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Surface Stress Improvement Technologies Qualification

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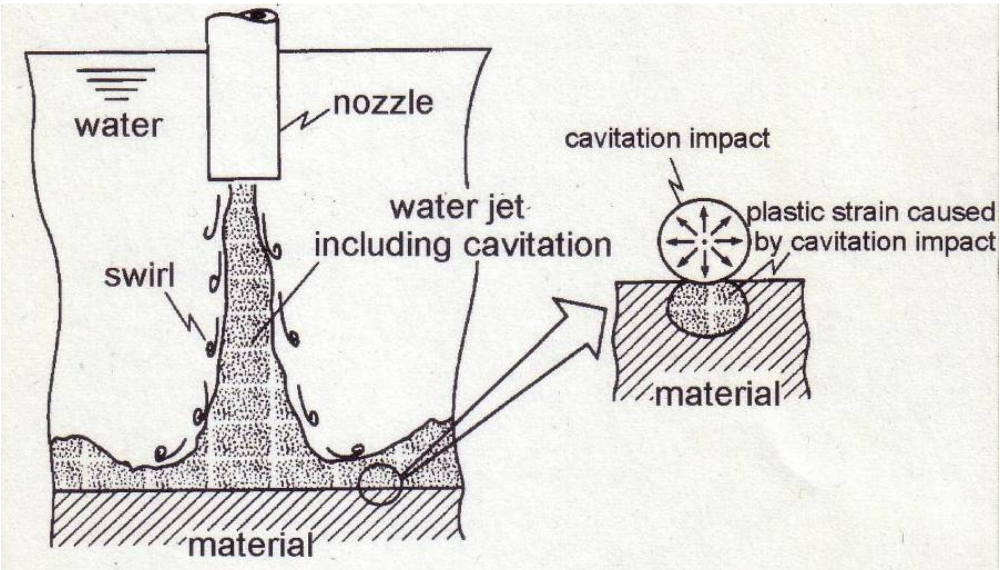
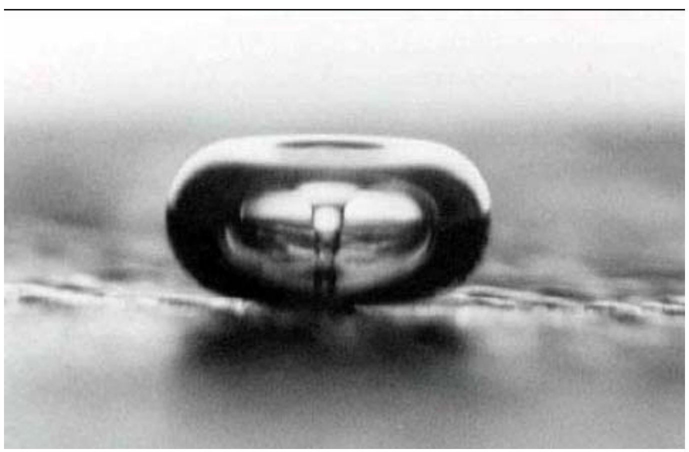
MRP/PWROG Mitigation Briefing to NRC RES

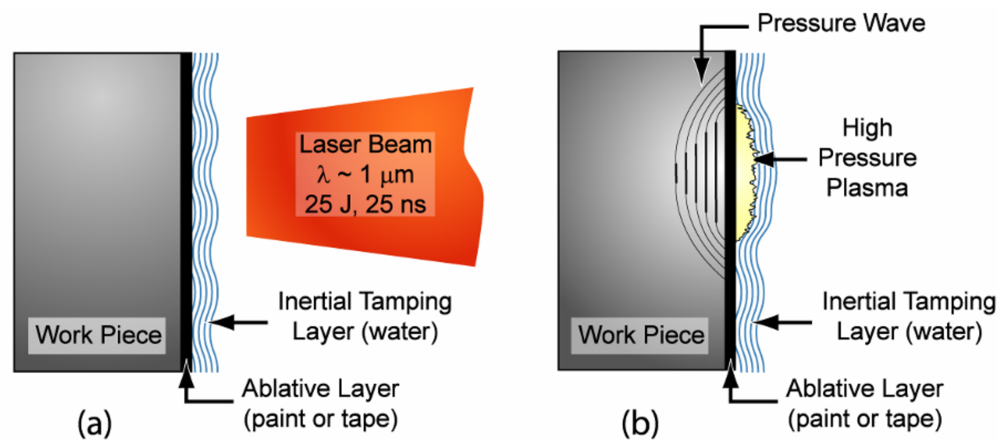
Technology Investigated: Cavitation Peening





- High pressure water jet create intense clouds of cavitation around the water jet
- Cavitation bubbles collapse on the surface of the material generating shockwaves
- Results in plastic deformation and compressive residual stress
- Also called water jet peening (WJP) in Japan

Technology Investigated: Laser Peening



Laser peening: (a) Set up of work & (b) A high pressure plasma is generated by the laser impact, resulting in a pressure wave

- Laser System
  - Nd:Glass slab flash lamp pumped laser (1 µm)
  - Excellent beam quality
  - High average power
    - Energy output – to 20 Joules
    - Pulse width range – 10-50 ns
    - Rep. rate – 6 Hz
  - Spot size: 3-5 mm

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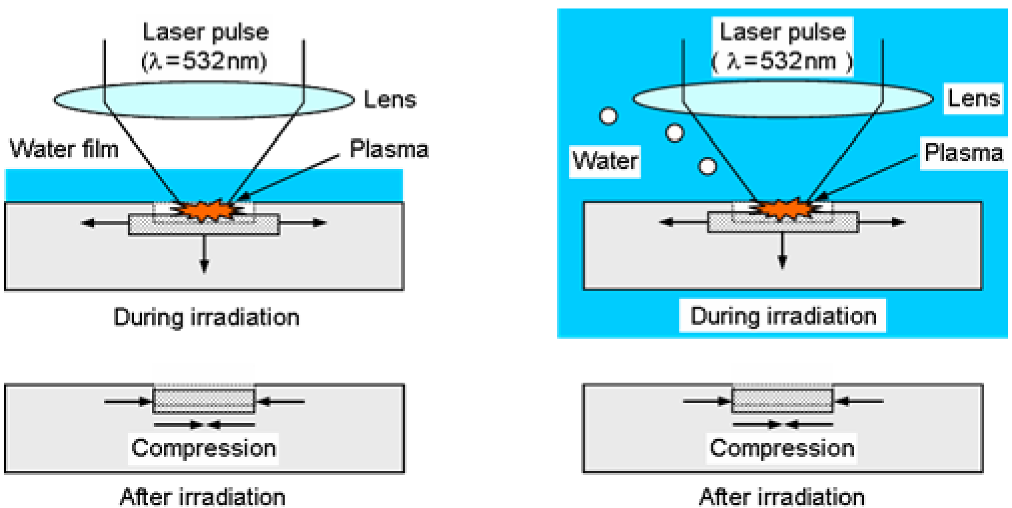
Technology Investigated: Fiber Laser Peening



Fiber laser peening: Process in **air** (left) and **under water** (right)

- Laser System:
  - Underwater application
    - Nd:YAG laser (532 nm)
    - Pulse energy: 40-100 mJ/pulse
    - Pulse width: 8 ns
    - Spot diameter: 0.4-1.0 mm
    - Pulse density: 18-135 pulse/mm^2
    - Repetition rate: 120-300 Hz
  - No ablative layer

(Source: Toshiba)

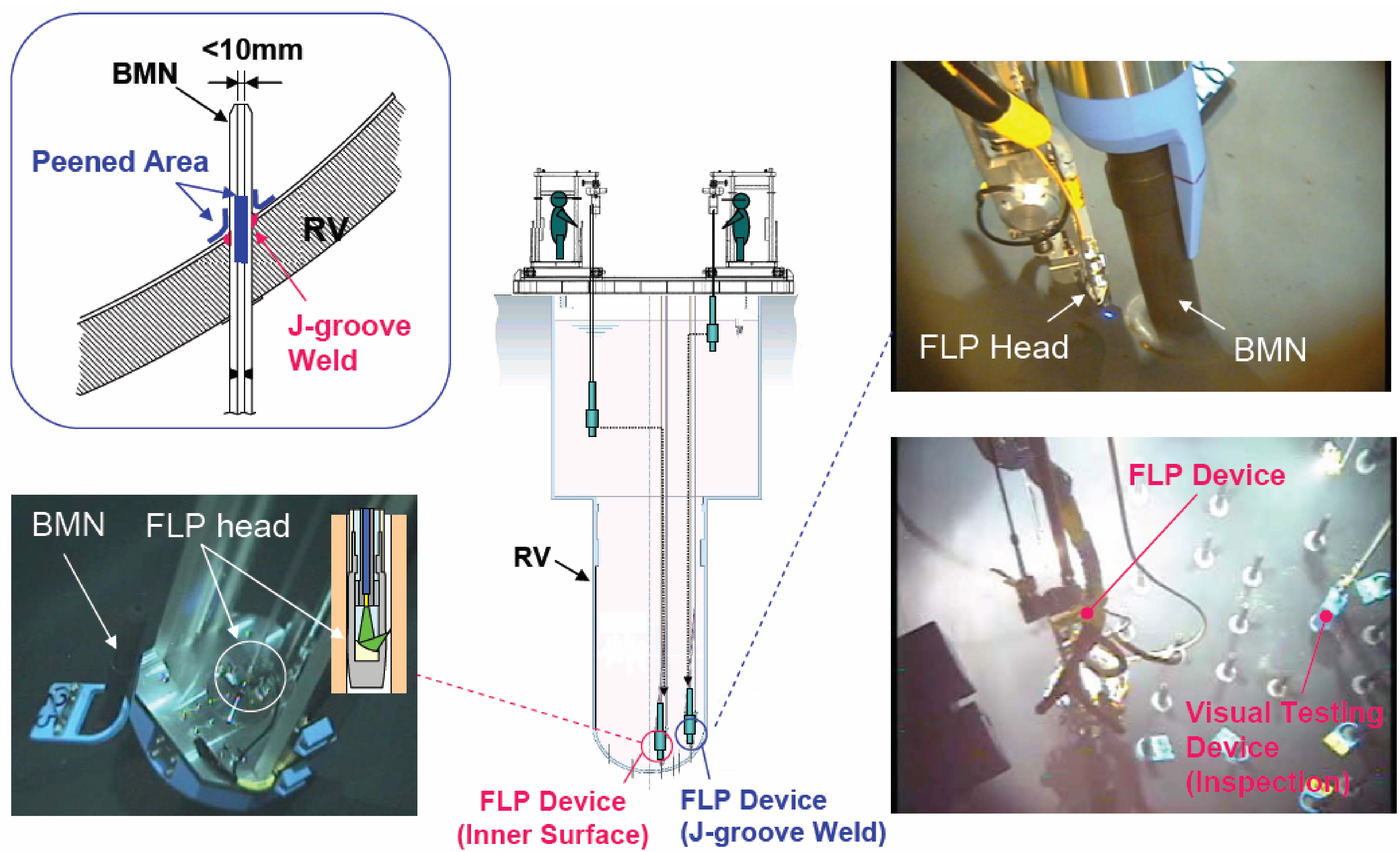
Cavitation Peening Applications in Nuclear Plants

- To date, cavitation peening applied to:
  - BWR Reactor Internals in Japan (by Hitachi)
    - Core shroud welds
    - Jet pump risers
    - Jet pump diffusers
    - ICM housing/ICM guide tube weld OD
    - ICM housing ID & OD
    - CRD housing/stub tube OD
  - ID of PWR BMNs in Japan (by MHI)

Fiber Laser Peening Applications in Nuclear Plants

- To date, laser peening has been applied (by Toshiba) to:
  - BWR Core shrouds & Reactor Pressure Vessel (RPV) bottom heads in Japan
    - Using water penetrable laser peening with optics delivery initially (since 1999)
    - Then fiber laser peening (since 2002)
  - PWR BMNs and PWR Vessel Nozzles since the end of 2004

Example of Fiber Laser Peening Application



U.S. Work for Surface Stress Improvement Technologies

- In the U.S., initial MRP focus for these technologies is for SCC Mitigation of PWR Alloy 600 Bottom Mounted Nozzles (BMNs)
  - BMNs are a pressure boundary location
  - Complete replacement not practical here
  - Other mechanical methods, i.e. MSIP and PWOL not feasible here due to component geometry
  - Addresses IMT gap

  → Testing in materials and geometry related to BMNs

- Applications to other Alloy 600 locations may be investigated in the future

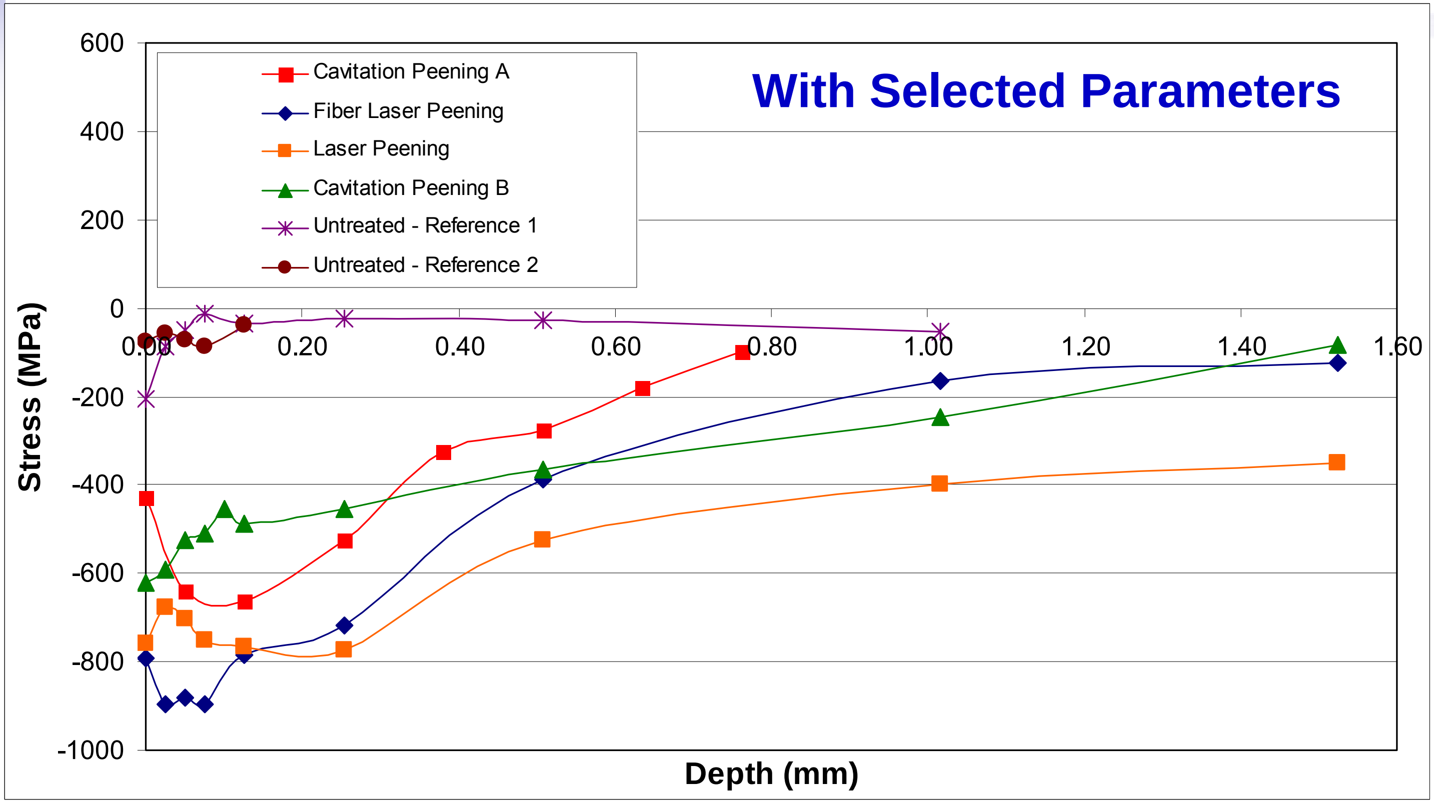
MRP Project on Surface Stress Improvement Technologies

- Multiphase project:
  - Phase 1 (Completed)
    - Proof-of-concept project
    - Selection of technologies
      - Based on residual stress, microhardness, and microstructural evaluation
    - Selection of parameters for each technology
  - Phase 2 (Under way)
    - Verification of technologies for U.S. PWR fleet BMNs
      - Testing for SCC initiation testing and stress relaxation
  - Phase 3 (under consideration)
    - Demonstration at a U.S. plant

MRP Project on Surface Stress Improvement Technologies

Phase 1

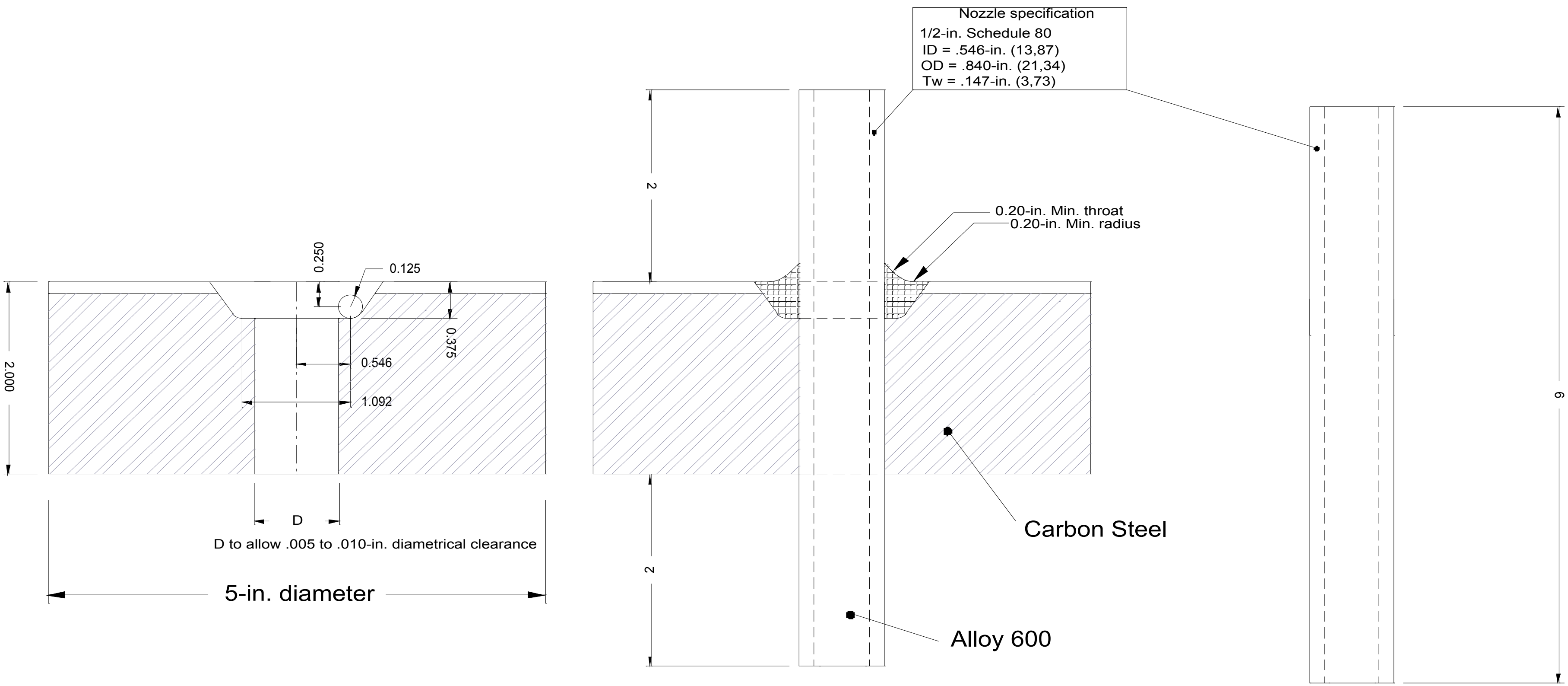
Residual Stress - Flat Plate Specimens



- Compressive surface stress for all processes w/ selected parameters
- Depth of compressive residual stress in alloy 600 flat plates:

- > 0.8 mm, for cavitation peening A & > 1.4 mm, for cavitation peening B
- 1 mm < d < 1.5 mm, for fiber laser peening
- >1.5 mm, for laser peening

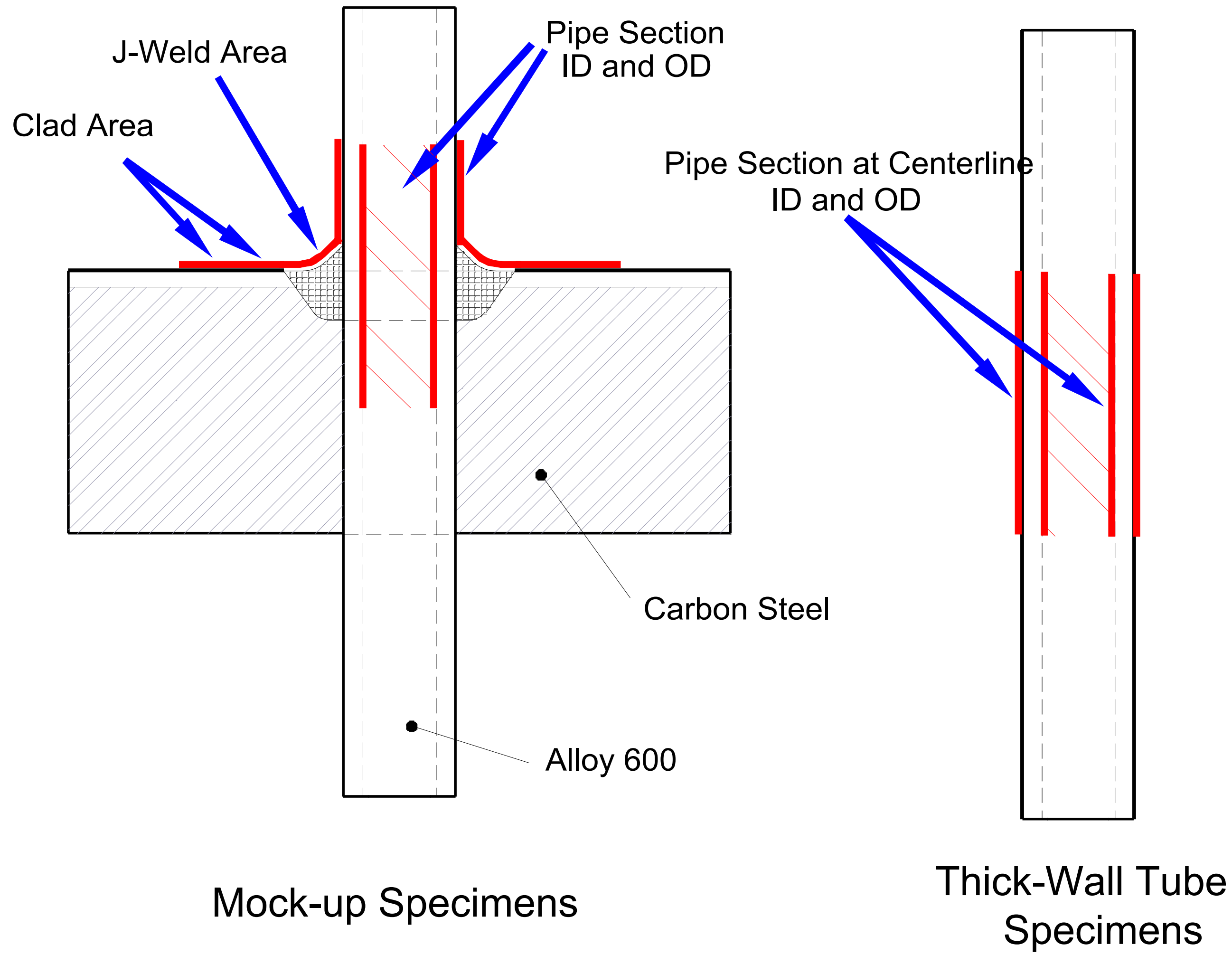
Thick-Wall Tube Specimens & Mock-up Specimens - Geometry and Materials



Mock-up Specimens

Thick-Wall Tube Specimens

Thick-Wall Tube Specimens & Mock-up Specimens Treated Areas and Stress Measurement Locations



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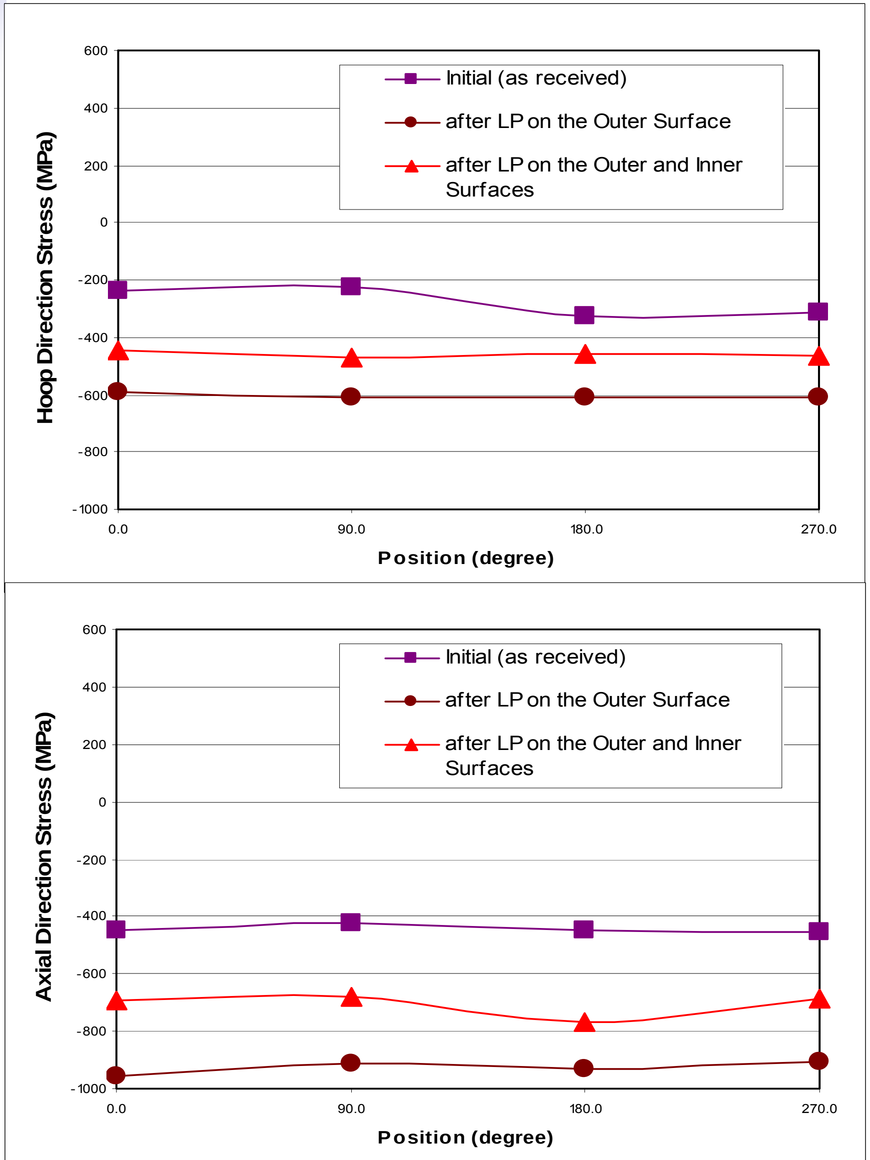
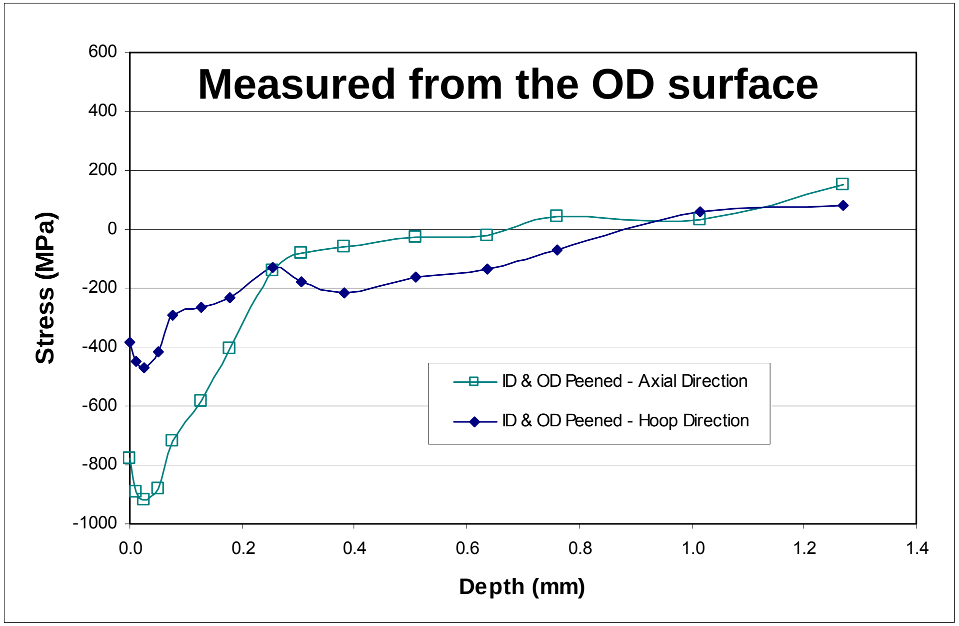
Surface Stress of Thick-Wall Tubes: before Fiber Laser Peening, after FLP of OD, & after FLP of OD and ID

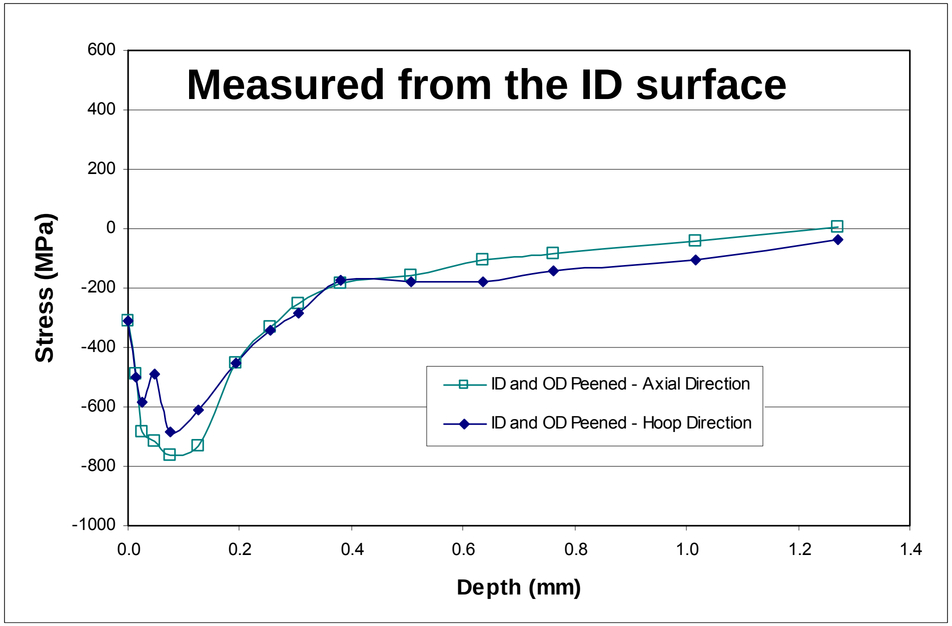


- Uniform compressive surface residual stress around the circumference
- FLP on the OD increases the OD compressive stress magnitude compared to as-received
- FLP of the ID (after peening of the OD) slightly reduces the OD compressive stress magnitude compared to OD peening only, but increases it compared to as-received
- Wall thickness: 3.75 mm

Stress with Depth on Fiber Laser Peened Thick-Wall Tubes

After OD and ID treatment





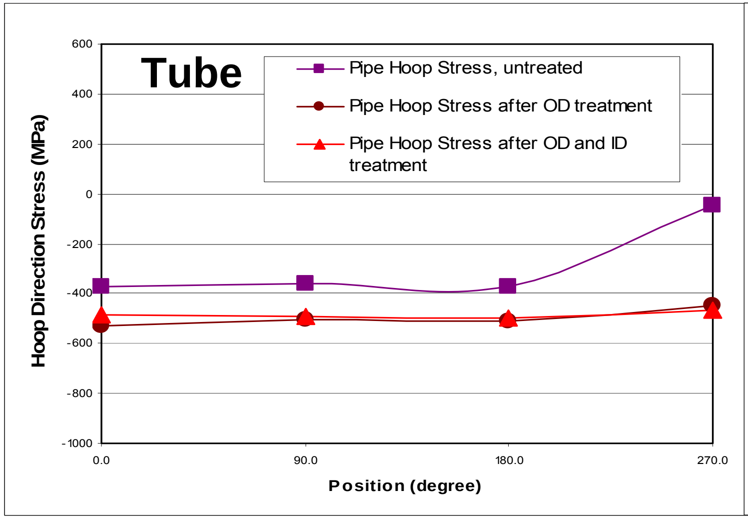
After OD and ID treatment:

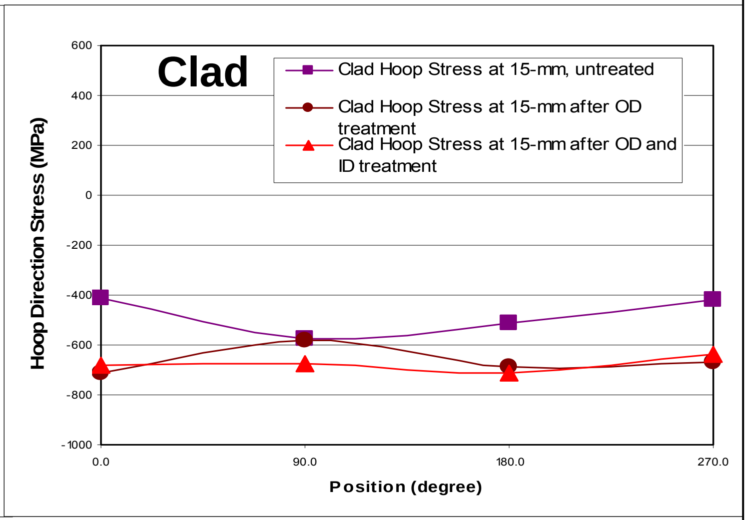
- High compressive hoop and axial surface stress on both OD and ID surfaces
- Depth of compressive residual stress: on OD side: 0.6 mm < d < 1 mm

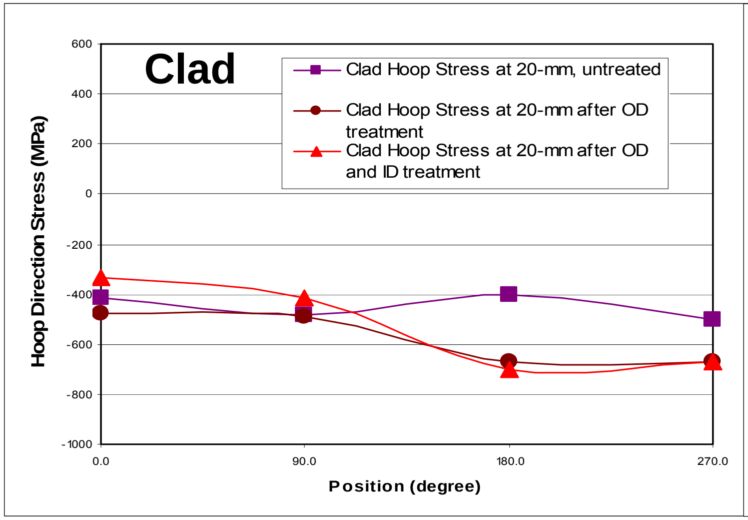
  on ID side: 1 mm < d < 1.3 mm

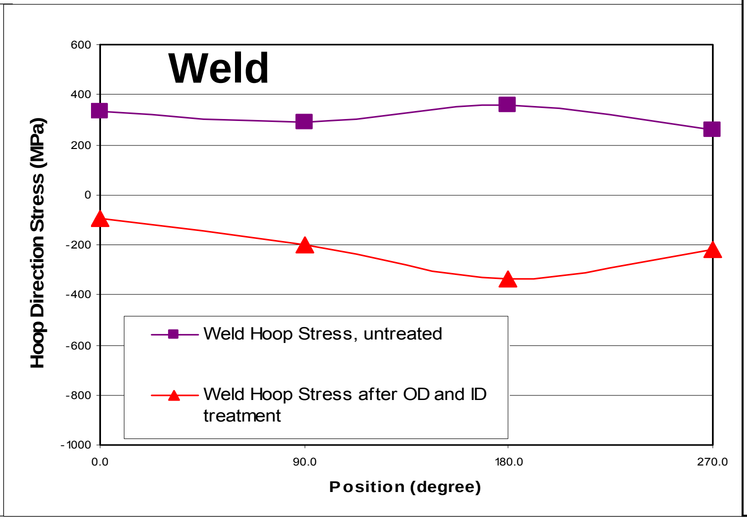
→ Due to the peening order: surface treated last (ID) has deeper compressive stress

Surface Stress of Mock-ups: before Fiber Laser Peening, after FLP of OD, & after FLP of OD and ID









- FLP on the OD increases the OD compressive stress magnitude compared to as-received in tube and clad (at 15 mm & 20 mm) regions
- FLP of the ID (after peening of the OD) increases the OD compressive stress magnitude compared to as-received in tube, clad (at 15 mm, but not at 20 mm), & weld regions
- FLP of the ID (after peening of the OD) results in OD compressive stress magnitude close to OD peening only

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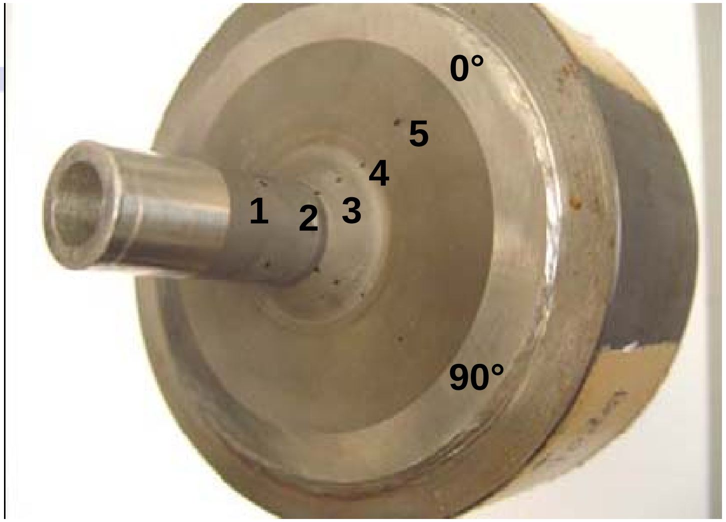
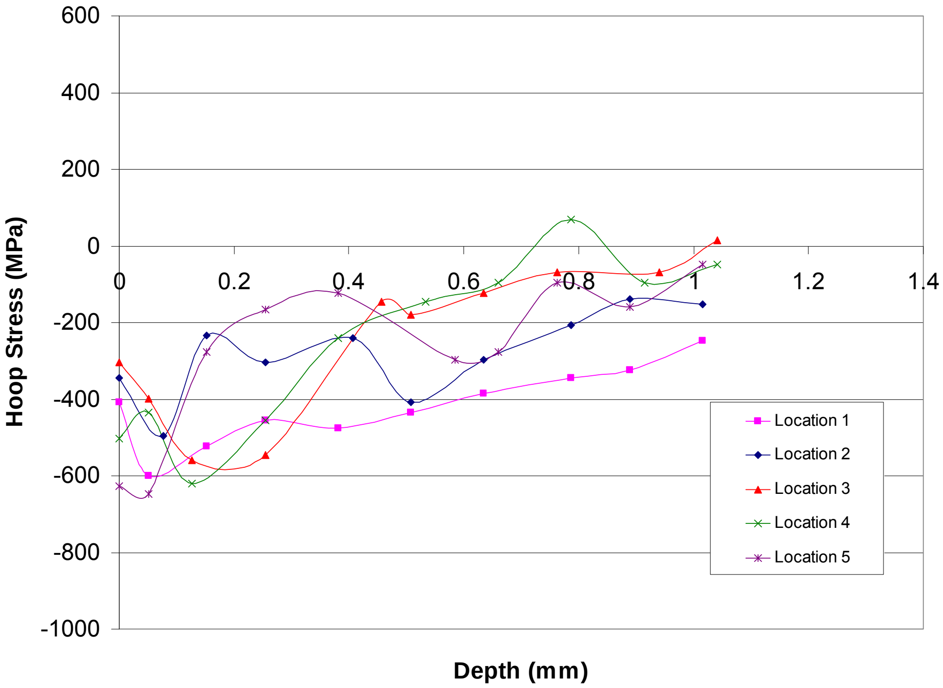
OD Stress with Depth on Fiber Laser Peened Mock-ups

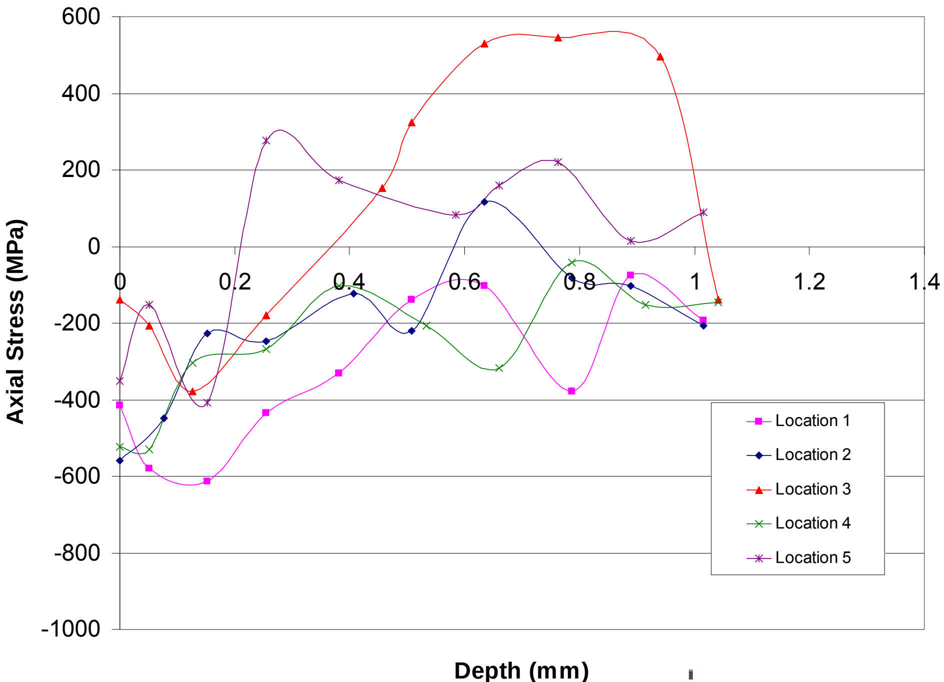
For locations 1 through 5 →

– Hoop stress compressive for 0.7 mm or more

– Axial stress compressive for 0.2 mm or more (depending on location)







Conclusions of Phase 1 (1)

- Stress improvement confirmed in flat plates for all processes w/ selected parameters, up to 0.8 mm or more
- Stress improvement confirmed in thick-wall tubes for fiber laser peening w/ selected parameters - treated on both OD and ID
- Stress improvement in thick-wall tubes not confirmed for cavitation peening w/ selected parameters - tubes treated on ID and OD separately → New vendor for Phase 2 for cavitation peening
- Compressive OD stress results w/ depth for fiber laser peening mock-ups measured

Conclusions of Phase 1 (2)

- Cavitation & fiber laser peening selected for Phase 2 of project
  - Applicability under water
  - No surface preparation required
  - Further work under way to verify these processes for US fleet (SCC testing, stress relaxation testing, …)
- Laser peening not selected for Phase 2
  - Requires the use of an ablative layer to produce compressive stress on the treated surface and protect the surface from micro-cracks
  - Not a practical surface stress improvement process for the BMN location, but could be considered for some other applications (replacement or new plant components)

Phase 2 - Surface Stress Improvement Technologies Qualification – Tasks and Objectives

Testing under way to complete MRP assessment of these technologies for application to BMNs

1. Base metal SCC susceptibility identification

   → Select an SCC susceptible A600 heat among several

2. SCC initiation testing of "simple" specimens

   → Demonstrate that fiber laser peening and cavitation peening improve resistance to SCC initiation in significant number of simple specimens

3. SCC initiation testing of BMN mock-ups

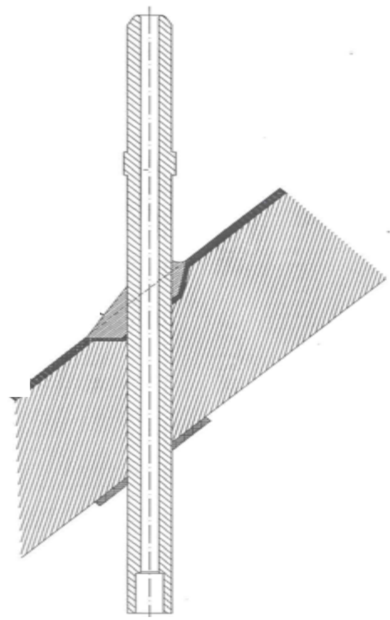
   → Verify improvement in a small number of BMN mock-ups

4. Stress relaxation testing of the peening induced compressive stress layer

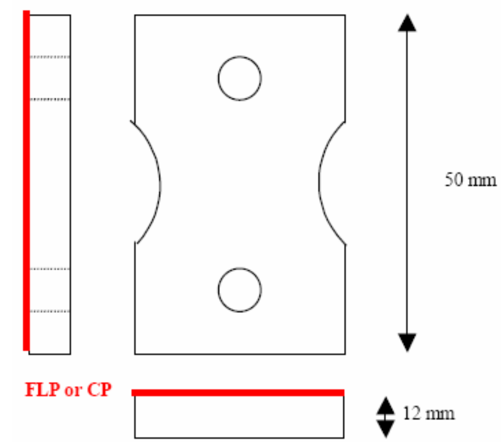
   → Quantify any stress relaxation of the compressive stress layer induced by peening, during exposure to PWR environment

Specimens for Phase 2

Task 1 and 2 specimens:
C-Rings and RUBs



Task 3 mock-up



Task 4 specimens

Phase 2 Schedule and Status

- Finalizing specimens design for Tasks 1 & 2: Q4 2006: Done
- RUBs & C-Rings machining & testing for Task 1: Q1 2007: In progress
- U-Bend & C-Rings machining and testing for Task 2: Q2 through Q4 2007 In progress
- Finalizing specimens design for Task 3: Q2 2007: In progress
- Mock-up manufacturing: Q3 2007
- Mock-up treatment: Q3 2007
- Mock-ups testing for Task 3: Q4 2007 through Q3 2008
- Final Reporting: Q4 2008

In Conclusion

- Surface improvement technologies being investigated have been tested/analyzed and applied in nuclear plants in Japan (Multiple vendors)
- These technologies offer reliable PWSCC mitigation option for BMNs where alternatives are few and replacement is impractical; application to other locations to be considered later
- MRP effort is to “verify” these technologies for the US PWR fleet by utilizing Japanese data/experience supplemented by limited independent confirmation of critical parameters
- Demonstration/application for BMNs at a US PWR plant is anticipated

Questions