Laser-based Maintenance Technologies for Nuclear Reactors

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  – SCC Measure for Mitigation

• Underwater Laser Beam Welding
  – SCC Measure for Repair and Mitigation

• Summary
Background

- SCC is a major issue for aged reactors.
- Laser Peening and ULBW are developed as the SCC measures for reactor components.

### SCC measures

- Hydrogen injection
- Noble metal addition
- Stress improvement
  - IHSI
  - Laser Peening
- Replacement
- Cladding
- Underwater Laser Beam Welding (ULBW)
Laser Peening
- SCC measure for mitigation
Principle of laser peening

- Focused short pulse laser irradiate metal surface in water.
  (Pulse duration: ~10 ns)

- High-pressure plasma forms on the metal surface.
  (Plasma pressure: ~5 GPa)

- Compressive stress remains in the surface layer by constraint of surrounding material.
  - No treatment is needed before or after peening.
  - Reactive forceless process without any high pressure flow eliminates FIV issues.
  - Good accessibility.

Laser system:
Type: Nd:YAG laser (532 nm)
Average Power: < 30 W
Peak Power: approx. 10 MW
Stress Improvement Test in Dissimilar Weld Joint

Type 304SS
Alloy 182
Alloy 600

Measurement points

Laser-peened areas

Irradiation spot

Residual Stress (MPa)

Depth from Surface (mm)

Type 304SS

Alloy 600

σx with LP
σy with LP
σx without LP
σy without LP

σx with LP
σy with LP
σx without LP
σy without LP
SCC test results

 Reverse u-bend test specimens of Alloy132 were exposed to simulated PWR primary water at 360°C for 1000 hours.

 Creviced bent beam test specimens of Type304SS were exposed to simulated BWR reactor water at 288°C for 500 hours.
# Time-line of development and authorization

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- **1990**
  - Mirror-delivered system

- **2000**
  - Actual Application to BWR

- **2010**
  - Fiber-delivered system

- **2020**
  - Compact system (prototype)

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**Notes:**
- JAPEIC: Japan Power Engineering and Inspection Corporation
- JANTI: Japan Nuclear Technology Institute
- JSME: Japan Society of Mechanical Engineers

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**Diagram:**
- **Optical fiber**
- **Laser system**
- **Controller**
- **Shroud**
- **Remote handling system**
- **CRD stub tube**

**Fiber-delivered Laser Peening System**
Experiences of Japan BWR

Experience; 5 BWR Plants

Experience; 4 BWR Plants

H1 (outside & inside)
H2 & H3 (outside)
H4 (outside)
H6a & H6b (inside & outside)

V2 (inside)
V4 & V5 (inside)

RPV
Shroud

CRD Stub Tube
ICM Housing

: Peening Area
Experiences of Japan PWR

Bottom-Mounted Instrumentation Nozzles:

- OD Surface (J-weld)

Reactor Vessel Nozzles:

- ID Surface of Core Flood Nozzles
- ID Surface of Primary Water Inlet Nozzles

Experience; 2 PWR Plants
New compact system

- Improved system with compact laser oscillator
  - No need of long fiber cables nor a large laser system
    - First, easy setup
    - Small footprint

Core Shroud System for BWR

BMI Nozzle System for PWR
Underwater Laser Beam Welding (ULBW)
- SCC measure for repair and mitigation
Features of ULBW

- No need to drain up reactor water
  - Short work window and low dose
- Low heat input
- High accessibility using optical fiber

Shielding gas (Ar)

Laser

Welding wire

Water

Cladding layer

Base metal

Welding direction
Test result of cladding on Alloy600

- Excellent cladding layer of Alloy690 was obtained on Alloy600WM (Alloy132).

Cross-sectional micrograph

Side bend test
Test result of seal welding on Alloy600

- Artificial crack was sealed with 5 layers of Alloy690 on Alloy600WM (Alloy132).

Welding direction

Slit (0.3mm width)

Bead appearance  Penetrant test  Cross-sectional micrograph
Chromium content distribution of welded Alloy600

- Chromium content increased as the number of layers and it was above 27% at the third layer.

![Graph showing chromium content distribution](image)
PWSCC test result of welded Alloy600

- SCC susceptibility was reduced with 3 layers of Alloy690 on Alloy600WM.

Penetrant test results

No crack

Crack

3 layers of Alloy690
Alloy600WM (Alloy132)

80mm
22mm
Ambient temperature temper bead welding technique was developed to weld Alloy690 on Low Alloy Steel (LAS).

![Graph showing Vickers hardness (HV) vs. distance from fusion line (mm) after 1st and 6th layers of welding.]

- **1st weld bead**
- **Tempering area of the 2nd weld bead**
- **Degraded area**
- **Restore of whole degraded area**

**Notes:**
- Ambient temperature temper bead welding technique was developed to weld Alloy690 on Low Alloy Steel (LAS).
Application to PWR nozzles

- PWSCC has been found on the inner surface of RV nozzles and PWSCC-resistant Alloy 690 could be applied to weld for the repair and mitigation.

Outlet nozzle

Inlet nozzle

RV of PWR

Cladding (Stainless steel)

Weld metal (Alloy600)

Nozzle (LAS)

Safe end (Stainless steel)

Cladding (Alloy690)
Welding Machine for RV nozzles

- Underwater welding machine was developed for RV nozzles of PWR which needs no draining.

An earlier system with dam structure

A new ULBW machine

Upper work platform
Dum structure
Shielded work platform
RV nozzle
Welding head
Optical fiber
Accessing unit
Clamp cylinders
Mockup test of ULBW system

- Underwater excavation and inspection machines were also developed.
- Mockup test was carried out successfully in a water tank at the depth of 10m.
- ULBW system could reduce outage window by about half of an earlier system.
Time-line of development and authorization

1995  2005  2015  2025

Development

’06 (Seal welding & Cladding)
’10 Certification by JAPEIC (Temper bead welding & Cladding)
’09 JANTI Guideline (Cladding)
’11 Authorization by NISA (Application to PWR RV Nozzles)
’11 ASME Code Case N-803 (Temper bead welding)
’13 Actual Application to PWR RV Nozzles

JAPEIC: Japan Power Engineering and Inspection Corporation
JANTI: Japan Nuclear Technology Institute
NISA: Nuclear and Industrial Safety Agency
ASME: American Society of Mechanical Engineers
Summary

• Laser peening was developed and applied to BWRs and PWRs in Japan for the mitigation of SCC.
• Underwater laser beam welding (ULBW) system was developed for the repair and mitigation of RV nozzles of PWRs.
• These underwater technologies enable significant reductions in radiation dose associated with maintenance efforts and also reduces impact on nuclear plant outage schedules.
• Toshiba is going to utilize these technologies to enhance the plant lives both in Japan and abroad.