CRIEPI’s Studies on the SCC of the Canister for Spent Nuclear Fuel

Central Research Institute of Electric Power Industry


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SCC of the Canister

1. Stainless steel
2. Deposition of sea salt particles
3. Spent fuel storage building
4. Concrete cask
5. Weld line
6. Air containing sea salt particles
7. Sea

Criteria I
- Loss of confinement

Criteria II
- Deliquesce of sea salt
- Rust
- Pitting or crevice corrosion
- Crack occurs around weld
- Crack penetrates through the plate
- Crack penetrates through the plate

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Minimum amounts of salt for SCC initiation should be set to $0.8\text{g/m}^2$ as Cl.
Salt Deposition on the vertical Surface

(1) The temperature of the canister surface is hot.

(2) The surface of the deposition is vertical.

(3) The cooling air including the sea salt particles goes upward in parallel with the canister surface.

(4) The concrete cask is placed in a building and the canister surface is not exposed to wind and rain.

(5) Because the radiation dose is very high near the canister surface and the gap between the canister surface and the concrete container is very narrow, it is difficult to measure the amount of the deposition and check the surface condition.
Salt Deposition Test on the Metal Surface

**Test Results of Salt deposition Test**

- **Field Test (Choshi)**
- **4km**
- **Test Site in Choshi City**

**Sea**

**Laboratory Test**

**鹽凝固試験結果**

- **Test Site in Choshi City**

**Time (h)**

<table>
<thead>
<tr>
<th>Amount of salt Deposition (mg/m² as Cl⁻)</th>
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</thead>
<tbody>
<tr>
<td>0.01</td>
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</tbody>
</table>

- **Q_{Labo}=2.68 \times t^{(1/2)}**  (Salt in Air 10 mg/m³)
- **Q_{Field}=0.0143 \times t^{(1/2)}**  (Salt in Air 2 μg/m³)
- **Q_{Field}=0.0504 \times t^{(1/2)}**  (Salt in Air 3.7 μg/m³)

**Field Test (Yokosuka)**

- **Test Site in Choshi City**

- **4km**

- **Sea**

**Field Test (Choshi)**
Prevention of the Initiation of SCC

- Estimation of Deposition rate at High Temperature MPC
  - Salt Deposition Tests: Laboratory and Field
  - Temperature Dependence of the Salt Deposition rate
- Temperature decay of the canister over time
  - Performance Data with Full-Scale Demo Test
- Prevention of the Initiation of SCC
  - more than 50 years under an airborne salt concentration of $100\mu g/m^3$
Evaluation of Crack Growth

- **4 Point Bending Test**
  - Type 304 stainless steel, 80°C, 35%RH, 270MPa
  - About 10g/m² as Cl of sea salt
  - RDCPD (Reverse Direct Current Potential Drop) method
  - Potential drop data was converted to crack depth, assuming half elliptical crack propagated

- Crack Growth Rate as $2 \times 10^{-11}$ m/s

(S30403 stainless steel, 80°C, 35%RH, 270MPa, about 10g/m² as Cl of sea salt)
Crack Growth Depth (CGD) Control

- Humid Period in which the relative humidity exceeds 15% would be approximately **15,000 hours during a 60 year storage period** crack growth test.
- Consequently, the estimated crack propagation value during this period is **only 1.1mm**.

![Crack Growth Test Result]

\[ \text{CGR: } 2 \times 10^{-11} \text{m/s} \]

\[ \begin{align*}
38 \text{mm} / 60\text{years} & \quad \text{1.1mm} / 15000\text{hr} \\
\end{align*} \]

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### Countermeasure for SCC

<table>
<thead>
<tr>
<th>Method</th>
<th>Example</th>
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<tbody>
<tr>
<td>Decrease residual stress</td>
<td>Laser welding</td>
</tr>
<tr>
<td>Stress relaxation</td>
<td>Annealing</td>
</tr>
<tr>
<td>Apply compression stress</td>
<td>Shot peening, Ball-burnishing</td>
</tr>
<tr>
<td>Use high-Cr, high-Mo material</td>
<td>Duplex stainless steel, Super austenitic stainless steel</td>
</tr>
<tr>
<td>Use SCC free material</td>
<td>Titanium, Ferrite Steel</td>
</tr>
<tr>
<td>Isolate from chloride</td>
<td>Painting, Corrosion resistant plating</td>
</tr>
<tr>
<td>Decrease salt deposition</td>
<td>Sea salt particle collection, Washing</td>
</tr>
<tr>
<td>Keep salt dry</td>
<td>Keep surface temperature high</td>
</tr>
<tr>
<td>Design standard</td>
<td>Threshold salt density, etc.</td>
</tr>
<tr>
<td>Operational standard</td>
<td>Crack growth evaluation</td>
</tr>
</tbody>
</table>
SCC Test using Small Scale Test Model with Surface Treatment

- Salt Concentration on the surface
  - 10g/m² as Cl over 10 times of threshold chloride density for SCC initiation of S30403 stainless steel
  - 80°C with RH=35% over 1000 hours
  - SCC initiation was not observed on the treated surface.

[Corrosion Test Results]

Surface Condition after Cleaning (Laser-Beam weld plates with LPB)

- Circular Plate Dia.100mm x 13 mm
- Residual Stress Measurement
  - Radial Direction
- Thickness Direction

After LPB  |  As-Machined

Non-Treated surface (SCC occurrence)

Treated surface by LPB (only corrosion)
SCC Test using Mock-up MPC Model

- Verify the effectiveness of the surface treatment technique
  - MPC with full-scale diameter (1,836mm) and wall thickness (12.7mm)
  - Half of the weld lines were treated by SP (Shot Peening)
  - $4g/m^3$ as Cl, $80^\circ C$ with RH=35% over 2000 hours
  - As the indication of the existence of the SCC was not visible due to the rust
  - At the suspicious areas selected by PT, SCC initiation was detected only on the as-weld surface (measured crack depth: 3mm) by SEM observation.

[Measured Residual Radial Stress Distributions in the Mock-up MPC]

[Typical Indication detected in PT]
Monitoring salt concentration by LIBS

- Inspection of the occurrence of SCC
  - Evaluation of the deposition of chloride attached on canister during storage
  - Development of the laser measurement system

Monitoring Technology for Canister Confinement

- Monitoring of the occurrence of the loss of the canister containment
  - Evaluation of the loss of the canister containment during storage
  - He leak detecting method using by $\Delta T_{BT} = \left( T_{\text{center of bottom}} - T_{\text{center of top}} \right)$
  - $\Delta T_{BT}$ is yielded due to the change in the inner pressure and temperature profile resulting from the reduction of Helium convection in the canister
  - Develop the monitoring system based on the thermal-hydraulic calculation

Ref: H. Takeda, Development of the detecting method of helium gas leak from canister, Nuclear Engineering and Design 238 (2008)
Summary

The items which the CRIEPI is continuing to study is as follows;

- Critical value of initiation of SCC
- Countermeasure technology for SCC
- Inspection technology for salt deposition by LIBS
- Monitoring technology for canister confinement
- Preparation of revision of JSME code