Fracture of Tungsten in a HAPL Chamber

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Outline

- Latest results for crack propagation in tungsten-coated steel walls
- Thoughts on how to measure mass loss in samples
Introduction

• In Albuquerque, I presented a fatigue analysis for a tungsten-coated, steel HAPL wall
• This analysis indicated that surface cracking can be expected within the first hour of operation
• This does not tell us whether cracks will reach the steel (this requires fracture mechanics)
Approach

- Place crack into structural model and calculate stress intensity factor for several crack depths
- If stress intensity goes to 0, cracks will stop
- Otherwise, the stress intensity determines the crack growth rate (per cycle)
- Unfortunately, no crack growth data for tungsten has been found
Fracture Mechanics Analysis of Tungsten Coating

Crack tip stress intensities during thermal cycling calculated using ANSYS J-integral fracture mechanics algorithm
Thermal Response of Structure

Temperature Contours Near Surface at end of Pulse

6.5 m chamber
154 MJ target
No gas
50 microns W
Stresses Resulting from Thermal Cycle

Stresses at Maximum Temperature

Stresses After Cool Down

MPa

MPa
Fracture Mechanics Analysis Results

- Maximum stress intensities occur at end of cycle (when structure is cool).
- Stress intensity decreases with increasing crack depth

Stress Intensity vs. Crack Depth
After One Thermal Cycle

Transient Stress Intensity
(30 μm Crack Depth)
Crack Tip Stress Intensity Variation with Time and Crack Spacing

Stress intensity for a 30 μm crack in a 50 μm thick tungsten layer

Variation of Stress Intensity for a 30 μm Crack over 20 Thermal Cycles

Variation of Stress Intensity with Crack Spacing for a 30 μm Crack (Single Cycle)
Stress Intensity Variation with Crack Depth
50, 100, and 200 μm Tungsten coating thicknesses

500 μm crack half spacing – single thermal cycle
Crack Tip Stress Intensity Variation with Crack Spacing

Variation of Stress Intensity with Crack Spacing (Single Cycle)

- 20 um crack
- 30 um crack
- 40 um crack

50 \( \mu \)m thick tungsten layer
Next Step

- What if crack reaches steel?
Stresses in Steel

• As long as we avoid yielding in the steel, the stress will always be compressive
• Hence, fatigue is not an issue and we can just compare the steel stress to the allowable stress (factoring in yielding, creep, etc.)
# Allowable Stresses

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Allowable Stress (MPa)</th>
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<tbody>
<tr>
<td>500</td>
<td>268</td>
</tr>
<tr>
<td>650</td>
<td>133</td>
</tr>
<tr>
<td>700</td>
<td>111</td>
</tr>
<tr>
<td>Chamber radius (m)</td>
<td>Xe Pressure (mTorr)</td>
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<tr>
<td>-------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>6.5</td>
<td>10</td>
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</tbody>
</table>
## Designs That Work

<table>
<thead>
<tr>
<th></th>
<th>6.5 meter radius</th>
<th>10 mTorr Xe</th>
<th>250 microns W</th>
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</thead>
<tbody>
<tr>
<td>150 MJ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300 MJ</td>
<td>8.5 meter radius</td>
<td>10 mTorr Xe</td>
<td>250 microns W</td>
</tr>
</tbody>
</table>
Conclusions

- Tungsten will crack and cracks may well reach the steel (results are inconclusive)
- Modeling a crack which has reached the steel may not be of any benefit
- Experiments will be the key
- Steel stress requirements lead us to tungsten thicknesses on the order of 250 microns
How to Measure Mass Loss

- Weigh Samples before and after
- Measure Remaining Thickness of Armor (Profilometry, Auger, RBS)
- Measure What Comes Off (Spectrometry/RGA)
- Measure velocity of vapor cloud (shadowgraphy or similar)
- Put layer of trace element at fixed depth