Mechanical Properties of an Irradiated Inconel 718 Beam Window

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A Few Notes on Wing 9 Hot Cells in CMR at LANL

- Chemistry and Materials Research - CMR- Facility started in late 1940’s, finished in 1950’s
- Wing 9 CMR hot cells were designed in late 50’s, commissioned in 1962-1963.
- Initial work was with plutonium fuels for experimental reactors and other conventional fuels and cladding work for civilian reactors.
- 16 General Purpose Hot Cells, 2m x 2m x 3.6m
- Central corridor between groups of 4 cells.
- Hydraulic doors separating Corridor from cells and lab.
- Large capacity trolley takes heavy casks from truck bay into corridors
JR Lilienthal “Los Alamos Alpha-Gamma Cells” 7th Hot Laboratory and Equipment Conference, April 1959, Cleveland Ohio, USA
Hot Cells and Central Corridor
CMR Building circa 1952
First Hotcell Operator, Wing 9 CMR, 1962
H+ is produced at the source injector, accelerated through DTL, diverted to IPF at the TR region through magnets, and ended on targets inside a heavily shielded target irradiation chamber.
Isotope Production Facility and Beam Window

The proton beam is delivered via a vacuum beam pipe. Inconel beam window isolates the beam pipe (under vacuum) and the target irradiation chamber (15 psig of cooling water).
Irradiation Damage and Replacement

- Beam transmission through the window incurs heating causing thermal stress.
- Beam irradiates the window causing mechanical properties to change and to become more ductile.
- Beam window design criteria is 20 dpa (displacement per atom). Beam window reached the end of its life.
- Estimate dose rate is 100 R/hr at contact without shielding and highly contaminated.
- We replaced window in March 2010, stored at Area A and shipped to CMR in November 2010.

Calculated Von Mises stress under pressure and thermal load at the center of the target is ~ 510 MPa. Window will fail when Von Mises stress > the yield strength.
The Reality of High Rad Testing
At CMR
Into the Hot Cell Corridor
Graphite Colimator
Retaining Springs not Intact
Melted Haynes 25 Spring, 50+R/hr, ~1350C Melt
Beam Window Surface
Beam Window Bulging and Beam Profile Measurements

GAFCHROMIC HD-810 dosimetry film was used to measure the absorbed dose of high energy photons from the activated beam window.

Beam window was bulged 1.5mm into the vacuum side.

Rastered beam profile shows a Gaussian distribution and the highest dose region corresponds to the darkest blue region on the Gafchromic film.
Temperature and Dose Map

- 109°C
- 25°C
- 0.25-1.5 dpa
- 2-5 dpa
- 14 dpa
- 11 dpa
Cutting and Shear Punch Testing Plan

- Beam profile was superimposed on the window to determine the cutting plan as a function of radiation dose (dpa).
- 3-mm OD samples were cut with a Mill machine. A total of 3 cutting bits were spent to cut out 20 numerical samples (1-20) and 5 alphabetical samples (A, B, C, E, and F).
- Cut-out samples were polished and thinned from on both sides to 0.254 mm thickness.
- The shear punch testing for the following samples were completed as a function of radiation dose (dpa):
  - 2 controls samples of unirradiated Inconnel 718
  - 1-6, 8, 9, 10-13, 15-16, 17-18, 19-20, A-C, and E
Machining Samples
Trepan tool
Machined Window
Overlay

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Temperature and Dose Map

- 109°C
- 25°C
- 0.25-1.5 dpa
- 2-5 dpa
- 14 dpa
- 11 dpa
16mm Long, 0.75mm thick,
1.25 x 5mm Gauge
Shear Punch Testing Equipment at CMR Hot Cell

- Performed 25 shear punch tests on 3 mm diameter specimens.
- Tested at initial strain rate of $5 \times 10^{-4} /s$.
Shear Punch, Outer to Inner

Effective Shear Stress (MPa) vs. Displacement (mm)

- High Rad 3
- High Rad 4
- Outer Ring 17
- Outer Ring 18
- Beam Center 1
- Beam Center 2
- Outside Collimator 10
- Outside Collimator 11
- Control

Effective Shear Stress at various displacement levels:
- 0.2 dpa
- 11 dpa
- 14.4 dpa
- 2.55 dpa
14 dpa ring

HighRad Ring

Effective Shear Strength (MPa) vs. Displacement (mm)

- #3
- #4
- #5
- #6
- #8
- #9

Operated by Los Alamos National Security, LLC for NNSA

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Control Material Tensile Tests vs Shear Punch

- UTS correlation - 1.28
- Yield Correlation - 1.77
- Lit values 1.4, 1.73

Toloczko & Kurtz
Optical Images of Control Sample #1 (Unirradiated)
Optical Images of Control Sample #6 (Unirradiated)
Optical Images of Sample # 3 (High Radiation Ring)
Optical Images of Sample # 8 (High Radiation Ring)
Preliminary Shear Punch Test Summary

- All samples display ductility in both yield vs UTS and optically.

- Samples taken in outer ring and outside collimator have a higher yield and UTS than control or high radiation dose samples.
  - Expected that they would be similar to the control samples.

- Shear Punch centers are being prepped for FIB and TEM to view radiation damage and initial condition.
Thank You
Examples of Brittle Fracture in Shear Punch

- EP-823 tested at 25C
- irradiated to 15 dpa
- Tirr = 360C

- TA-1W
- 26 dpa
- 3300 appm He

- Pure Ta
- 21 dpa
- 1333 appm He
Shear Punch Results

Almost All Middle Range

HighRad Ring

Around the Outside of Colimator

OuterRing

Control + 4 regions
Inconel 718-unirradiated

Bright field TEM images showing dislocations and some precipitates
Bright field TEM images showing dislocations, precipitates are not detected?
Inconel 718 #E ~11 dpa @~75°C
Inconel 718 #19 ~ 0.5 dpa @50°C

Bright field TEM images showing dislocation loops.

Under-focus TEM images on the right are showing a high density of bubbles/voids that are on the order of 5-10nm.
Inconel 718 #19 ~ 0.5 dpa @50°C γ″ precipitates
Inconel 718 #16~ 2.5 dpa @ ~40°C
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