Cold Spray Repair and Mitigation for Hydropower Parts

KEN ROSS, XIUJUAN "HELLEN" JIANG, NICOLE OVERMAN, JACK LAREAU, DAVID ANDERSON

Introduction: Cavitation

- Most metal hydropower components are manufactured and repaired using materials and techniques used 30 years ago
- During manufacture, alloying and thermomechanical history of high performance steel is tightly controlled to create the desired microstructure
- When turbine blades are originally installed their surfaces are smooth and produce little or no cavitation
- Over time pits begin to form on the surface of the metal
  - Once Pits are large enough to act as nucleation sites wear rates and intensity of cavitation increases with time
  - Eventually the turbine is shut down for repair

Introduction: Cavitation

- High heat input and melting associated with the type of arc welding repair common for cavitation degrades the steel microstructure
- **Once the first weld repair occurs, the frequency of repair dramatically increases**
- This is because high heat input during the welding processes degrades the material around the repair zone making it weak
- **There is a better way!**

Introduction: Solid Phase Processing

- Fusion Welding
  - Melting
  - High heat input
  - Degradation of properties that can't be recovered
- Solid Phase Processing (SSP)
  - No melting
  - Low heat input
  - Grain refinement
  - Superior properties can be achieved

Goals

- Repair that does no harm to base metal
- Repair with superior properties/performance than original "as fabricated" component

Cold Spray

- Solid phase process
- Hand-held and robotic equipment are safe and commercially available
- Very low process forces
- Can be applied without removing impeller
- Can be easily applied to 3D geometries
- Cold spay processes can be developed to induce compressive residual stresses in to the deposited material and substrate
- Will cold spray repair hit our goals?
  - No harm to base metal
  - Improved properties/performance relative to new components

Experimental Work: Design

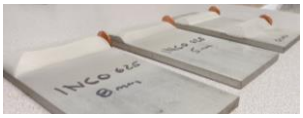
Cold Spray Coupons Generated
- Stainless Steel (SS) 316
- Inconel 625

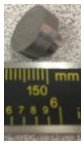
Base Metal Coupons
- SS 316
- SS 304/304L

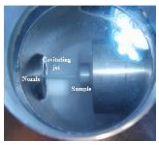
Stainless steel weld overlay coupon
- SS 309 nugget
- 1045 Carbon Steel arc weld HAZ

Friction Stir Processed 304/304L

ASTM G-134 Cavitation samples created for competitive benchmarking of cavitation erosion resistance



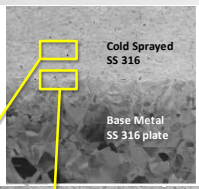


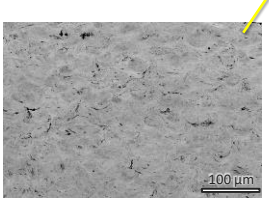


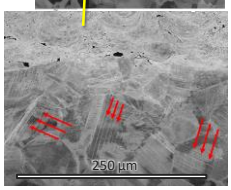
ASTM G134 cavitation sample and test chamber

Experimental Work: Cold Spray Microscopy

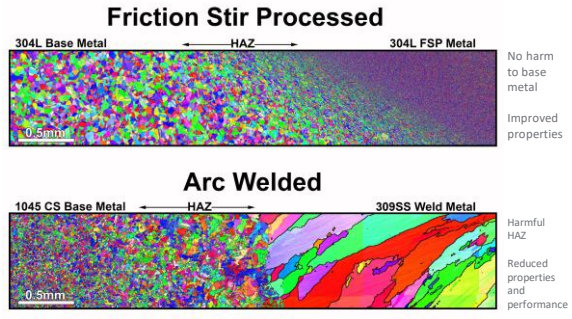
- No heat affected zone!
- Cold sprayed material is highly cold worked
  - Highly deformed with areas of dynamic recrystallization and Nano sized grains
- Base metal near the cold sprayed interface is severely deformed, extensive slip lines are visible as indicated by arrows below.



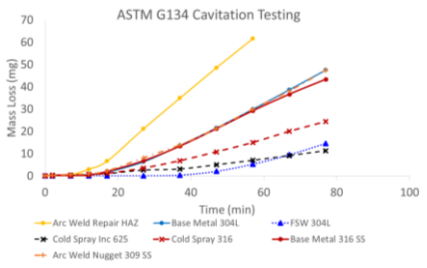




Experimental Work: Microscopy



Experimental Work: Cavitation Results



- ~31% mass loss of Cold Spray material compared to SS 304L Base metal and less than 10% that of the HAZ
- SS 304 and SS316 base metals and SS 309 have approximately the same mass loss curve
- Cold sprayed Inconel is competitive with friction stir processed stainless steel

Results suggest cold spray can produce material that have a 3-10x improvement in cavitation resistance compared to traditional materials/repairs

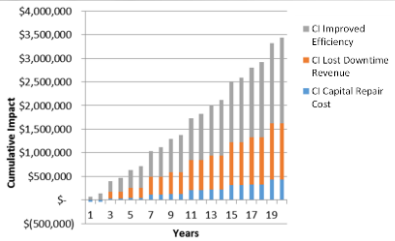
Advantages of Cold Spray Repair

- Increased Service Life
  - Improved corrosion resistance
    - ~3x improvement over SS 316 and SS 304 base metal and SS 309 weld nugget.
    - ~10x improvement over arc welded heat affected zones in carbon steels commonly used in turbine castings
- Can be applied in-situ
- Wide variety of applications
  - Turbine
  - Spill gates
  - Bearing housings
  - Shafts
  - Wicket gates
  - Etc.

Anticipated Value of Cold Spray - Direct

- Significantly improved life of repair or new component
  - Reduced frequency of repair
    - Less cost associated with downtime
      - Lost revenue
    - Reduced capital cost of maintenance and repair
      - Fewer inspections
      - Fewer repairs
  - Process does not damage base metal
    - No HAZ
    - No warping
- Improved Efficiency
  - Improved efficiency over time compared to existing technology
  - Enables new design concepts
- Improved wear and corrosion resistance

Anticipated Value of Cold Spray - Direct



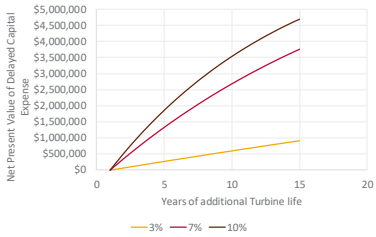
- Analysis of using cold spray instead of arc welding for a single 40 MW turbine at Green Peter Dam
- Assumes that repair interval is halved

Anticipated Value of Cold Spray - Direct

- Process does not damage base metal
  - No HAZ
  - No warping
- Could extend the service life of turbines
  - Delay large capital expenses for dam owner/operators

Anticipated Value of Cold Spray - Direct

NPV Avoided Costs @ Alternative Rates



For one 40MW turbine at green peter dam

Anticipated Value of Cold Spray Repair - Indirect

For some organizations the indirect benefits of dramatically improved service life of components outweigh the direct benefits.

Environmental Benefits
- No toxic gasses generated
- Reduced cavitation energy fish can be exposed to

- Increased robustness of dam system
  - Increased service life allows for buffer period so that repairs are made when convenient
  - For Example: **Ability to delay repair in drought years**
    - Fulfil other water uses such as irrigation
    - Eliminate fish entrainment due to reservoir drawdown
    - Maintain recreation in reservoir

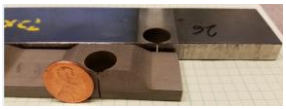
Anticipated Value of Cold Spray Repair - Indirect

- Example: Spill gates at Grand Coulee
  - Cavitation repair is required on spillways every 3 years or less
  - Lake Roosevelt must be drawn down below spillways to effectuate the repairs
  - Recently, required repairs fell on a drought year
  - Emptying and refilling the lake with low flow conditions resulted in a large entrainment of resident fish
  - Cold spray repair could have prevented this by providing a multi-year buffer

Current Work at PNNL

- Demonstrate cold spray's applicability to hydropower components
  - Generate performance data using ASTM testing to demonstrate that dramatic improvements in mechanical properties and service life can be obtained using SSP.
  - Data set and subsequent report will provide a roadmap for development of cold spray for existing and next-generation hydropower systems at the component level.
- Competitive Benchmarking
  - ASTM Testing
- Prototypical demonstrations
- Industry outreach
  - Meetings
  - Publications

Friction stir processed SS 304



Cold sprayed CrC-NiCr on SS 316 substrate

Current Work at PNNL

- Develop a cold spray repair process for hydro turbines
  - Optimize microstructure and material
  - Demonstrate superior cavitation resistance
  - Cost model to prove economic viability
- Establish a foundation for commercialization
  - Create standards/best practices
  - Create analysis tools
  - Generate performance data
  - Dam operators feel comfortable switching to cold spray repair

ARL VRC METAL SYSTEMS MOOG

BONNEVILLE POWER ADMINISTRATION U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION IDAHO POWER An IDACORP Company

Invitation

If you would like to learn more or become involved in this effort please contact:

Kenneth Ross
Materials Research Engineer
Applied Materials and Performance Group

Tel: 509-375-6513
kenneth.ross@pnnl.gov
www.pnl.gov