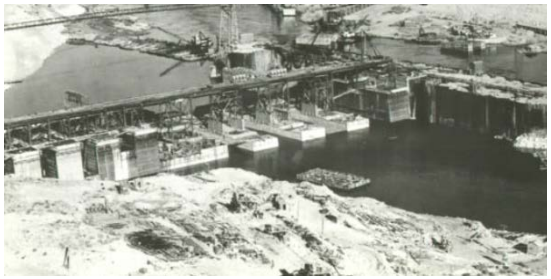
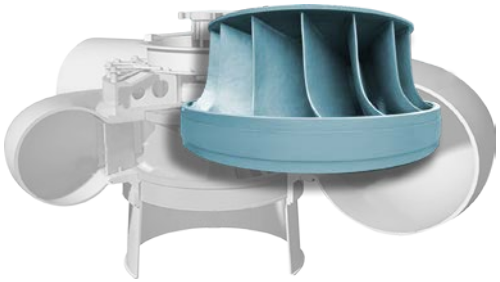




# Solid State Processing for Improved Performance of current and Next-Generation Hydropower Components

Agreement #31902

**WPTO TCF**

Oct 10th 2019

**Ken Ross**

PNNL

# Project Overview

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

## Project Summary

- Supported by TCF, the objective is to demonstrate feasibility of ***solid state processing (SSP)*** for repair and manufacturing of hydropower components, with increased service life and repair cycles. SSP, such as cold spray and friction stir welding, distinguishes itself from conventional fusion welding, produces improved materials' properties and performance through refined microstructures.

## Project Objective & Impact

- This project was to kick-start the US hydropower industry's use of SSP to dramatically enhance the performance and service life of new and repaired hydropower components. This will result in increased robustness and sustainability of America's hydropower infrastructure.
- This project also generated data showing that the SPP can dramatically outperform existing technology and address technical concerns relative to implementation of SPP technologies for hydropower.

## Project Information

Project Principal Investigator(s)

Ken Ross

WPTO Lead

Marisol Bonnet

Project Partners/Subs

Bonneville Power Administration
MOOG,Inc
VRC Metal Systems
Army Research Laboratories

Project Duration

10/01/2016
09/30/2019

# Alignment with the Program



## Hydropower Program Strategic Priorities

Environmental R&D and Hydrologic Systems Science

Big-Data Access and Analysis

- Technology R&D for Low-Impact Hydropower Growth
- R&D to Support Modernization, Upgrades and Security for Existing Hydropower Fleet
- Understand, Enable, and Improve Hydropower's Contributions to Grid Reliability, Resilience, and Integration

# Alignment with the Hydro Program



## Technology R&D for Low-Impact Hydropower Growth

- Leverage new advancements in manufacturing and materials to dramatically lower costs of SMH components and systems designs

– Results from this project are expected to help incorporate **solid state processing** for hydropower manufacturing

## Understand, Enable, and Improve Hydropower's Contributions to Grid Reliability, Resilience, and Integration

- Invest in innovative technologies that improve hydropower capabilities to provide grid services

– improved performance enabled by **solid state processing** is expected to improve hydropower capabilities and resilience

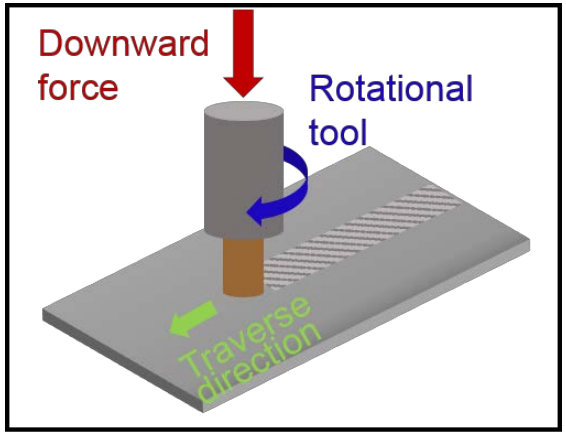
# What is Solid State Processing?



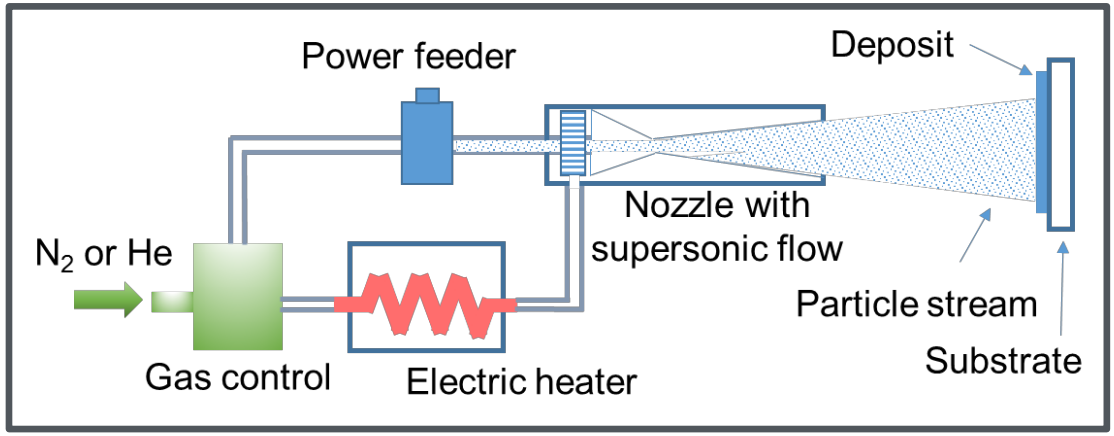
Solid State Processing: materials processing in the solid state, with no melting. Typically involves mechanical/shear strain that facilitates diffusion & phase transformations.

The microstructures produced through SSP → improved, and sometimes dramatically improved, performance in metal alloys, relative to the performance of the same alloys produced by conventional processes

## 1. Friction Stir Welding (FSW):




## 2. Cold Spray



# Project Budget



| FY17 | FY18 | FY19 (Q1 & Q2 Only) | Total Project Budget FY17–FY19 Q1 & Q2 (October 2016 – March 2019) | |
|---|---|---|---|---|
| Costed | Costed | Costed | Total Costed | Total Authorized |
| [$129.552 $K] | [$41.712 $K] | [$24.079$K] | [195.342 $K] | [$200 $K] |

This project was funded by the Technology Commercialization Fund (TCF), which aims to promote promising energy technologies to the marketplace. A 50% cost match was provided by funds from PNNL's Technology Investment Program which are derived from commercial IP licensing revenues.

# Management and Technical Approach



- **Technical approaches**
  1. Solid state processing of materials, including friction stir welding and cold spray;
  2. Testing of their cavitation erosion performance;
  3. Mechanical testing and microstructure evaluation.

- **Technical milestones**
  - 30% improved cavitation erosion resistance relative to base metal for FSW of stainless steel (SS) 304
  - Improvement in mechanical properties
  - Produce a large area cavitation test coupon with equivalent or greater cavitation erosion greater than that of extruded stainless steel 316 plate.
  - Written final report and a final presentation

# End-User Engagement and Dissemination Strategy



## Benefits to End Users:

- Improved resilience and efficiency enabled by SPP of hydropower infrastructure is a benefit to project owner/operators, power regulators and regional economies.
- Regional environmental and agricultural stakeholder benefit from the ability to build multiyear buffers in repair schedules to prevent lowering of reservoirs during drought years, providing a safeguard for irrigation resources and reducing the risk of fish entrainment.
- This project directly collaborates with many end users. This ensures end users provide input and stay up to date with project developments. It will also accelerate technology application because relationships of trust are being built between end users and technology providers who are participating in this work.

# End-User Engagement and Dissemination Strategy, cont'd



## Owner/operator outreach for repairs:

- Bonneville Power Administration (BPA), the U.S. Army Corps of Engineers (ACE), the Bureau of Reclamation (Reclamation), and Idaho Power have contacted PNNL to discuss use of SPP technologies for repairs at various projects.
- BPA, ACE, and Reclamation are working to identify hydropower projects where SPP technologies can be applied and evaluated.
- Collaborators are supporting efforts to expand SPP R&D by providing cost share to DOE funding opportunities. Project partners participated in two additional TCF proposals, one of which awarded.
- Collaborators are increasing awareness of SPP technologies for hydropower within their own organizations by holding webinars to reporting findings from this project internally, including findings from this project in internal reports and sending engineers to join PNNL at technical meetings and conferences.

# End-User Engagement and Dissemination Strategy, cont'd



**PNNL engaged the broader hydropower community on SPP at the following events:**

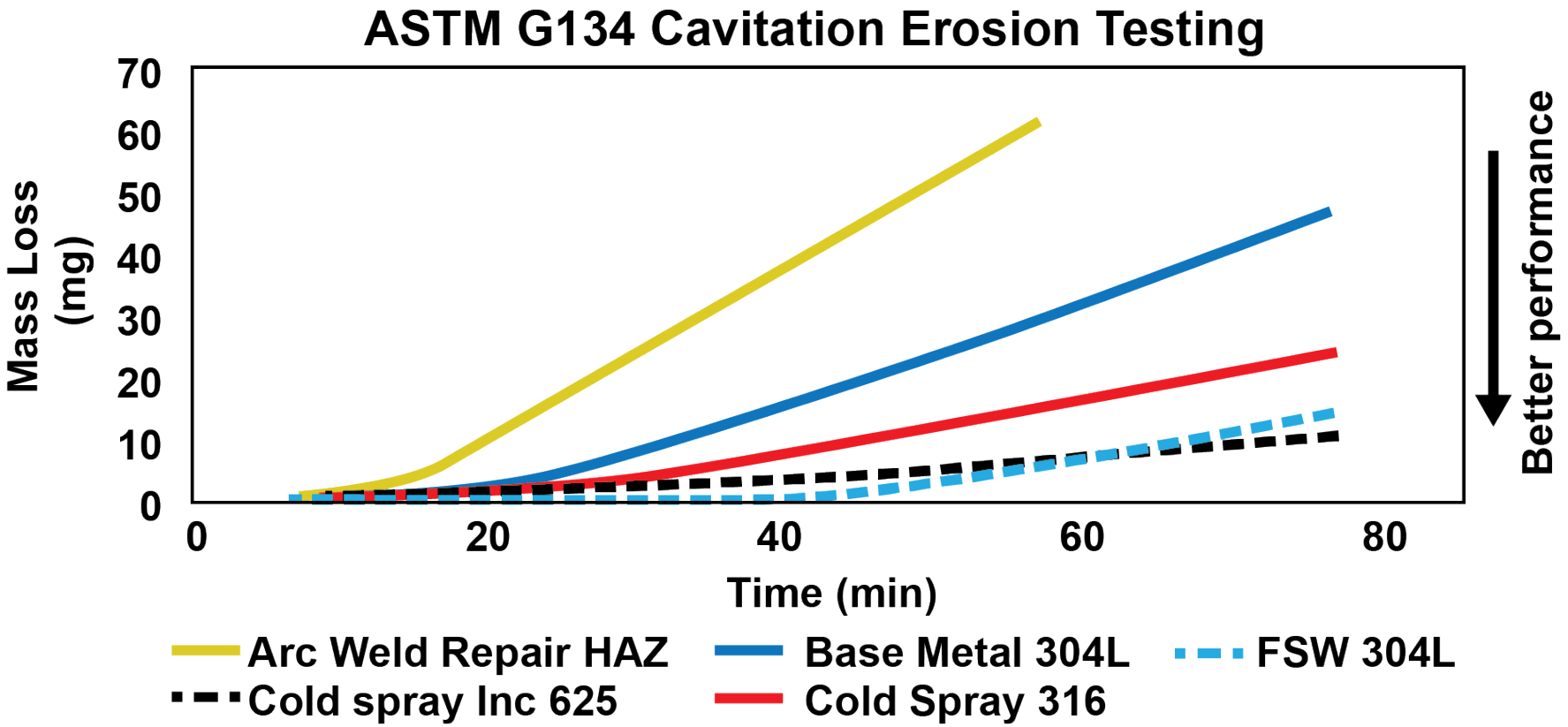
- NWHA Technical Workshop; April 2016
- PNNL Cold spray for in-situ repair technical meeting at Grand Coulee; August 2016.
- NHA Southwest Regional Meeting; February 2018
- NHA Waterpower Week; May 2018
- Cold Spray Action Team Meeting; June 2018
- NHA Hydraulic Power Committee (HPC) Fall Retreat & NWHA Technical Conference; October 2018
- NW Hydropower O&M Workshop (Northwestern Division USACE, Reclamation, BPA); December 2018
- Cold Spray Action Team Meeting; June 2019
- CEATI Hydraulic Plant Life Interest Group: Sept 2019
- MS&T conference: Sept 2019

# Technical Accomplishments



- **Greatly exceeded the project milestone to demonstrate at 30% improvement in cavitation erosion resistance relative to 304/304L:**
  - ASTM G-134 testing showed cold sprayed Inconel 625 produces a 342% improvement in cavitation erosion resistance, calculated using volume loss, compared to SS 304/304L plate.
  - ASTM G-134 testing showed FSP of 304/304L produced a 224% improvement in cavitation erosion resistance calculated using volume loss compared to SS 304/304L plate.
  - ASTM G-134 testing showed cavitation erosion resistance of the region adjacent to FSW/P had the same cavitation erosion resistance as the base material. This implies that there is no detrimental heat affected zone.

# Technical Accomplishments (Cont.)




- Cavitation erosion behavior (mass loss) of different materials

# Technical Accomplishments (Cont.)



- **Primary mechanism for improved cavitation erosion resistance were identified through materials characterization and analysis**
  - Induced cold work was the primary mechanism for improve performance of cold spray
  - Grain refinement was the primary mechanism for improved performance of FSW/P

- **ASTM E-8 with digital image correlation (DIC) testing showed FSW/P exhibited improved strength relative to base metal**

# Technical Accomplishments (Cont.)



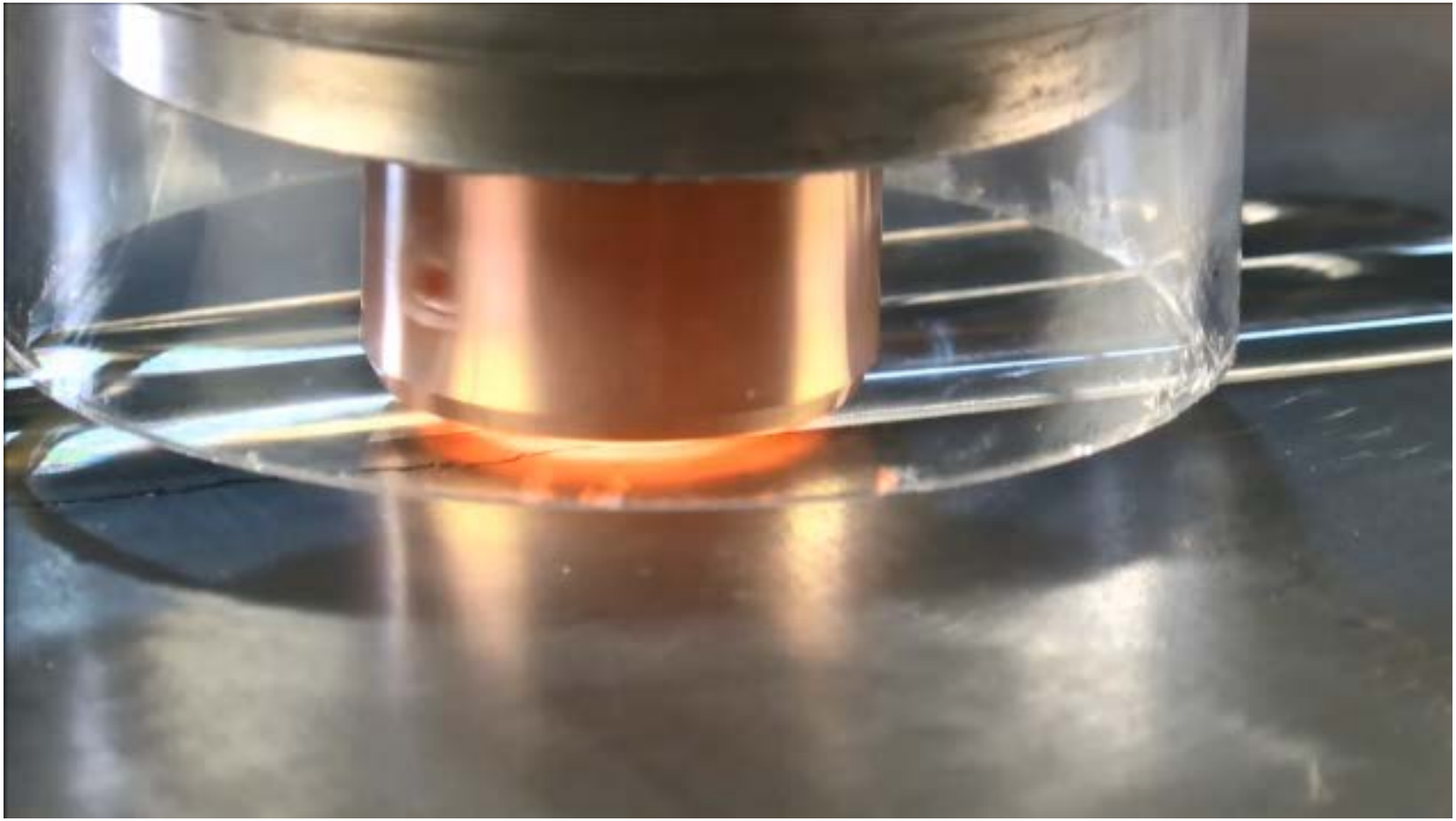
- Weld temperature can be controlled during FSW/P to produce smaller grained material with improved cavitation erosion resistance
- Field equipment was identified with tooling to execute cold spray repairs in areas with clearances as small as 1.5 in.
- Demonstrated that existing field NDE techniques can detect small differences in cold spray deposits and therefore are likely to be affective for in field inspection and quality assurance
- Produce 2 large area cavitation coupons using cold sprayed SS 316. ASTM G134 testing shows that cold sprayed used of the large area coupons has 51% the mass loss compare to SS 304/304L.

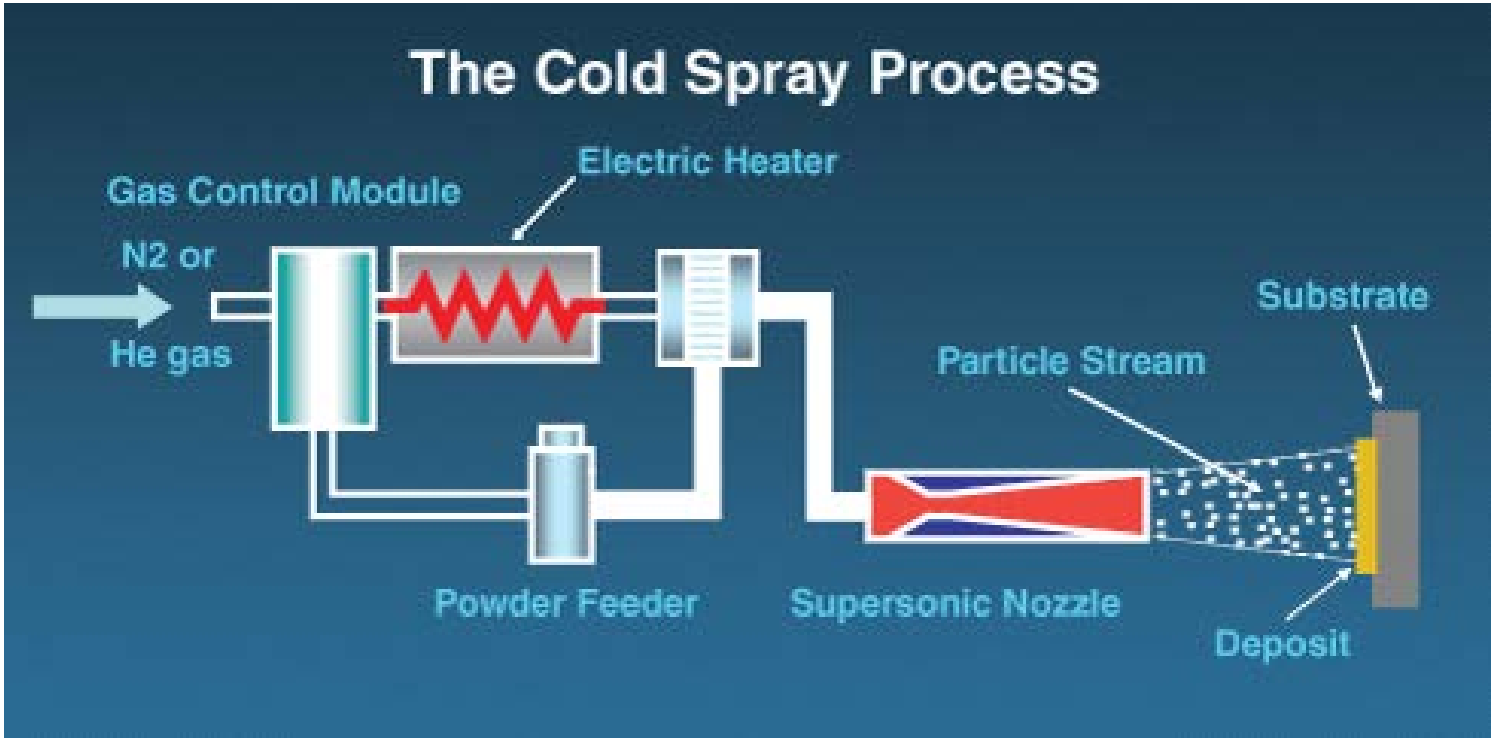
# Future work

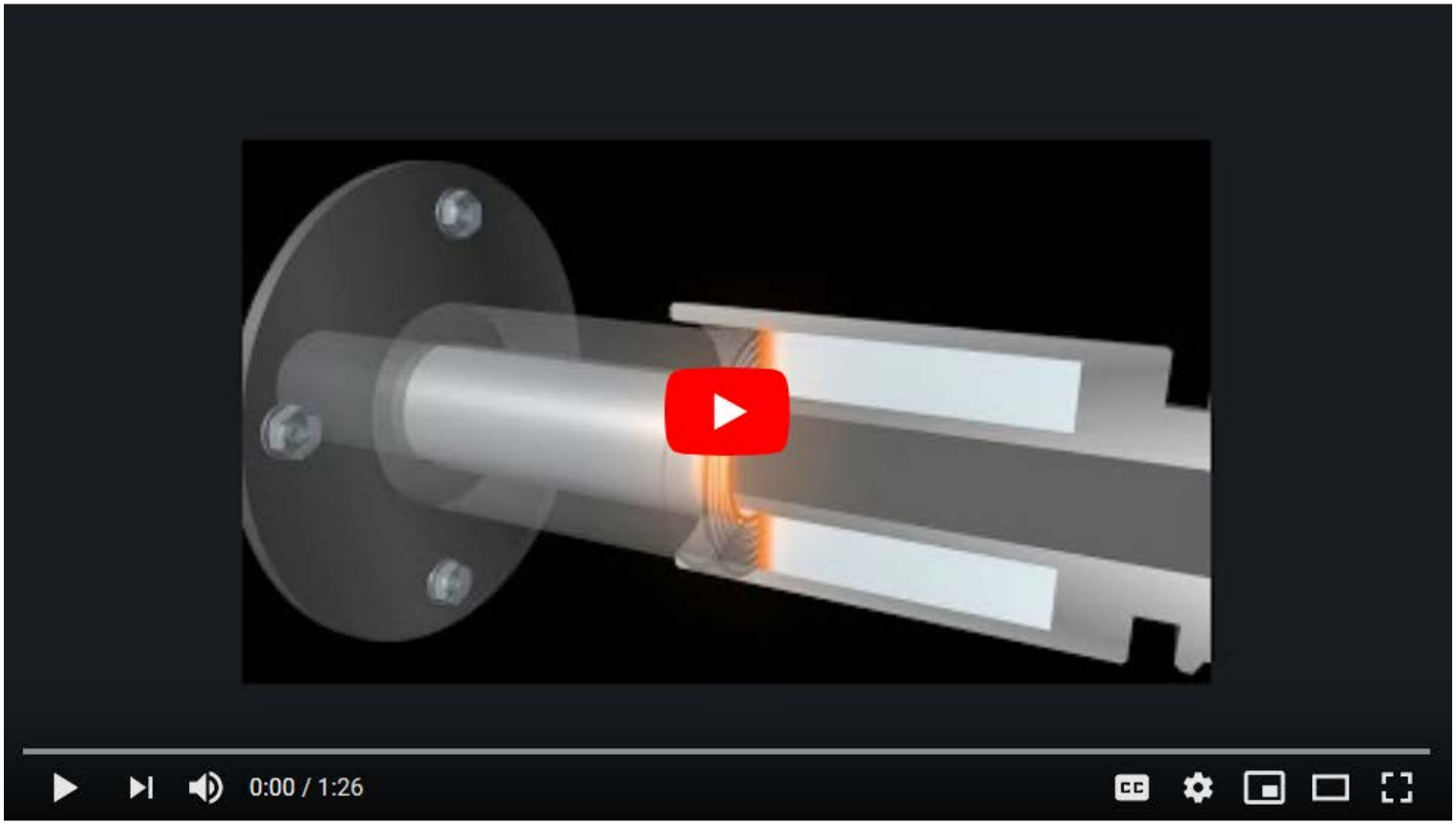


- Powder and process development for cold spray technology
- Field testing and application of cold spray repair
- Modular manufacturing of hydropower components using solid phase processing

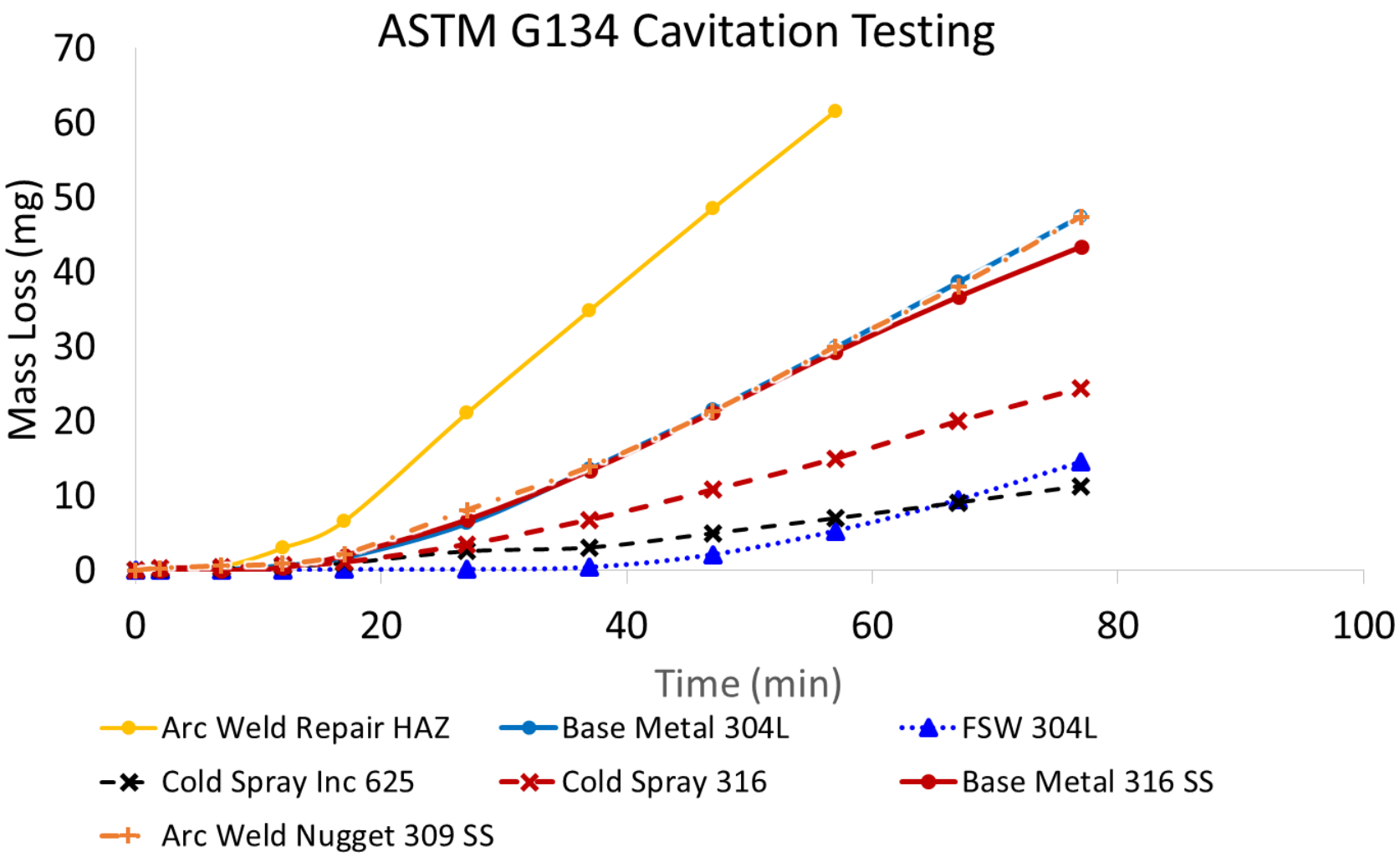
# Backup slides

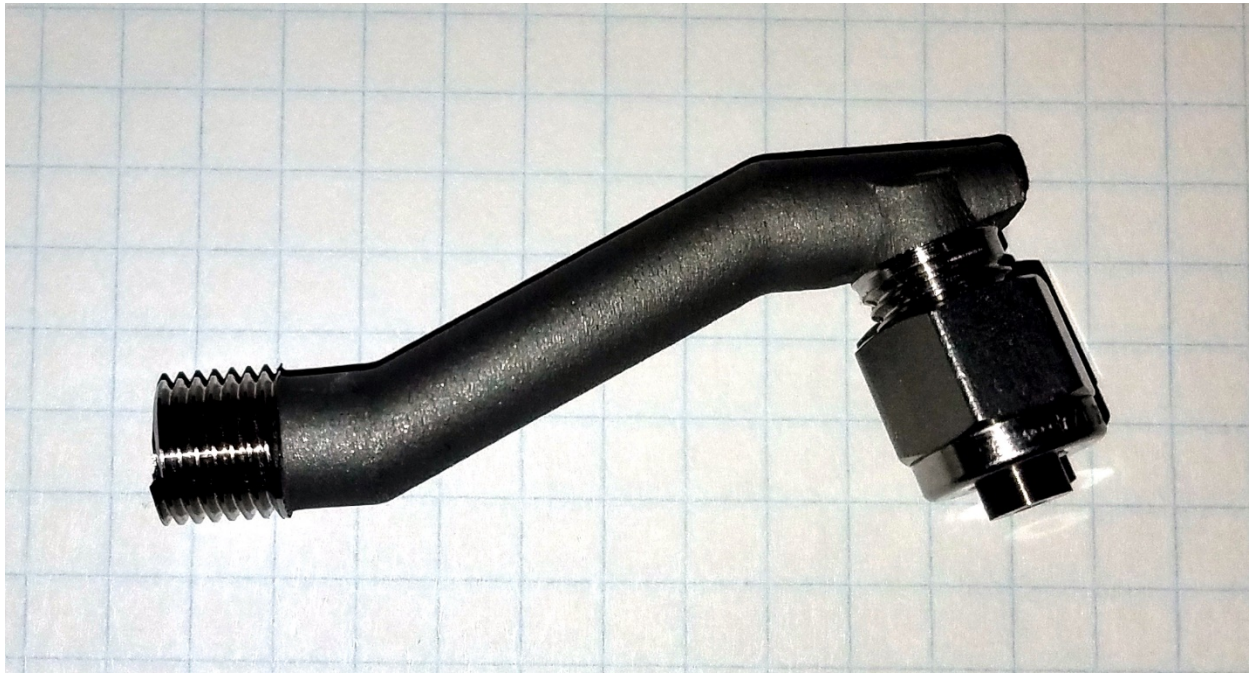



The Cold Spray Process
Gas Control Module
Electric Heater
N2 or
He gas
Substrate
Particle Stream
Powder Feeder
Supersonic Nozzle
Deposit




https://www.youtube.com/watch?v=rsjkZZv-irg&feature=youtu.be


ASTM G134 Cavitation Testing
Mass Loss (mg)
70
60
50
40
30
20
10
0
0
20
40
60
80
100
Time (min)
Arc Weld Repair HAZ
Base Metal 304L
FSW 304L
Cold Spray Inc 625
Cold Spray 316
Base Metal 316 SS
Arc Weld Nugget 309 SS



Army Research Lab's cold spray nozzle for clearances as small as 1.5in.