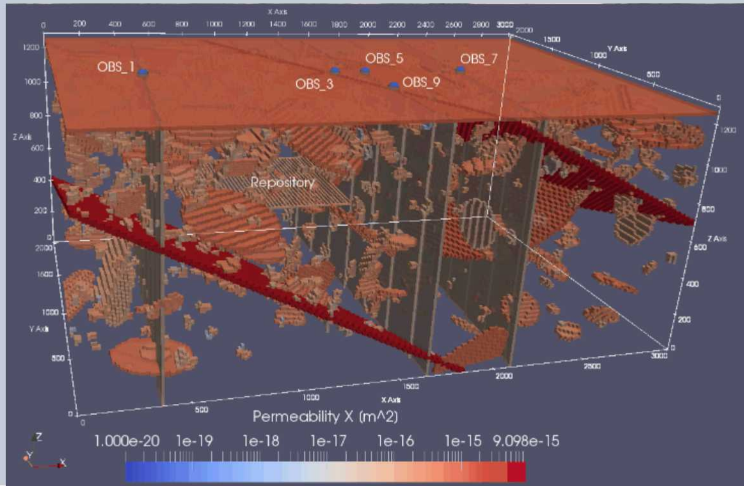
Summary of NEUP Programs—CISCC Mitigation and Repair

SAND2020-2861PE



SFWD

Spent Fuel & Waste Disposition

CISCC Program Meeting
March 4, 2020

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Five projects, all started in FY18

1. Purdue University (Project 18-15559): Cold Spray Repair & Mitigation of Stress Corrosion Cracks in Spent Nuclear Fuel Dry Storage Canisters
2. The Ohio State University (Project 18-15531): Repair and Mitigation of Chloride-Induced Pitting and Chloride-Induced Stress Corrosion Cracking in Used Nuclear Fuel Dry Cask Canister Materials
3. University of Idaho (Project 18-15261): Friction Stir Based Repair Welding of Dry Storage Canisters and Mitigation Strategies: Effect of Engineered Barrier Layer on Environmental Degradation
4. University of Wisconsin (Project 18-15332): Low-Force Solid-State Technologies for Mitigation of Stress Corrosion Cracking in Dry Storage Canisters
5. University of Cincinnati (Project 18-15372): Development of Repair and Mitigation Methods for Enhancing Stress Corrosion Cracking Resistance of Austenitic Stainless Steel Spent Nuclear Fuel Canisters

<u>SCC predictive model development</u>

- University of Virginia (Project 19-17350): Development and Experimental Validation of Pitting and SCC Models for Welded Stainless Steel Dry Storage Containers Exposed to Atmospheric Environments (started in FY19, will not be discussed)

*National labs (SNL, PNNL, SRNL, INL) are collaborators and/or TPOCs on all of these projects.

Mitigation and Repair Techniques Being Tested

Lead University	Methods being examined
Purdue University	Cold spray
Ohio State University	Cold spray
	Friction stir welding (FSW)
	Soldering
	Vaporized foil actuator welding (VFAW)
University of Cincinnati	Laser-assisted cold-spray (LACS)
	Additive friction stir deposition (AFS-D)
	Laser shock peening
	Ultrasonic nanostructure surface modification
University of Idaho	Additive friction stir welding (AFSW)
University of Wisconsin	Cold spray
	Friction Surfacing (FS)

NEUP: SCC Mitigation and Repair Techniques

- Tasks:
  1. Optimizing techniques
     - Physical/mechanical properties, microstructure
     - Effects on stress field
     - Effects on corrosion properties
  2. Designing corrosion test samples
  3. Developing and implementing appropriate procedures for corrosion testing
- Why:
  - The canisters *will* eventually crack. Field deployable mitigation and repair techniques will be necessary.
- Who/What else it feeds:
  - DOE—necessary to demonstrate the safety of long-term interim storage
  - Industry (cask vendors, ISFSI site owners, EPRI)
- What is needed?
  - More standardization between projects?
    - Sample types and geometries
    - Corrosion testing procedures

Partners:

- VRC metal systems – cold spray samples
- SNL – corrosion testing

Sample geometry (current):

- 304 SS, 1/8” plate (SNL-supplied)
- 4-Point bends

Corrosion testing methods:

- Boiling $MgCl_2$ (ASTM G-36)
- $FeCl_3$ pitting (ASTM G-48)

Notable results to date:

- Boiling $MgCl_2$:
  - Weld samples cracked rapidly
  - Inconel 625 coated samples did not crack
- $FeCl_3$
  - Inconel spray coating did not pit; however, spray coating did delaminate from underlying metal
  - Possible martensite formation in underlying metal and preferential attack?
  - Sample edges exposed—results may not be characteristic. Spray-coated surface did not appear to delaminate.

Boiling $MgCl_2$ test

$FeCl_3$ pitting test

As-received coupon (Crack after 17h)

As-received coupon

Inconel 625 sprayed coupon (No crack after 216h)

Inconel 625 sprayed coupon (Delamination observed)

Partners:
- VRC metal systems – cold spray samples
- PNNL – FSW consultants
- Titanium Brazing Inc. – soldering

Sample geometry (current):
- 304 SS, 1/8” plate (SNL-supplied)
- 4-Point bends

Corrosion testing methods:
- Boiling $MgCl_2$ (ASTM G-36) (not started yet)
- Full immersion testing w/SNL sea-salt brines

Notable results to date:
- Metallurgical characterization complete
- All repair methods developed and tested
  - Cold spray samples (304L/304L)
  - FSW optimization in progress
  - Solder composition perfected (wettability)
  - VFAW geometry optimized (304L/304L)
- Corrosion test specimens being made for each method

Figure 8: a) deposition t

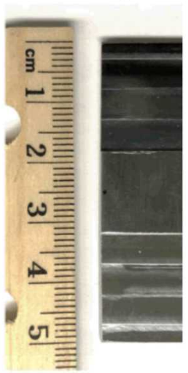

Figure 10: Examples of VFA inclined VFAW

Images from DE-NE0008765 FY19 Annual Report

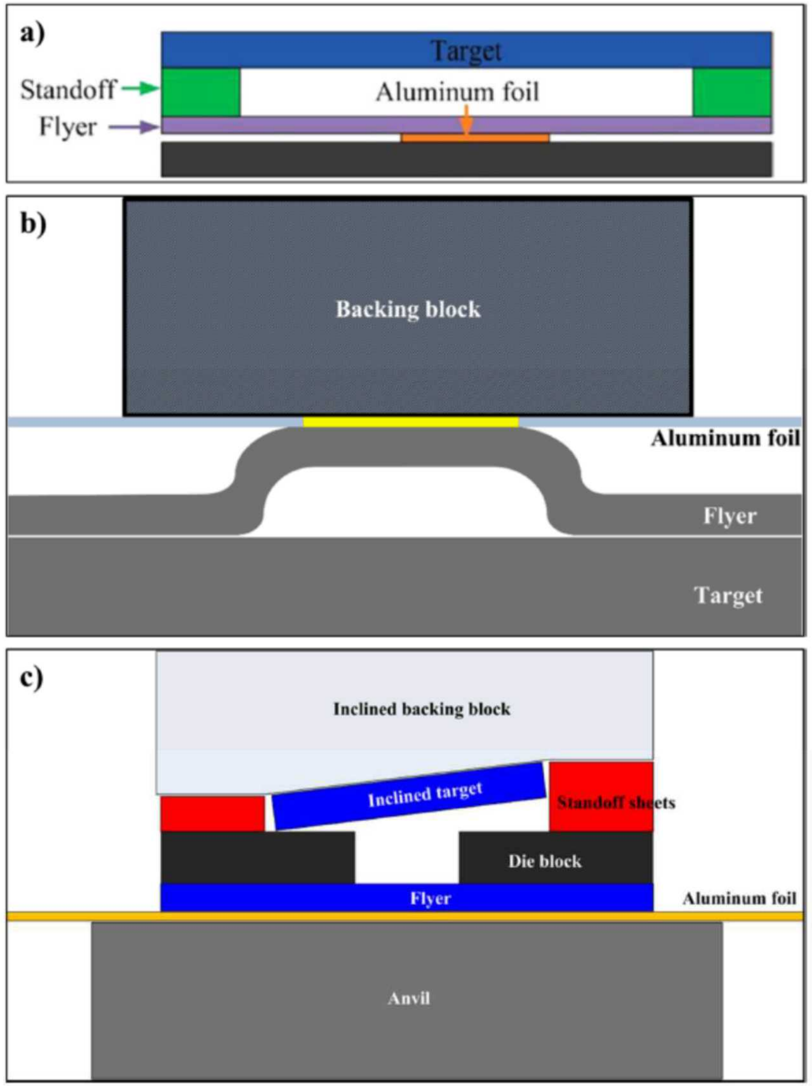

Figure 9: Schematics of VFAW process variants; a) patch VFAW; b) preformed flyer VFAW; c) inclined VFAW

1-100mm/min; b) 200RPM-

rlay samples

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Partners:

- PNNL – AFSW samples

Sample geometry (current):

- 304 SS (following FWS, Mo and N added in a FSW surface layer to improve corrosion resistance)
- Plates with EDM simulated cracks

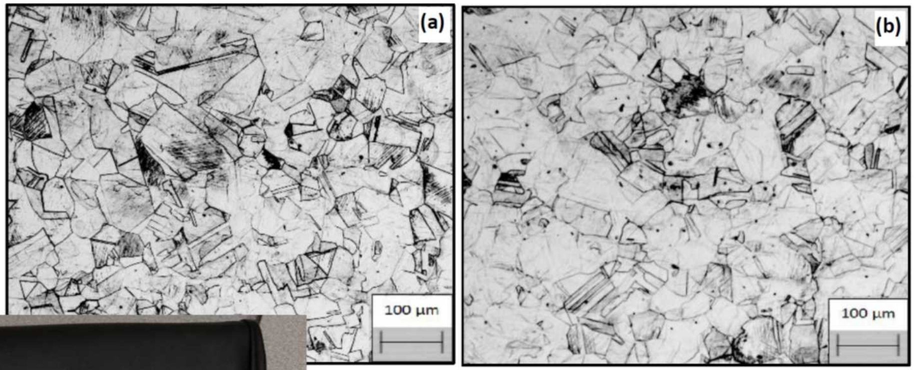
Corrosion testing methods:

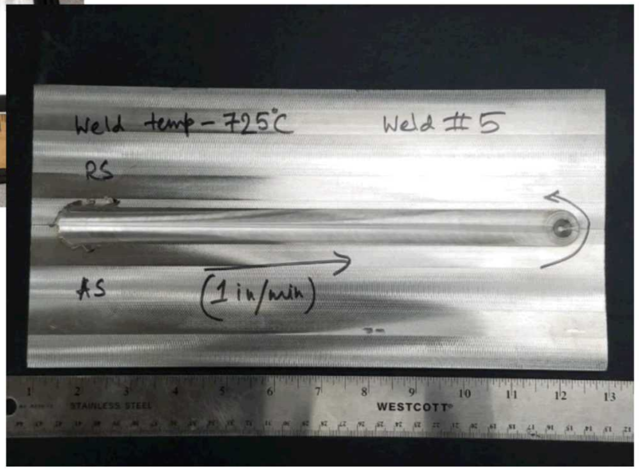
- Corrosion testing in "dilute electrolyte"

Notable results to date:

- Metallurgical characterization complete
- Simulated crack samples prepared for FSW
- FSW optimization in progress
- Neutron diffraction stress measurements of FSW specimens completed—little difference as a function of weld temperature.

Images from several picsne reports for this NEUP project





Wisconsin

Partners:

- Fluor – produce GTAW welded test samples
- PNNL – produce FSW for comparison

Sample geometry (current):

- 304L(?) SS, 1/8" plate (reported carbon content is not 304L)
- 4-point bends, U-bends, simulated SCC samples (EDM)

Corrosion testing methods:

- Not specified

Notable results to date:

- Repair methods developed and being tested
  - Cold spray samples (304L/304L)
  - Friction surfacing optimization in progress

Images from DE-NE0008801 FY19 Annual Report

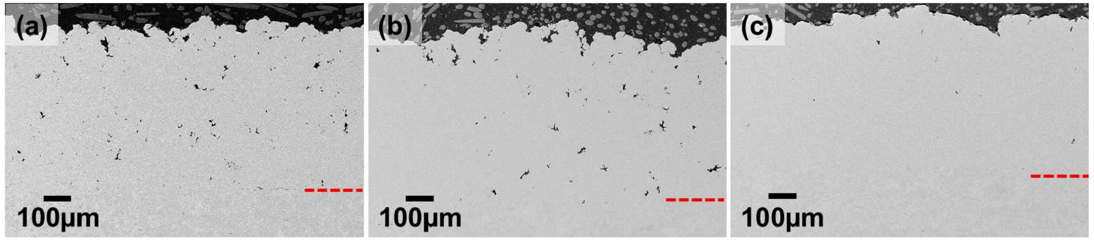


Fig.8. Cross-sectional SEM images of cold spray 304L stainless-steel coating on the as-received substrate with increasing particle velocity: (a) 635 m/s, (b) 727 m/s, (c) 844 m/s, by adjusting propellant gas condition.

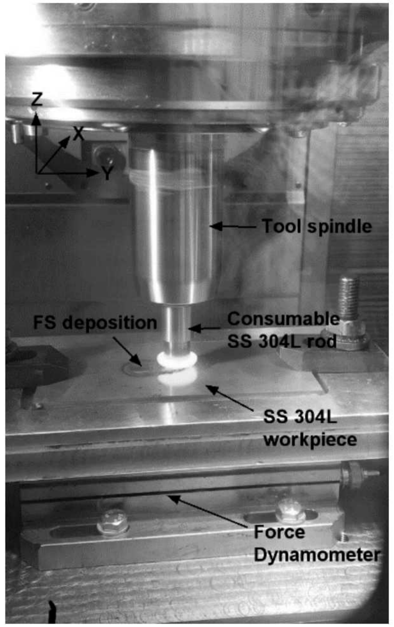


Fig.18 Experimental setup for friction surfacing tests

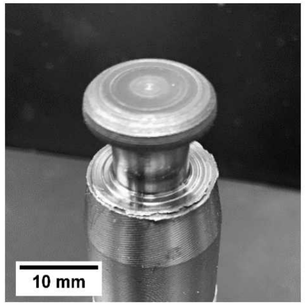


Fig.21. Flash generated on tool during friction surfacing

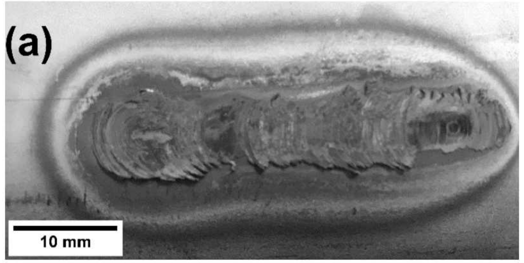


Fig.19. (a) Image of deposited layer of SS 314L

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Partners:

- University of Alabama
- INL

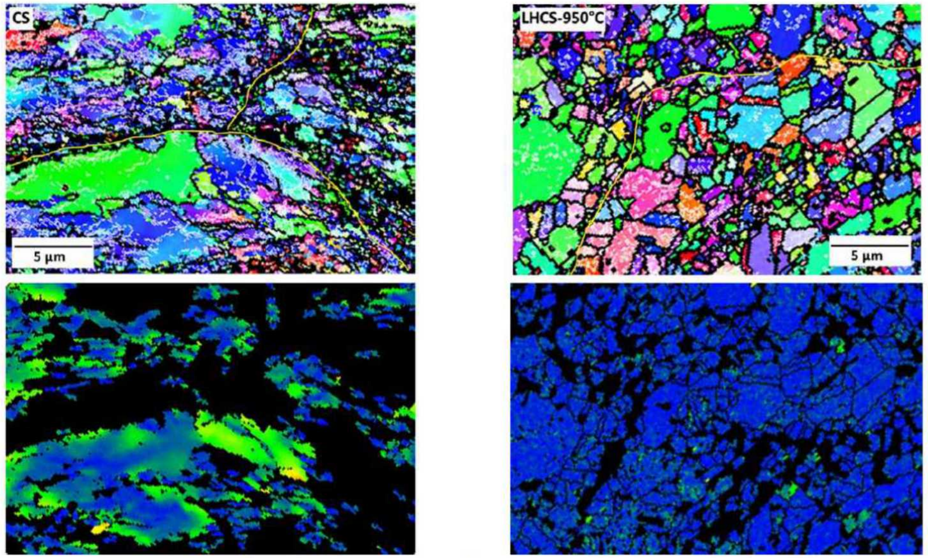
Sample geometry (current):

- To date—sensitized 304L plate samples
- Weld test samples being produced

Corrosion testing methods (not started yet)

- Boiling $MgCl_2$ (ASTM G-36)
- Oxalic acid pitting tests
- Double loop EPR to measure changes to sensitized materials.

Images from NEUP 18-15732_Q1 FY20 Report



Inverse Pole Figure (IPF) (top) and grain reference orientation deviation (GROD) (bottom) of CS and LHCS Coatings along the deposition direction

Notable results to date:

- **Ultrasonic nanostructure surface modification** (produces compressive stresses); 100% martensite formation on the treated surface. Corrosion effects being evaluated.
- **Laser shock peening** produces compressive stresses to a depth of about 600 µm; does not appear to produce martensite; DLEPR suggests effect on corrosion resistance is mixed.
- **Laser-assisted cold spray;** produced coating of mixture of austenite/ferrite. Corrosion effects being evaluated.
- **Additive friction stir deposition**—tested, and optimization in progress. Frictional wear and damage to the tooling requires optimization of tool design and lubricant.

CONCLUSIONS

- Six NEUP programs working on SCC, five on mitigation and repair.
- Technologies examined
  - Prophylactic, during manufacturing
    - Laser shock peening
    - Ultrasonic nanostructure surface modification
  - SCC repair
    - Cold spray variants (cold spray, laser assisted cold spray)
    - Friction stir weld and friction surfacing variants (friction stir, additive frictions stir, friction surfacing)
    - Innovative (soldering, vaporized foil actuator welding)
- Evaluation methods used
  - Stress Measurements (neutron diffraction, XRD)
  - Corrosion testing
    - Boiling $MgCl_2$ (ASTM G-36)
    - $FeCl_3$ pitting (ASTM G-48)
    - Immersion testing in relevant(?) brines
    - Double loop EPR
- Most programs currently optimizing processes, preparing corrosion test specimens