Effects of Neutron Irradiation on Damage Structure Evolution of Tungsten in Fusion Device

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Materials

# Tungsten Alloys (Plansee) : Hot rolled sheet (0.15mmt)

<table>
<thead>
<tr>
<th>W</th>
<th>Re%</th>
<th>C(ppm)</th>
<th>O(ppm)</th>
<th>N(ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pure W</td>
<td>bal.</td>
<td>&lt;30</td>
<td>&lt;30</td>
<td>&lt;10</td>
</tr>
<tr>
<td>W-3Re</td>
<td>3.00</td>
<td>3</td>
<td>16</td>
<td>&lt;10</td>
</tr>
<tr>
<td>W-5Re</td>
<td>4.99</td>
<td>20</td>
<td>37</td>
<td>&lt;10</td>
</tr>
<tr>
<td>W-10Re</td>
<td>9.12</td>
<td>15</td>
<td>&lt;10</td>
<td>&lt;10</td>
</tr>
<tr>
<td>W-26Re</td>
<td>26.0</td>
<td>&lt;30</td>
<td>&lt;30</td>
<td>&lt;10</td>
</tr>
</tbody>
</table>

Final heat treatments before irradiation:
(a) Pure-W and W-Re alloys : 1300 °C for 1h in vacuum
(b) 1600 °C for 1h in vacuum

# Arc-melt Tungsten alloys : Fabricated in IMR Tohoku Univ.

Pure W, W-5Re, W-10Re, W-26Re, W-xRe-yOs

(c) 1400 °C for 1h in vacuum after arc melting

# Powder Metallurgical Processed W-alloys (A.L.M.T)

Pure W, W-1%La2O3, K-dope W : Hot rolled

(d) 1200 °C for 1h in vacuum

Test Matrix of Neutron Irradiation

JMJTR(JAEO) Mixed spectrum
600,800°C: 0.15 and 0.22dpa

HFIR(ORNL) Mixed spectrum
500,800°C: 1dpa

JOYO(JAEO) Fast spectrum
400°C: 0.17dpa
538°C: 0.4dpa
583°C: 0.45dpa, 0.96dpa
740°C: 0.4dpa
750°C: 1.54dpa

Irradiation period: 1-12 month

Nuclear Transmutation by Fission Reactor Irradiation

Re production rate in DEMO
5%Re/30dpa (10MW/m2) (Boll J.N.M. (2004)
Transmutation rate: 0.2 %Re/dpa

Microstructural Observation of Irradiated W
Microstructure Map of Irradiated Pure W

Characteristic Microstructure of pure W after Higher Fluence Irradiation

Summary of Damage Structure Map of W

Microstructure Near G. B. of pure W

Results of HFIR Irradiation

Microstructural development of W under high transmutation rate condition

Irradiation temperature, °C

Displacement damage, dpa

Defect Distribution Near GB

Swelling of neutron irradiated Tungsten
Microstructure of pure-W

- Lower irradiation temperature (500 °C, 538 °C): void and loop.
- Higher irradiation temperature (800 °C, 750 °C): void

Precipitates were observed in HFIR irradiated pure W specimens. The precipitates might be $\chi$-phase(Re,W).

[Image of microstructures with annotations]

Re Effects on Irradiation Hardening (0.15dpa)

- Irradiation hardening of pure W was significantly larger than W-Re alloys.
- Re addition suppressed irradiation hardening.
- Higher temperature irradiation caused larger irradiation hardening.
- Temperature change suppressed irradiation hardening.

Irradiation Damage of Advanced W-Alloys

- Behavior of the microstructure development in the matrix and irradiation hardening in pure-W, La, and K-doped W under neutron irradiation at 531–756 °C and 0.42–0.47 dpa were similar.

Irradiation Hardening

- Precipitates in HFIR irradiated pure-W was caused by higher Re concentration by nuclear transmutation.

Irradiation Hardening Behavior of W and W-Re Alloys

- Irradiation hardening of pure W appeared in lower fluence compared to W-Re alloys. [Void and loop hardening]
- When precipitates were observed, irradiation hardening of W-Re was larger than that of pure W. [Precipitation hardening]
Defect Clusters in Matrix after JOYO Irradiation

- Irradiation response of the advanced W alloys were almost the same as pure W.
- Matrix condition for defect clustering were considered to be similar between these specimens.

Summary of Damage Structure Map of W

- Void lattice formed after 1.5dpa irradiation, above 400°C. Upper limit of loop formation could not be confirmed.
- Void lattice formation after higher level irradiation (>1dpd).

Summary and Prediction of Microstructural Development of W

- Data on mechanical property change by irradiation is not enough.
- Heavy irradiation up to 10 to 30 dpa is required.
  - Limitation of irradiation field and irradiation rate. 1-2 dpa/yr
  - Fast Reactor → Temperature limit: <800°C
  - Additional heating system is needed.

Materials Development

- Large production scale is needed.
- Economical benefits and reliability of material qualification are important.

Plans of Irradiation Experiments in Japan

- Reactor irradiation at high temperature up to high fluence irradiation with thermal neutron shield
  - HIFR irradiation dpa: <2.5dpa (W)
  - Mechanical property measurement of irradiated tungsten
  - Hydrogen retention behavior of irradiated tungsten
  - High heat load response of irradiated tungsten
  → Japan JOYO 2015 ??? ~

Accelerator Irradiation (Japan)

- TIARA: 10 dpa, 800-1300°C 18MeV W+ ion (+ He ion)
- Cyclotron: 50 appm at 600°C implantation and annealing or tensile test at high temperature

Thank you for your attention.
References of our works


2) J. C. He, G. Y. Tang, A. Hasegawa and K. Abe, Microstructural development and irradiation hardening of W and W-(0.26)wt%Re alloys after high-temperature neutron irradiation to 0.15 dpa", Nucl. Fusion 46 (2006) 877-883.


