Irradiated T2K Ti alloy materials test plans

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The 2nd RaDIATE collaboration meeting
May 20, 2015
Motivation for the studies on Ti-alloys

- Ti alloys at J-PARC neutrino beam-line
  - Beam window (Ti-6Al-4V)
  - Target window-case, surrounding graphite (Ti-6Al-4V)
  - OTR profile monitor, upstream of the target (Ti-15V-3Cr-3Sn-3Al)

- 1st beam window still in service: $1 \times 10^{21}$ pot
- The 1st target / OTR replaced during 2013-14 maintenance: $6.6 \times 10^{20}$ pot, $1.2 \times 10^7$ pulses

- Expected radiation damage > O(1) DPA
  - Larger than the existing data ($\sim 0.28$ DPA@BLIP)
Neutrino experimental facility at J-PARC

Near Neutrino Detectors
Muon Monitors
Beam Dump
Decay Volume
Target Horns

RCS

295km To Kamioka

110m

280m

MLF

J-PARC, Tokai

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The secondary beam-line

Beam Transport From RCS to MLF

Helium Vessel
L=110m, V=1,300m³

Decay Volume

Beam Dump

OA 2° 2.5° [3°]

Hadron Absorber

Target

OTR

Baffle

Horn-1 Horn-2 Horn-3

Beam window 15.0m

Baffle
# Parameters of Main Ring operation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Original</th>
<th>Achieved [Mar. 2015]</th>
<th>Doubled rep rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>circumference</td>
<td></td>
<td>1567.5m</td>
<td></td>
</tr>
<tr>
<td>beam kinetic energy</td>
<td></td>
<td>30 GeV</td>
<td></td>
</tr>
<tr>
<td>beam intensity</td>
<td>$3.3 \times 10^{14}$ ppp</td>
<td>$1.66 \times 10^{14}$ ppp</td>
<td>$2.0 \times 10^{14}$ ppp</td>
</tr>
<tr>
<td>[RCS equivalent power]</td>
<td>$4.1 \times 10^{13}$ ppb</td>
<td>$2.12 \times 10^{13}$ ppp</td>
<td>$2.5 \times 10^{13}$ ppp</td>
</tr>
<tr>
<td>harmonic number</td>
<td></td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>number of bunches</td>
<td></td>
<td>8/spill</td>
<td></td>
</tr>
<tr>
<td>spill width</td>
<td></td>
<td>~5us</td>
<td></td>
</tr>
<tr>
<td>bunch full width (at extraction)</td>
<td></td>
<td>~50ns</td>
<td></td>
</tr>
<tr>
<td>maximum RF voltage</td>
<td></td>
<td>280kV</td>
<td>560kV</td>
</tr>
<tr>
<td>repetition period</td>
<td>2.1 sec</td>
<td>2.48 sec</td>
<td>1.28 sec</td>
</tr>
<tr>
<td>beam power</td>
<td>750 kW</td>
<td>320 kW</td>
<td>750kW~</td>
</tr>
</tbody>
</table>

- Original (old) planned parameters for 750kW was MR cycle: 2.1s, PPP: $3.3 \times 10^{14}$
  - Components of the neutrino facility (target/beam window) were designed
- Present expected parameters: Doubled rep-rate, MR cycle: 1.3 s, PPP: $2.0 \times 10^{14}$
  - Instantaneous temperature rise / pulse (thermal shock) will be reduced by 60%
Beam window

Design: 2 x 0.3mm thick titanium domes cooled by helium flow
Material: Titanium alloy bar Ti6Al-4V (Grade 5) (Windows I & II)
Proton beam: 30GeV, 4.2mm sigma
Beam power: 345kW (750kW window design power)
Number of protons to date: 1.04x10^{21} (May 2015 and still in service)
Max temp (at beam centre): 52°C estimate at current beam power (82°C @750kW)
Results for 750kW simulations

- Estimate of current conditions at 345kW
- Peak stress $\sim 50$MPa
- Fatigue cycles $\sim 0.5 \times 10^6$ @ 0.5Hz
Effects of elevated temperature, fatigue & radiation damage

Significant loss of ductility at 0.2~0.28 dpa
Now likely to be entirely brittle at 1~2 dpa
Does it matter? (Low stress at moment)

C. Densham

N. Simos

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Target (He-cooled graphite)

Graphite IG-430U
26mmØ x ~900mm

Ti-6Al-4V
(0.3mmT)

30GeV-750kW (~20kW heat load)
Conductivity 140→20W/mK (rad. damage)

736°C

ΔT~200K ~7MPa (Tensile strength 37MPa)
Proposed new study items

We are proposing new studies:

1. Develop a compact Fatigue Testing Machine (FTM), to study fatigue effect for irradiated specimens in a hot-cell.
3. PIE for the OTR foils (PNNL + UK for micro-mechanical studies)

✓ Activities supported as one of KEK’s US-Japan cooperative research programs, since JFY2014
Fatigue Testing Machine (FTM)

* Compatible for spherically shaped beam-window

1,500 rpm, $10^7$ cycles / 4.6 days

Specimen production & a few pre-irradiated tests
Table 1
The foils used in the OTR system.

<table>
<thead>
<tr>
<th>Material (number of foils)</th>
<th>Thickness (µm)</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>AF955 (1)</td>
<td>100</td>
<td>&lt; 1 kW beam power</td>
</tr>
<tr>
<td>Al 1100 (1)</td>
<td></td>
<td>1-40 kW beam power</td>
</tr>
<tr>
<td>Ti 15-3-3-3 (4)</td>
<td>50</td>
<td>&gt; 8 kW beam power</td>
</tr>
<tr>
<td>Ti 15-3-3-3 (1)</td>
<td></td>
<td>Calibration with no beam</td>
</tr>
</tbody>
</table>

S. Bhadra et al., NIM A 703 (2013) 45–58
OTR PIEs ?

- Two Ti foils receive most of the beam.
- The damage localized within beam-spot size (a few mm)
- PIE as func. of distance from beam center

Ti2: 5.0e20
Ti1: 1.6e20

- Optical microscopy at PNNL (SEM/EDS/EBSD, TEM, XRD)
- Under discussion:
  - Micro hardness test
  - Michro-mechanical studies w FIB
- We need your expertise!

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