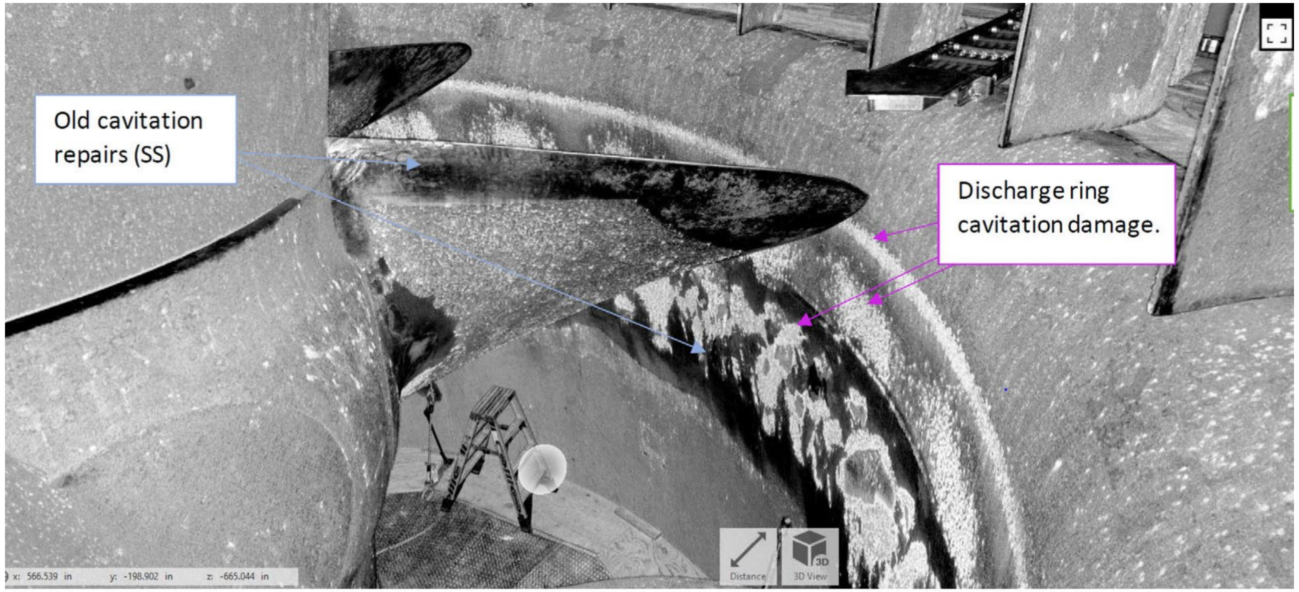
1.1.1.611: Cold Spray Process Development for In Situ Repair and Mitigation of Cavitation Erosion



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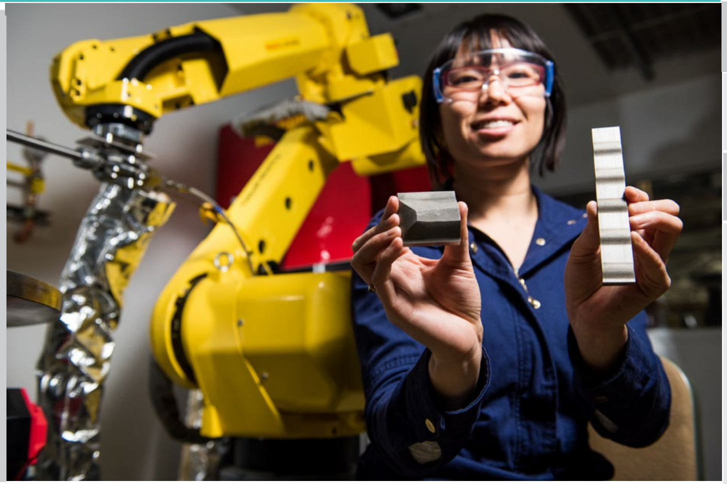
Project Overview

Project Summary

The intent of this project is to develop a cold spray (CS) coating process for in situ repair of hydropower turbine hardware that provides superior cavitation erosion resistance to current base materials and repair methods.



Intended Outcomes

- Development of a cold spray process that provides significantly improved cavitation erosion resistance compared to the traditional repair approach
- Development of a robust cold spray process that can be applied manually and in situ with portable capable cold spray equipment
- Development of a cold spray process that reduces hydropower turbine downtime / outages and results in improved economics for hydropower operators
- Complete an initial field application of the developed cold spray process

Project Information

Project Manager & Principal Investigator

Christopher Smith (PM), Kenneth Ross (PI)

Project Partners/Subs

- Bonneville Power Admin. (BPA)
- Army Corps of Engineers (ACE)
- VRC Metal Systems
- Penn State University

Project Status

Ongoing

Project Duration

- Project Start Date: 12/17/2018
- Project End Date: 9/30/2024

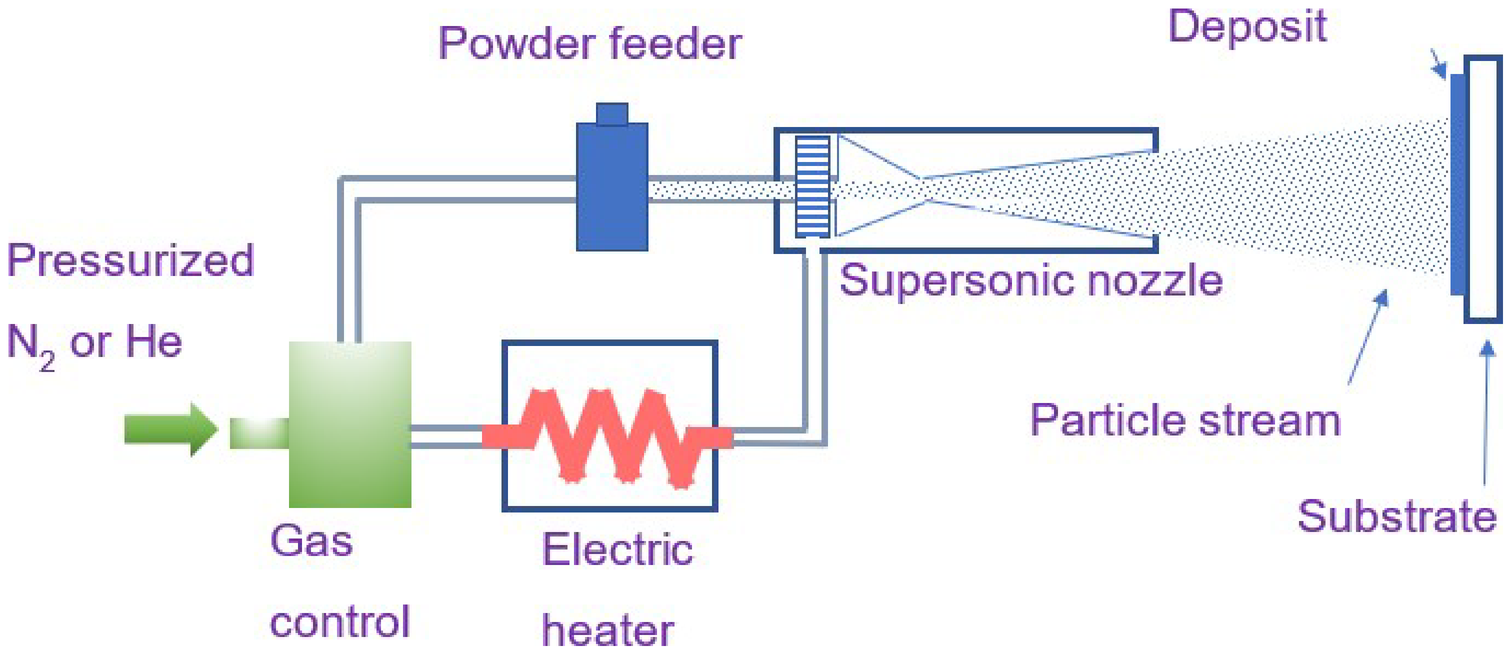
Total Costed (FY19–FY21)

$1.26M

Project Objectives: Relevance

- The development of a qualified cold spray repair process will address
  - Untapped potential for hydro and pumped storage to support a rapidly evolving grid
  - Maintaining affordability and security of existing hydro given fleet age and repair needs
- These goals can be realized because
  - Cold spray repairs have the potential to last significantly longer than repairs made with current approach, providing a positive impact on the operational economics of hydropower

- Surfaces with improved cavitation erosion resistance can allow
  - Turbine operation a greater percentage of the time (less down time)
  - Operation of facility more flexibly, such as in sub-optimal flow conditions that would otherwise exacerbate cavitation erosion
  - Prevent lowering of reservoirs by delaying repairs during drought years enabling preservation of water resources to combat effects of climate change



Cold Spray Process Schematic

Project Objectives: Approach

- The development of a repair process that employs solid-phase processing (SPP) technologies which previously have not been considered for repair of hydropower turbine hardware
  - SPP includes manufacturing processes that operate in solid-phase (without melting) such as cold spray, friction stir welding / processing, friction welding, cladding, etc.
  - SPP is known to provide superior properties versus fusion-based processes (involving melting) in many other material systems and applications
  - Current repair approach involves gas metal arc welding (GMAW), a fusion based process
- The development of a CS repair process that can be implemented on portable capable commercial equipment
  - Can be applied manually to enable an in situ repair process.
- Characterization of CS coating cavitation erosion resistance versus various process inputs to ensure development of a robust CS process

Project Objectives: Expected Outputs and Intended Outcomes

Outputs:

- Qualified cold spray repair process
- Cold spray repair process that can be deployed on portable-capable cold spray equipment
- Cold spray process that can be implemented manually and enable an in situ repair approach
- Completion of an initial field application / demonstration of the developed cold spray repair process

Outcomes:

- A CS process will be developed that will enable commercial entities to proceed with future application of cold spray as a repair process
- A superior repair process that allows hydropower operators to reduce downtime, lower cost, preserve reservoir water, and operate during less optimal conditions (increase in revenue) that has the potential to reduce electricity rates for the public

Project Timeline

FY 2019

-Determine feasibility of cold spray as a repair process to improve cavitation erosion resistance of hydro turbine hardware

-Establish baseline capacity of CS cavitation erosion resistance*

* Associated Go/No-Go decision based on the viability of the CS process

FY 2020

-Initiate efforts to transition CS process to commercially available portable capable equipment to enable a manual in situ repair process

-Identify additional approaches (e.g. equipment or process enhancements) that may be necessary to realize transference to portable equipment*

-Identify potential sites for field application of developed repair process

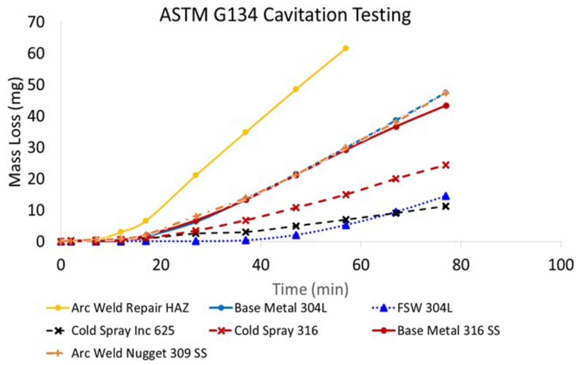
FY 2021

-Continue efforts to transition CS process to commercially available portable capable equipment to enable a manual in situ repair process, including development of additional approaches to enable or enhance process transference*

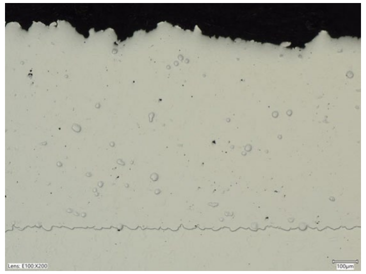
-Initiate efforts to characterize CS cavitation erosion performance versus CS input variables (i.e. ensure robust CS process)

-Finalize site for field application of developed repair process

Initiate planning efforts for field application



Initial Cavitation Performance Data



Example Cold Spray Deposit Cross Section

Project Budget

Total Project Budget – Award Information		
DOE	**Cost-share**	**Total**
$1.06M	$200K (BPA)	$1.26M

FY19	FY20	FY21	Total Actual Costs FY19–FY21
Costed	**Costed**	**Costed**	**Total Costed**
$106K	$419K	$274K	$799K

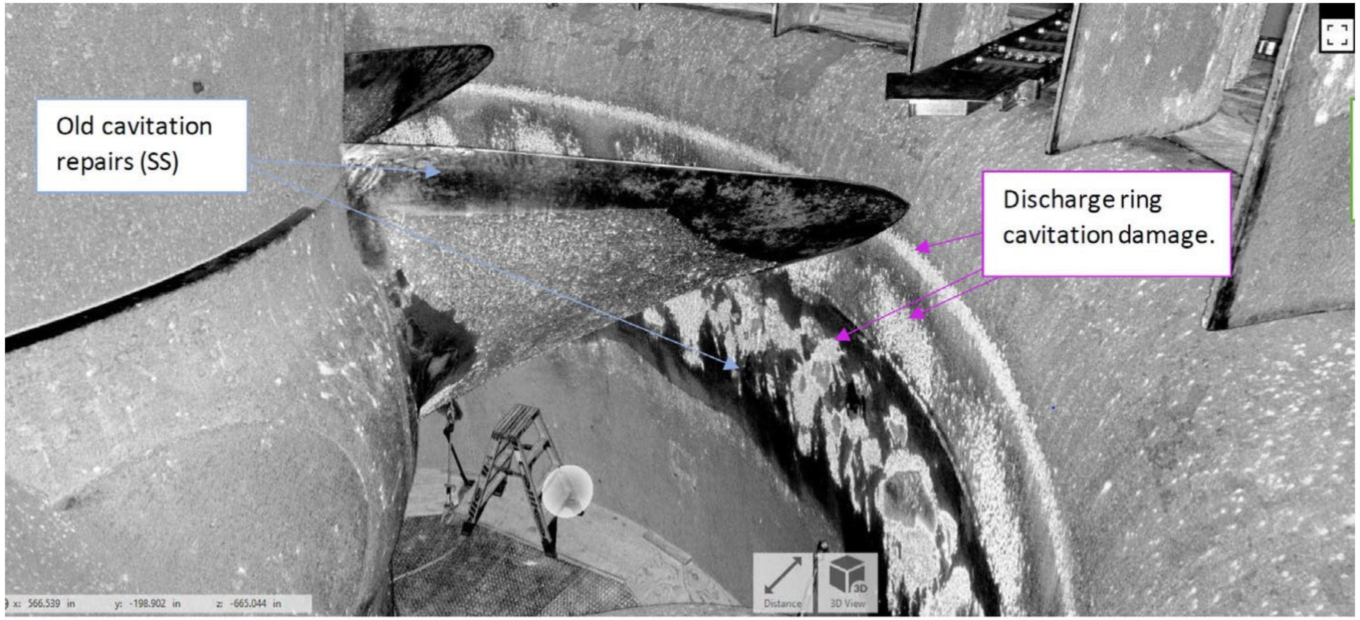
- FY21 planned budget was $500K. Received additional $257K near end of year and efforts were hampered by COVID related delays. Project progress (and expenditures have accelerated in FY22 to reduce difference between budget and expenditures

End-User Engagement and Dissemination

- Benefits
  - Lower operational costs and increased revenue to hydropower operators, which could ultimately impact the public and industry with lower electrical rates.
  - Operators and administrators also have the potential to improve their flexibility to help address ever increasing variable demand, especially as other renewable energy sources become a more significant part of the electricity supply
- A multi-faceted communication strategy has been developed and is being followed whose purpose is to optimize the commercialization path, which includes, but is not limited to
  - Engaging in monthly project review calls with hydropower administrator, BPA
  - Periodic project reviews and assistance in development plans and processes for the initial field application with ACE
  - Presenting at hydropower related conferences, especially those where administrators, operators, and field service providers will be in attendance
  - Journal publications with high impact factor and high likelihood of visibility to hydropower plant operators and administrators
  - Monthly project reviews and periodic summary reports/presentations to WPTO

End-User Engagement and Dissemination

- The project will culminate with a field application and multi-year post-repair inspection.
  - Will involve cold sprays in multiple areas to develop understanding of the transferability of the accelerated cavitation erosion testing process versus actual cavitation performance
  - Will include commercial repair service providers
  - Significant involvement of hydropower plant oversight organizations and operators
  - Objective is to aid in the commercialization of this technology after the initial field application



End-User Engagement and Dissemination

- Publications related to project
  - X. Jiang, N. Overman, C. Smith, K. Ross, Microstructure, hardness and cavitation erosion resistance of different cold spray coatings on stainless steel 316 for hydropower application, Materials Today Communications 25 (2020) 101305
- Presentations Related to project
  - NHA Water Power Week 2018
  - Cold Spray Action Team Conference, June 2018
  - SWHPA Meeting 2018
  - NW Hydropower O&M Workshop Northwester Division USACA, Reclamation, BPA 2018
  - DOE WPTO R&D Highlights 2019
  - CEATI HPLIG General Meeting 2019
  - Invited speaker to present project at EPRI Hydropower Materials workshop, May 2022
  - Cold Spray Action Team Conference, June 2022

Performance: Accomplishments and Progress

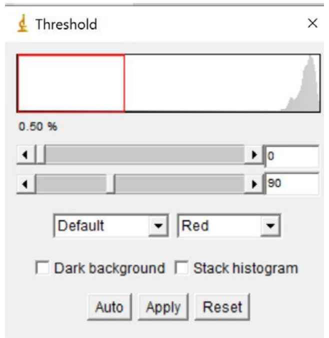
- Multiple factor potential improvement in cavitation erosion resistance has been demonstrated that could significantly positively impact economics of hydropower plant operations
  - Improvement is greater on fixed equipment as compared to portable capable equipment
  - Fixed equipment is not suitable for in situ hydropower repair application
- Initial transference to portable capable equipment resulted in clogging of CS nozzle
- Alternate approaches considered and/or investigated to resolve clogging
  - Blending of powders with hard particles discovered to significantly reduce or eliminate issue
  - Cooling of nozzle does not appear to have significant impact
  - Alternate nozzle materials may have impact but not investigated to date

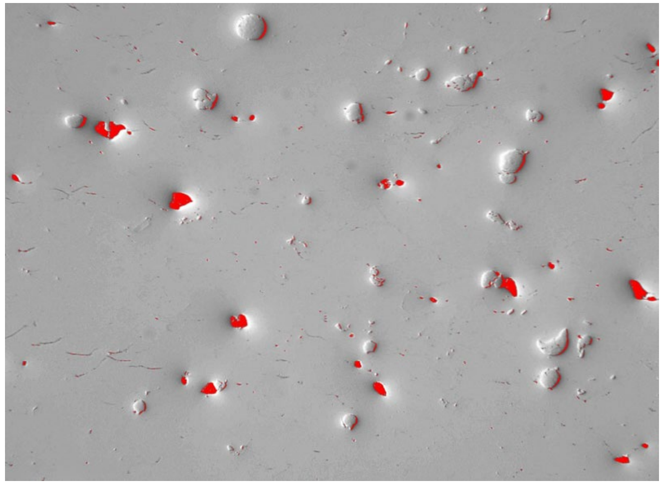
Typical Cold Spray Deposit (Top View)

Performance: Accomplishments and Progress (cont.)

- A major focus of the project is to develop and understanding of the effect of input variables on resulting cold spray deposit performance
  - Porosity (Image J Image Processing)
  - Deposit rate
  - Cavitation erosion performance per ASTM G134 (accelerated test)
  - Adhesion strength per ASTM D4541

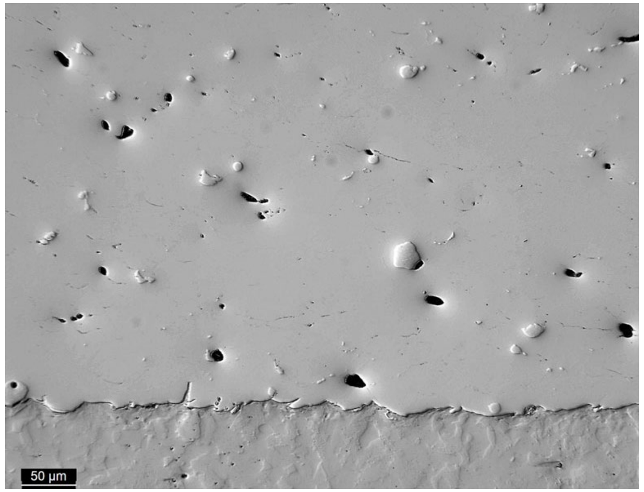
Adhesion Testing Equipment





Porosity Estimation

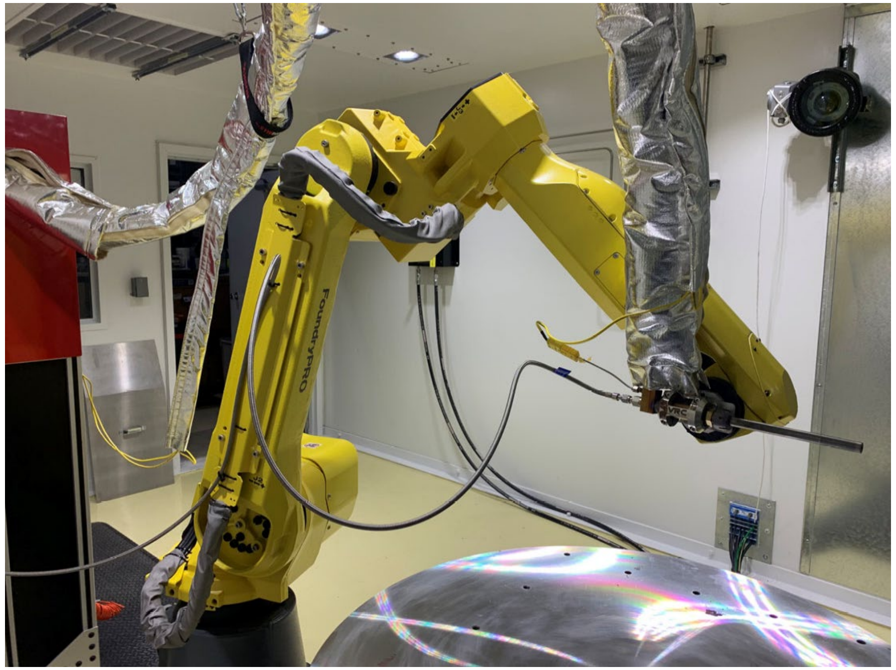
PNNL Cavitation Testing Equipment



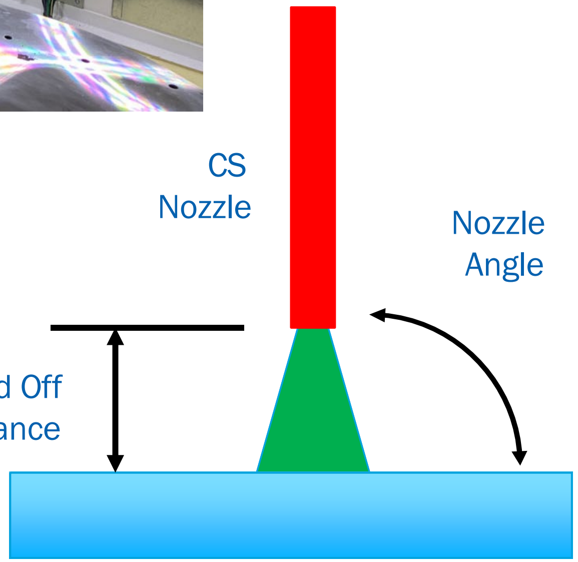
Cold Spray Deposit Near Substrate Interface

Performance: Accomplishments and Progress (cont.)

- Input variables
  - Process Parameters
    - Carrier gas temperature
    - Carrier gas pressure
  - Powder flow rate
  - Powder blend ratios
  - Substrate / base material
    - 304L Stainless
    - Stainless Steel weld Repair
    - A27 Cast Steel (turbine material)
    - A515 plate steel (discharge ring material)
  - Human Disturbance Inputs / Variables
    - Standoff distance
    - Nozzle angle
    - Travel speed
- Cold Spray Trials performed on robotic cold spray system

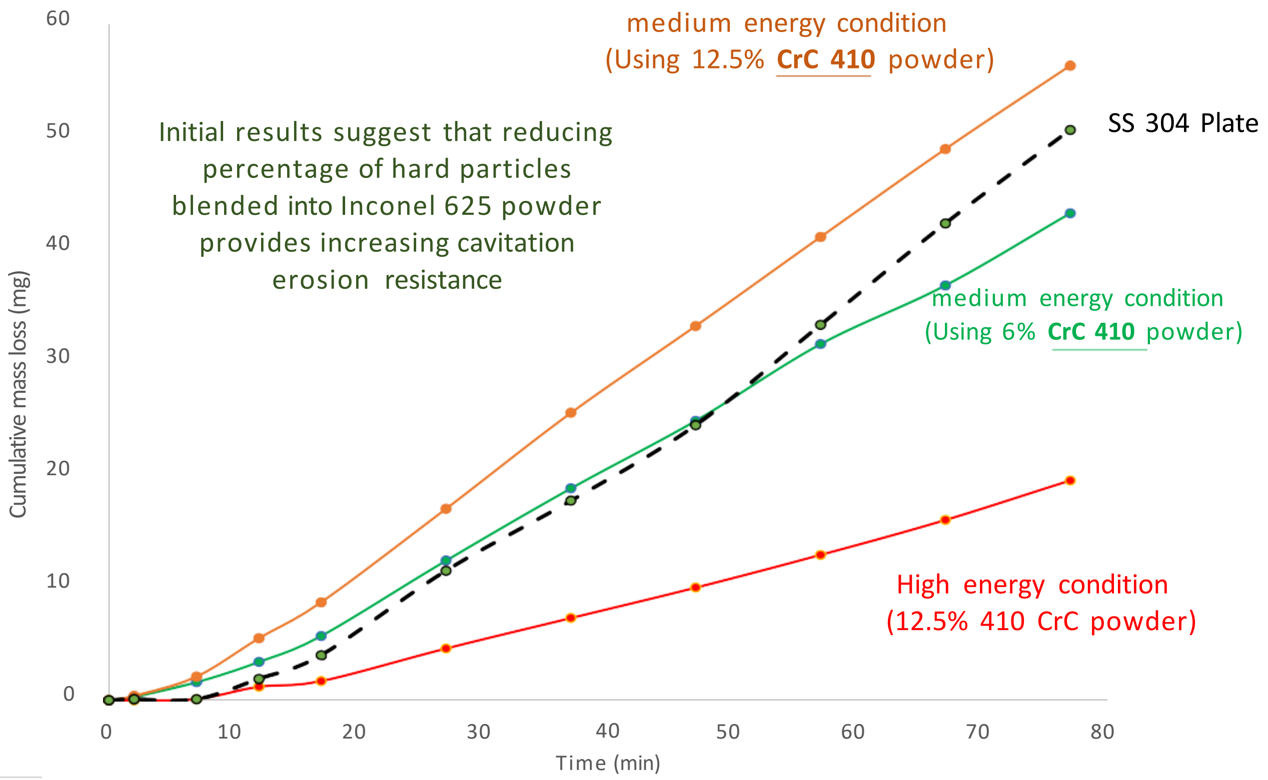


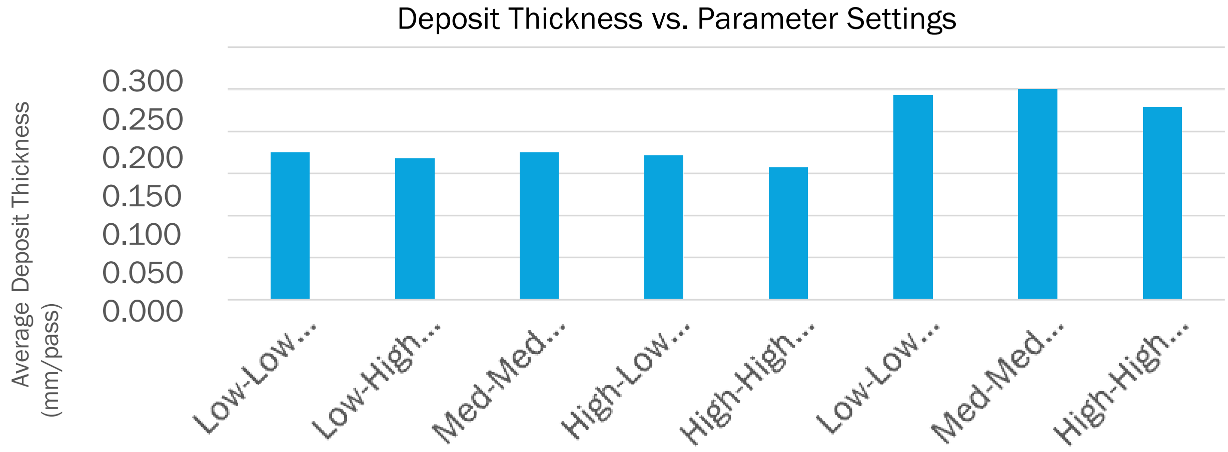
PNNL Robotic Cold Spray System



Performance: Accomplishments and Progress (cont.)

- Adhesion performance consistent over range of inputs tested
- Porosity is affected by CS parameters
  - Temperature and pressure
  - Lower porosity with higher energy condition
- Deposit rate generally unaffected except for input powder flow rate and blend ratios





- Initial data indicates cavitation results are a function of input parameters, suggesting there will be optimal operating conditions and opportunities to improve results

Performance: Accomplishments and Progress (cont.)

- A field application site has been identified
  - Little Goose Dam, Lacrosse, WA
  - Army Corps of Engineers has agreed to site and has active project related to field application
  - Field application actively being planned and pursued by ACE for late calendar year 2023 or early 2024 demonstration
- 2021 merit review noted this project as “probably the most promising hydropower research project I have seen in the last 10 years”
- Invited speaker to 2022 Hydropower Materials Workshop hosted by EPRI

Little Goose Dam on Snake River in Lacrosse, WA

Future Work

- Complete cold spray trials and characterization simulating the effect of human input disturbances to the process (e.g. travel speed variation, stand off distance variation, nozzle angle variation)
- Complete cold spray trials and characterization using different base materials found in hydropower hardware existing at Little Goose Dam (A27 Cast Steel and A515 wrought steel)
- Complete cavitation testing from cold spray deposits created using variation in all process inputs to develop understanding of impact of these inputs
- Perform R&D in an effort to transition to nitrogen or air as carrier gas versus helium (very costly) that is currently being used
- Develop hardware innovations on portable capable CS system that would enable improvements in cavitation performance that is known to be possible based on use of early fixed CS equipment results

Q&A