Development of Mechanical Test Techniques on Irradiated Grid Elements in a PWR Fuel Assembly

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Contents

I. Introduction

II. Detail Developed Technique List

III. Development Status and Application Results
   - Irradiation in HANARO Reactor
   - Development of Grid 1x1 Cell Spring Test Technique
   - Development of Grid 1x1 Cell Buckling Test Technique
   - Development of Grid Strip Spring Test Technique
   - Development of Tensile Test Technique for Grid Strip Material
   - Development of Irradiation Growth Measurement Technique
   - Development of Welding Strength Measurement Technique

IV. Concluding Remarks
I. Introduction

- Development of PWR nuclear fuel in Korea

<table>
<thead>
<tr>
<th>Fuel Model</th>
<th>Characteristics</th>
<th>PIE Data Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>WH type, KWU Type</td>
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<td>WH, KWU</td>
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<tr>
<td>PLUS-7</td>
<td>- OPR 1000 type reactor</td>
<td>Foreign/Korea</td>
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<td>- 2002: Complete to develop</td>
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<td>- 2007: Supply in the commercial reactor</td>
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<tr>
<td>ACE-7</td>
<td>- WH type reactor</td>
<td>Foreign/Korea</td>
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<td>- 2004: Complete to develop</td>
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<td>- 2008: Plan to supply in the reactor</td>
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<td>Advanced fuel</td>
<td>- Export to the foreign reactors</td>
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<td></td>
<td>- 2005: Start to develop</td>
<td></td>
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<td></td>
<td>- 2015: Complete and export</td>
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</tbody>
</table>

- R&D on the improvement of the PWR fuel reliability in a reactor
  - Integrated management system development of fuel reliability
  - Development of fuel performance examination technology
  - Development of irradiation performance inspection techniques for structural parts

Test techniques are developed to provide PIE data for the newly developing grids and the operated grids in the commercial reactors
Grid View in a PWR Fuel Assembly

- Fuel Rod
- Mixing Vane
- Contour Dimple
- Contour Spring
- Inner Strip
- Outer Strip
II. Detail Developed Technique

*Technique characteristics to be developed*

<table>
<thead>
<tr>
<th>Test Item</th>
<th>Part</th>
<th>Data Production</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irradiation Test</td>
<td>Capsule</td>
<td>Irradiation data</td>
<td>HANARO</td>
</tr>
<tr>
<td>Buckling Test</td>
<td>1x1 Grid Cell</td>
<td>- Buckling load-displacement curve</td>
<td>Hot Cell</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Buckling load</td>
<td></td>
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<tr>
<td>Spring Test</td>
<td>1x1 Grid Cell</td>
<td>- Force-Deflection Curve</td>
<td>Hot Cell</td>
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<td>Grid Strip</td>
<td>- Plastic deformation amount</td>
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<td></td>
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<td>- Spring Constant(k)</td>
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<tr>
<td>Tensile Test</td>
<td>Grid Strip</td>
<td>- Load-displacement curve</td>
<td>Hot Cell</td>
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<td>- Strength</td>
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<td>- Elongation</td>
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<td>Irradiation Growth</td>
<td>Grid Strip</td>
<td>- Dimension before and after irradiation</td>
<td>Hot Cell</td>
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<tr>
<td>Measurement</td>
<td>Inconel Material</td>
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<tr>
<td>Welding Strength</td>
<td>Spot Welded Part</td>
<td>- Tensile load-displacement curve</td>
<td>Hot Cell</td>
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<tr>
<td>Measurement</td>
<td>Butt Welded Part</td>
<td>- Welding strength, elongation</td>
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</tbody>
</table>
III. Development and Application of Test Techniques

- Irradiation Test in HANARO

- Irradiation in HANARO CT Hole
  - 30MW 4 Cycles, 100 days (72,000 MWD)
  - Specimen Temps. Controlled & Monitored

- Irradiation Temperature of Specimens
  - Strip Specimens: 300±10°C
  - Spacer Grid: 350±30°C (< Rcry.T(500 °C)

- Neutron Fluence
  - 1.00~2.56 x 10^{21} n/cm² (E>0.1 MeV)
  - 0.51~1.28 x 10^{21} n/cm² (E>1.0 MeV)
Characteristics of universal testing machine in a hot cell

- System: MTS 810 (modified for hot cell)
- Load cell for spring test: ±250 N
- Load cell for buckling and tensile: ±5 kN
- Min loading rate: 0.5 mm/min
- Control actuator positions by manual and automatic method
- Acquire load and displacement data during loading and unloading.
- Store the data to computer by ASCII format.

View of MTS 810 system in a hot cell
Development of Grid 1x1 Cell Buckling Test Technique

- Shape of grid 1x1 cell
- Development of Fixtures

Conceptual drawing of testing fixture
- Application of developed test technique in a hot cell

- Example of tested shape

Photo Test progress in a hot cell

Photo The shape of tested cells
- 1x1 cell buckling test
  - Compressive loading to 5.5 mm in a displacement with the speed of 0.5 mm/min

Irradiation effects to buckling properties
Maximum load is not changed (Unirrad. = 1385 N, Irrad. = 1356 N)
The rectangular shape in the irradiated cell is perfectly broken whereas that of the unirradiated are maintained by compressive loads.
Development of Grid 1x1 Cell Spring Test Technique

- Shape of grid 1x1 cell
- Grip device development

- Fixing the outside of a cell spring
- Insert loading bar in a spring
- Compressive loading to the bar
- Acquire load and displacement data
Application of developed test techniques in a hot cell

Photo Test progress in a hot cell
● Cell spring test
  ▪ 2 cyclic loading to 0.2 mm, 0.4 mm in displacements with the speed of 0.5 mm/min

Irradiation effects
Maximum compressive spring forces are increased by 10 ~ 30 %

Figure 2-cyclic load-displacement curves from cell springs
Development of Grid Strip Spring Test Technique

- Specimen shape

  - PLUS-7, Middle
  - PLUS-7, Bottom
  - Candidate-1, Middle
  - Candidate-1, Bottom
  - Candidate-2, Middle

- Test procedure development

  - Concept of grip

    - Fix specimen in jig
    - Inspection of specimen align
    - Close the upper cap
    - Compression loading

Photo Test progress in a hot cell
- Strip spring test
  - 3 cyclic loading to 0.5 mm, 0.7 mm, 0.9 mm in displacement with the speed of 0.5 mm/min

**Figure 3-cyclic load-displacement curves from strip springs**

Irradiation effects in strip spring specimen plastic deformation decreased by 40~50%, max spring force increased by 7~30%
Development of Tensile Test Technique for Grid Strip Material

- Specification of small specimen

  - Longitudinal & transverse small tensile type
  - Gage length 9 mm, width 5 mm
  - Thickness 0.46 mm, 0.66 mm
  - Total length 26 mm, grip width 5 mm
  - Hole diameter 4 mm

- Development of grip and test procedure

Photo Test progress in a hot cell
● Test results
  ▪ Loading to fracture with the speed of 0.5 mm/min

**Stress-strain curves from the longitudinal specimen**

**Stress-strain curves from the transverse specimen**

Irradiation effects in spring materials
Tensile strength increased by ~50%, max elongation decreased by ~30% in the irradiated.
Development of Welded Strength Measurement Technique

- Test procedure development

Spot Weld Specimen

- Specimen installation (lower grip)
- Alignment device removal

Butt Weld Specimen

- Specimen installation (upper grip)
- Test

- Tab bonding to maintain equal levels at chucking sides in spot weld specimen

Specimen and tab

Fix specimen on device

Specimen flattening

Tab bonding

Bond solidification
Test results
- Loading to fracture displacement with the speed of 0.5 mm/min

Load-displacement curves spot weld specimen

Load-displacement curves butt specimen

Irradiation effects to the maximum loads in tensile tests
Spot weld specimen show the similar value in a maximum load
Butt weld specimen shows the decreased value in the irradiated drastically
Development of Irradiation Growth Measurement Technique

- Specimen specification
  - Inconel material and Zr-base material
  - Specimen size:
    - 8 x 77 x 0.46 [mm] for inner strip
    - 8 x 77 x 0.66 [mm] for inner & outer strip
    - 8 x 77 x 0.81 [mm] for outer strip
    - 6.77 x 77 x 0.38 [mm] for Inconel

- Introduce simple micrometer system (1/1,000 mm)

Measurement results for the irradiated specimens

<table>
<thead>
<tr>
<th>Material ID</th>
<th>Unirradiated (mm)</th>
<th>Irradiated (mm)</th>
<th>Irradiation Growth (mm)</th>
<th>Average Irradiation Growth (mm)</th>
<th>Average Growth Rate (%)</th>
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<tr>
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IV. Concluding Remarks

1. Various mechanical test techniques for the irradiated grid components were successfully developed and applied to the newly developed grids. They will be continuously improved to evaluate the operated components in the commercial PWR reactors.

2. The external shape of the irradiated grid cell is easily broken during a buckling test compared to it of the unirradiated one.

3. Compressive forces in the irradiated cells and strips are higher than them of the unirradiated ones during spring tests with a uniform displacement.

4. The irradiated tensile specimen shows the higher strength and the lower elongation than the unirradiated ones