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Cold Spray Repair and Mitigation for Hydropower Parts

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Introduction: Cavitation

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- 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

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- 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

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- Fusion Welding
  - Melting
  - High heat input
  - Degradation of properties that can't be recovered
- Solid Phase Processing (SPP)
  - 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

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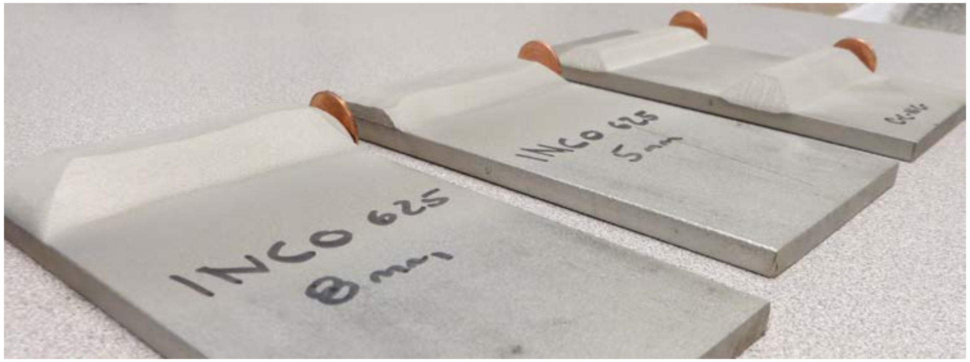
Cold Spray Coupons Generated
- Stainless Steel (SS) 316
- Inconel 625

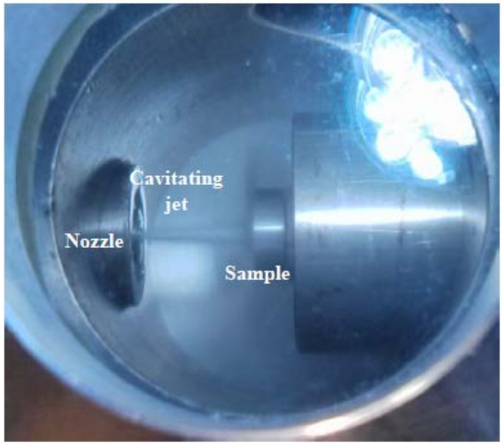
Base Metal Coupons
- SS 316
- SS 304/304L

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

Friction Stir Processed 304/304L



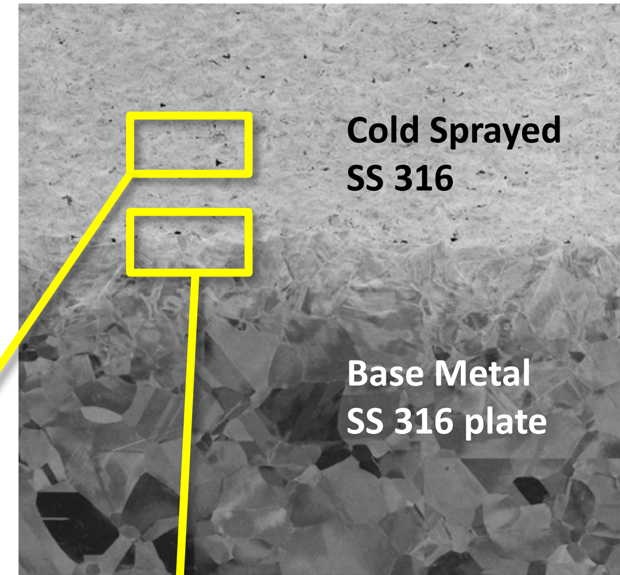
ASTM G-134 Cavitation samples created for competitive benchmarking of cavitation erosion resistance

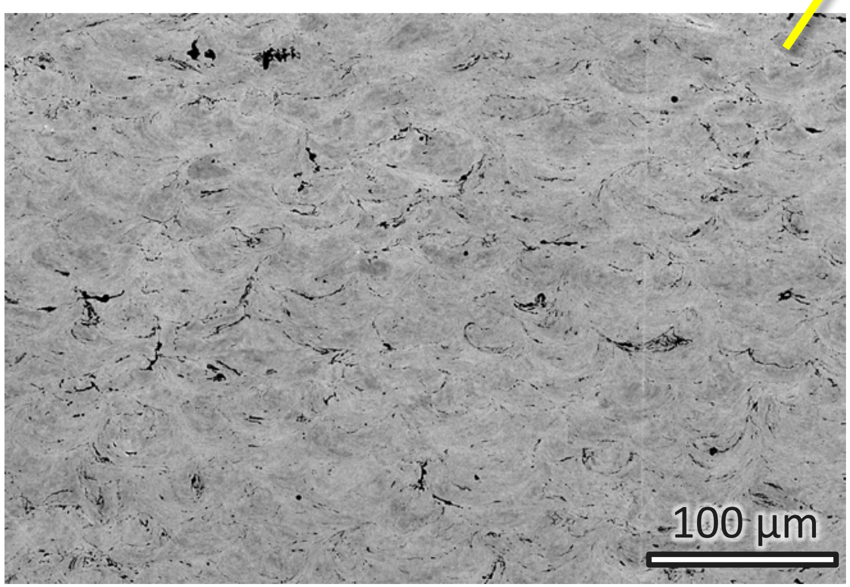


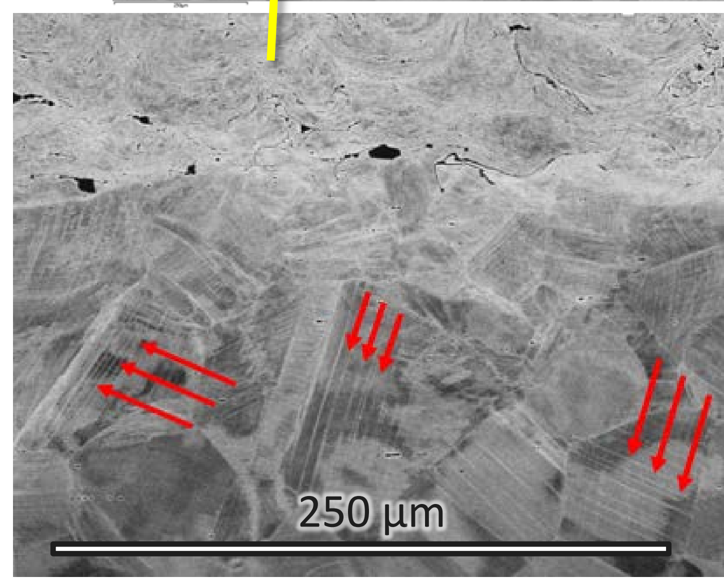
ASTM G134 cavitation sample and test chamber

Experimental Work: Cold Spray Microscopy

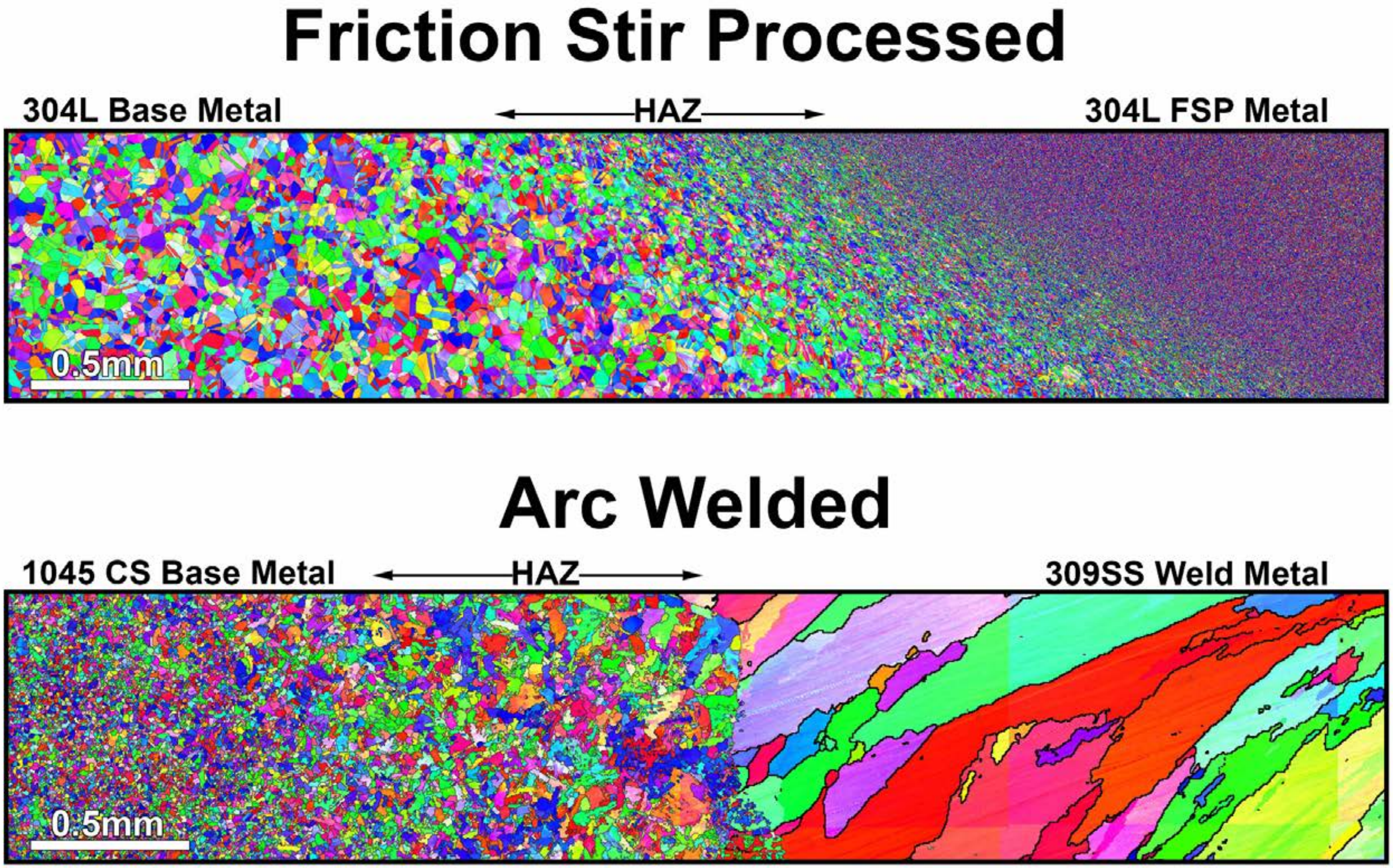
- No heat affected zone!
- Cold sprayed material is highly cold worked
  - Highly deformed with areas of dynamic recrystallization and Nano sized grains
- Base metal near the cold sprayed interface is severely deformed, extensive slip lines are visible as indicated by arrows below.







Experimental Work: Microscopy



No harm to base metal

Improved properties

Harmful HAZ

Reduced properties and performance

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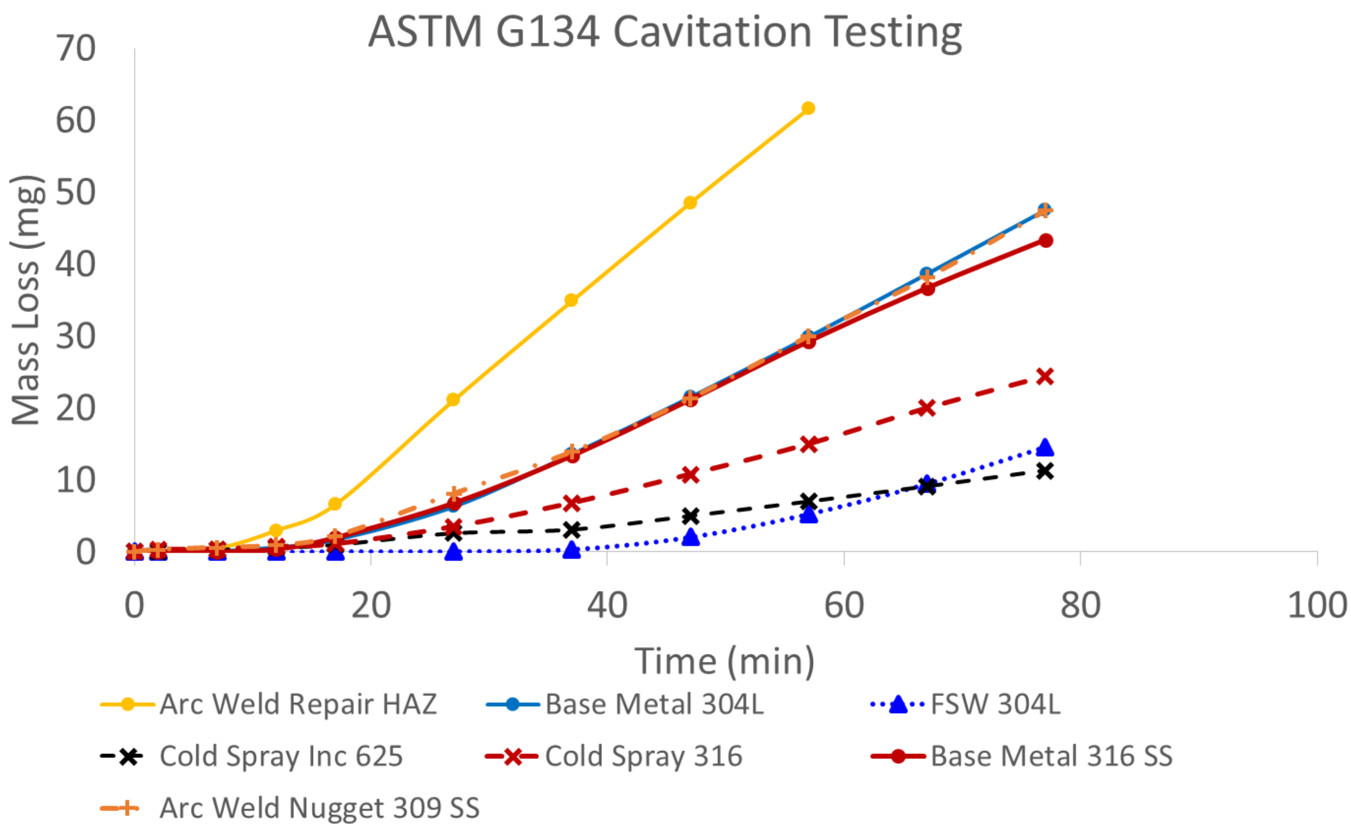
Experimental Work: Cavitation Results



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

- ~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

Advantages of Cold Spray Repair

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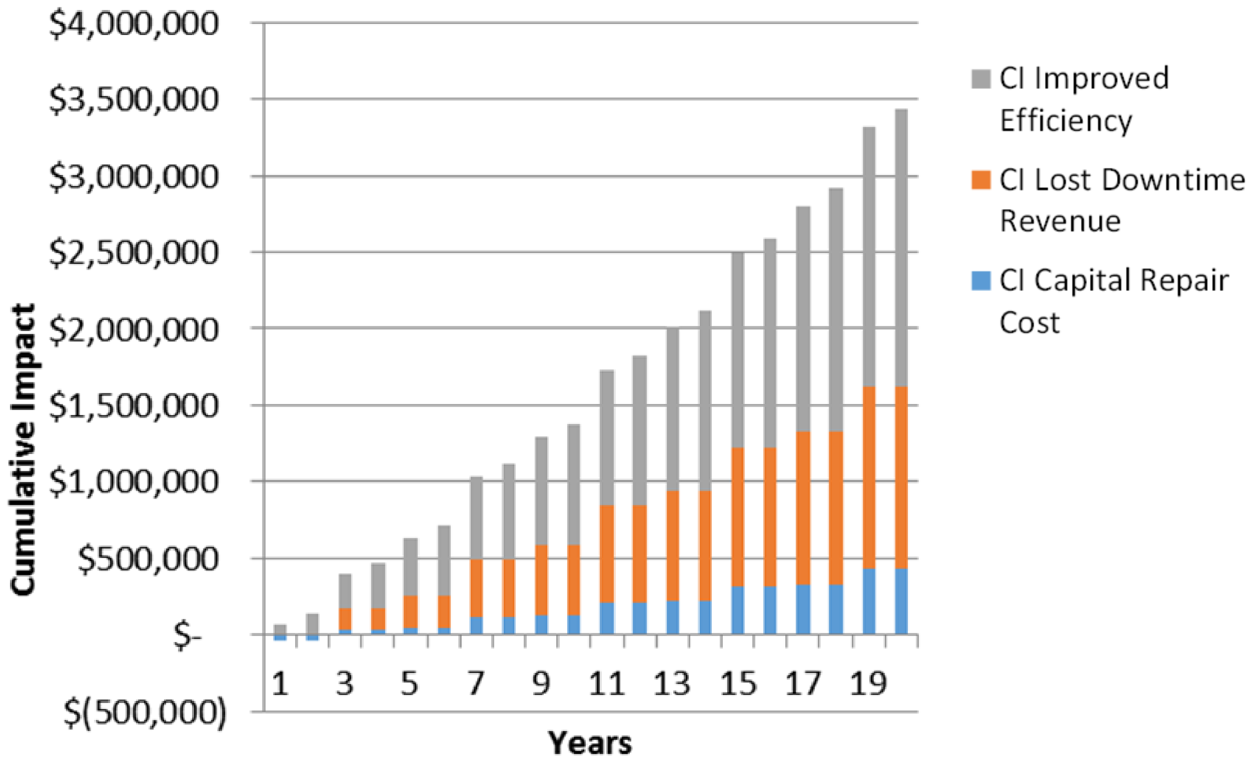
- Increased Service Life
  - Improved corrosion resistance
    - ~3x improvement over SS 316 and SS 304 base metal and SS 309 weld nugget.
    - ~10x improvement over arc welded heat affected zones in carbon steels commonly used in turbine castings
- Can be applied in-situ
- Wide variety of applications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

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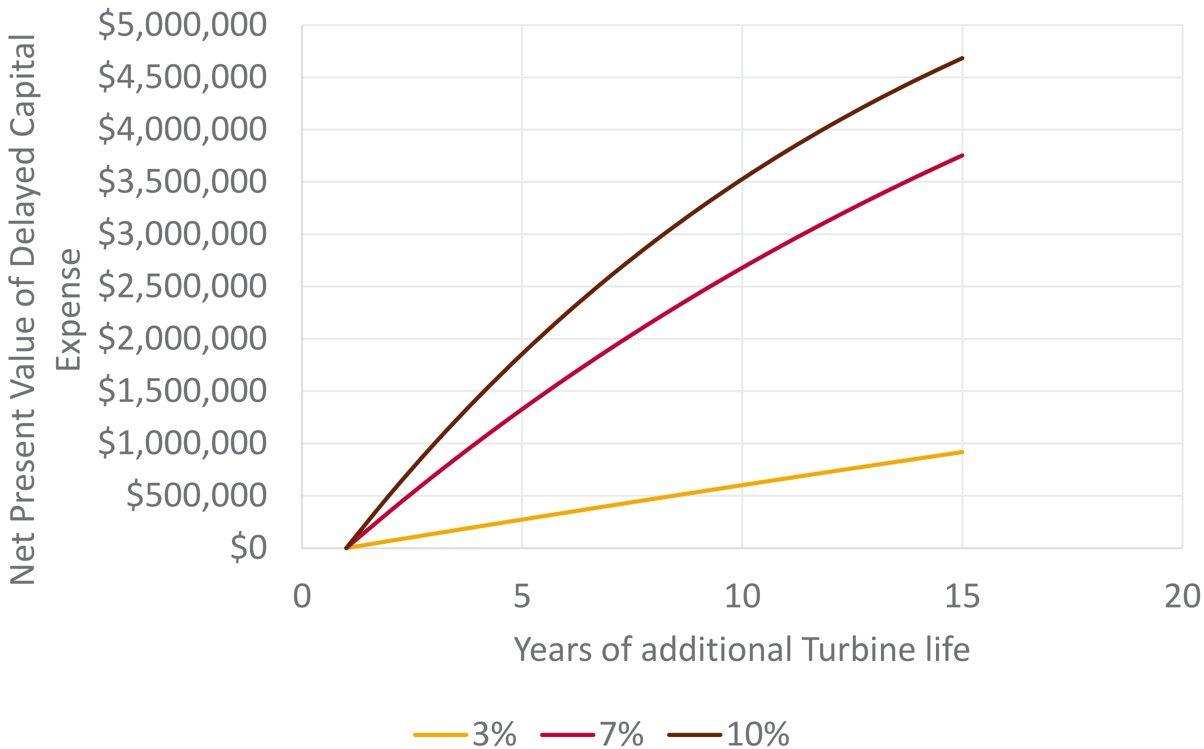
NPV Avoided Costs @ Alternative Rates



For one 40MW turbine at green peter dam

Anticipated Value of Cold Spray Repair - Indirect

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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

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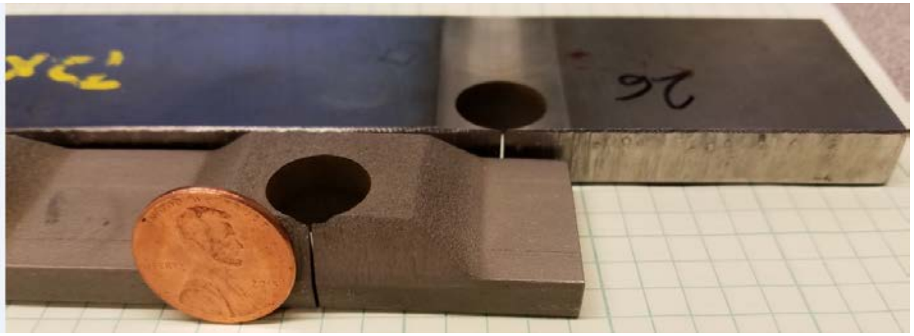
- Demonstrate cold spray's applicability to hydropower components
  - Generate performance data using ASTM testing to demonstrate that dramatic improvements in mechanical properties and service life can be obtained using SSP.
  - Data set and subsequent report will provide a roadmap for development of 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

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- 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

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Invitation

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

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