upper Flange Shell (Synertech PM-HIP)
Lower Head EB Welding

Nuclear AMRC (UK) – Responsible for All Component Assembly
Lower and Upper Flange Shells

Thick flange to be welded to lower shell via EBW

4 PM-HIP ring sections will be joined with EBW
Lower Assembly

Lower Flange Shell Mockup EB Weld -- ~6 ft (1.82m) diameter (Note, mockup is upside down)

Completed in 47 minutes

Lower head to Lower Flange Shell (again, upside down)
Upper Flange Shell – Four sections and flange

Vertical Welding of Sections

Circumferential Girth Weld to Attached Flange
Task 2—Upper Reactor Assembly --2019-2020

4. **RPV Top Head**
   - Manufacture via PM-HIP in two halves
   - EBW halves together, annealed, Q&T
   - DLC completed top head

5. **RPV PZR Shell**
   - Forged Section

6. **Steam Plenum**
   - PM-HIP & EBW together
Upper Head—27 Penetrations.

- Two half “head sections” will be produced via PM-HIP
- A508, Grade 3 Low Alloy Steel
- Penetrations will be solid and then bored/machined out
- Welded together with EBW
- At full scale, ~ 21,000 lbs (9525 kg)
Upper Head (Stamped Inner & Outer Capsule Shells)
44% Upper Head Demonstration - Laser Machining

Laser machining of the penetrations to attach CRD nozzles

Machining complete for outer capsule
Capsules for CRD Tubes Mounted in Upper Head

Upper head at 40% scale is ~2370 lbs
At full scale, ~ 21,000 lbs.
Capsules for Upper Head Completed and Ready for Powder Filling

Solid nozzles will be bored after HIP and heat treatment

Note “fill stems” on top of upside down upper head capsule
Upper Head– Hot Degassing & Crimping of Fill Stems

Hot Degassing of Powder Filled Upper Head

Following Degassing, All Fill Stems are Crimped and Welded Shut. Now Ready for HIP
Small Modular Reactor Upper Head

- ~44% scale
- A508 Class 1, Grade 3
- 27 penetrations
- 1650kg (3650lbs); 1270mm (50 inches) diameter
- Next, 2/3-scale head
- Need larger HIP Vessel -- ATLAS

DOE Project: DE-NE0008629

Photographs courtesy of EPRI and NuScale Power
Lower Head – One-Half Section
Lower Head EB Welding

Nuclear AMRC (UK) – Responsible for All Component Assembly
Lower Head—Stamped Capsule Sections

HIP Modeling—Shows Lower Head inside of the Finished Capsule

Final part: ~4300 lbs (1950 kg) @ 2/3rds scale; Full Scale is ~11,000lbs (1/2 section) (4990kg)
One half lower head under construction

3/8-inch (9.5mm) thick lower head construction; ~70-inches (1780mm) diameter (2/3rds scale)

Note: Two reactor internals support structures are included for each RPV head half
Completed Capsule for Lower Head

One-half of Lower Head. Note Support Legs inside of the Structure

One-half of Lower Head Read for Powder Filling
Custom Rack Build for the One-Half Lower Head Section

- Custom rack required due to size of existing HIP furnaces in USA.
- 1.67m (66 inches) diameter in USA; 2m (78.5 inches) in Japan
- Must be stood upright in custom rack/frame
- Remember, this is a non-symmetrical component in one-half section.
Custom Rack Build for the One-Half Lower Head Section
Lower Head Inserted Into HIP Vessel and Final Component
One-Half Lower Head HIP’ed & Dimensioned
Project Status (August 2018)

- Work packages developed for:
  - EBW, DLC, Machining, PM-HIP, Heat Treatment, etc.
  - Flange welding, head welding, vertical welding, circumferential welding
  - Lower assembly

- Steam plenum access port completed (EPRI ANT)
- 44% diameter (50-inch) A508 top head completed (EPRI ANT)
- Forgings for flanges, PZR shell, lower RPV section, and HT completed
- One-half section A508 lower head, completed
- EBW & DLC development underway @ Nuclear AMRC
- Heat treatment development underway soon.
Applicability to Advanced Reactors -- Summary

Must change the way we manufacture RPVs to be cost competitive!!!

Four technologies will have direct applicability:

- **PM-HIP** -- for higher alloyed components; eliminate long lead-time forgings; improve inspectability
- **EB Welding** – significantly reduced welding time; for difficult to join components
- **Diode Laser Cladding** – robotic cladding of vessels; difficult materials
- **Re-setting the Clock** – elimination of welds via heat treatment; eliminates in-service inspection
Together...Shaping the Future of Electricity
Four SA508, Grade 3 Class 2 Forgings Produced

- PZR Shell
- Lower RPV “Flange”
- Lower RPV Shell
- Upper RPV Transition Shell “Flange”

- Primary HT performed.

Forging for Two Flanges
Flange and Shell Forgings
Flange and Shell Forgings