Post Irradiation Evaluation of Inconel Alloy 718 Beam Window

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Introduction

Annealed Inconel 718 alloy was chosen for the beam window at the Los Alamos Neutron Science Center (LANSCE) Isotope Production Facility (IPF) [1]. The window was replaced after 5 years of operation. Mechanical properties and microstructure changes were measured to assess its expected lifetime.

Material and Methods

A cutting plan was developed based on the IPF rasterred beam profile (FIG. 1). 3-mm OD samples were cut out from the window and thinned to 0.25-mm thick. Shear punch tests were performed at 25 °C on 21 samples to quantify shear yield, ultimate shear stress, and ductility. From 1-mm OD, 0.25-mm thick shear punched out disks, 4 TEM specimens of ~30×10×2 µm were obtained using standard FIB lift-out techniques. TEM was performed on an FEI Tecnai TF30-FEG operating at 300 kV.

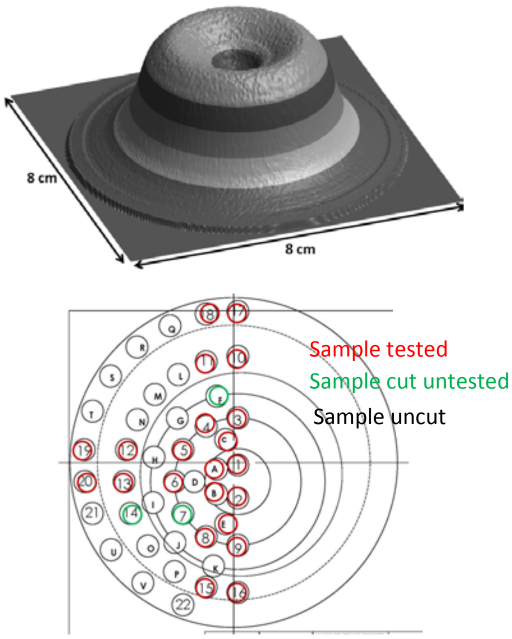

FIGURE 1. A 3D beam profile from MCNPX simulations (top) and cutting plan (bottom).

Results and Conclusions

TABLE 1 shows MCNPX tally results of accumulated dpa, He and H content from both protons and neutrons fluences and ANSYS steady-state irradiation temperature for the 3-mm OD samples [2]. These peak values are at the peak density of the Gaussian beam. These values are lower towards the outer edge of the window.

SAMPLE	DPA	H (APPM)	HE (APPM)	TEMPERATURE (C)
1–2	8.6	13.4–13.6	2.1–2.2	100
3–9	11.3	17.8–18.3	2.6–2.9	122
10–11	2.0	3.1–3.2	0.5	90
12–13	2.8	4.5–4.7	0.7	90
14	3.3	5.1	0.7	90
15–16	3.6	5.6–5.9	0.9	
17–18	0.2	0.2	0	40
19	0.7	0.9	0.1	40
20–21	0.8	1.3	0.2	40
22	1.4	2.2	0.3	
A–B	9.3	14.9–15.0	2.2–2.4	
C–E	10.6	16.5–17.0	2.7	
F–K	9.0	14.1–14.6	2.2–2.3	
L	2.2	3.2	0.4	
M	2.3	3.8	0.6	
N	2.5	3.9	0.7	
O–P	3.5	5.6–5.7	0.9–1.0	
Q–S	0.2	0.2–0.5	0–0.1	
T	0.5	0.7	0.1	
U	1.0	1.7	0.2	
V	1.2	2.1	0.3	

TABLE 1. MCNPX calculated dose (dpa), H and He content and temperature at various locations in the beam window at 100 MeV beam energy

Typically increases in shear yield and shear maximum stress occur with increasing dose. In this case, highest shear yield and ultimate stress was on the lowest dose samples at the outer edge (FIG. 2).

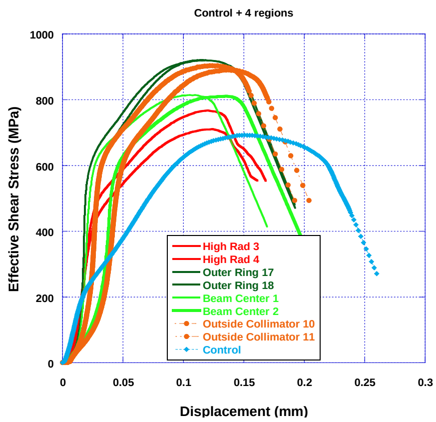

FIGURE 2. Shear punch results of samples at various locations shown in the cutting plan and control sample from un-irradiated Inconel 718.

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Optical microscopy images of the fracture surfaces on the shear punched out disks show no significant change in the fracture mode or reduction in ductility in the un-irradiated, high and low dose irradiated samples.

One un-irradiated and 4 irradiated samples (5, E, 16 and 19) were selected for TEM analysis. Figure 3 shows bright field TEM images of an un-irradiated, high and low dose irradiated samples.

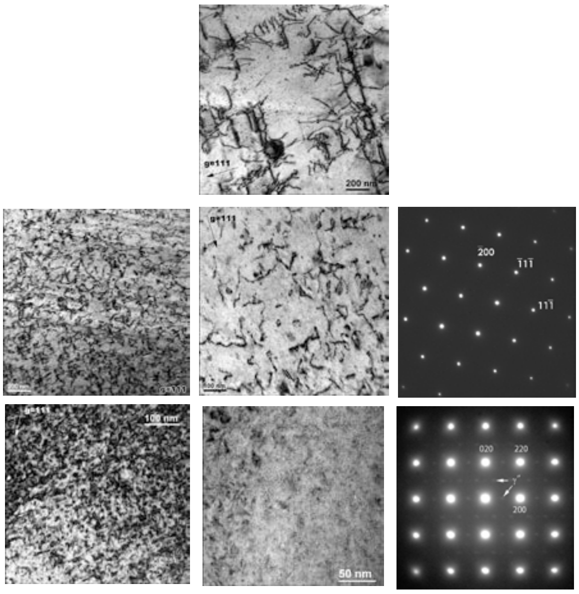

FIGURE 3. TEM images of un-irradiated (top row), high dose sample #5 (middle row) , and low dose sample #19 (bottom row)

Un-irradiated sample shows some dislocations and some large precipitates. The high dose sample #5 (~11 dpa, 122 ^{o}C) shows small loops and dislocations (left and center images) and no γ' or γ'' precipitates in SAD from z = [011] (right image). Low dose sample #19 (~0.7 dpa, 40 ^{o}C) shows a high density of dislocation loops (left image), high density of H/He bubbles (center image) and presence of γ'' precipitates in SAD from z = [011] (right image).

Radiation induced-hardening is highest at the low dose region in the outer most edge. The hardening from γ'' precipitates is determined to be more pronounced than that from trapped bubbles. The lack of significant hardening in the highest dose region is attributed to a lower dislocation density and no γ” precipitates or bubbles [3]. Identification of H or He bubbles and the higher accumulation of these bubbles in the low dose region (no direct beam hitting) warrant further studies.

Despite the evidence of irradiation-induced hardening, this spent beam window appears to retain useful ductility after 5 years in service. At the conclusion of 2013 run cycle, the current in-service beam window had reached the same dpa as of the spent window. We plan to extend the service of the current in-service window until it reaches its intended design threshold limit of ~20 dpa (in the highest dose region). Additional measurements at higher dpa values will enable better decision-making in managing risks of the window failure.

References

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3. S. A. Maloy et al.: *The change in the mechanical properties of alloy 718, 304L and 316L stainless stell and Al6061 after irradiation in a high energy proton beam*, LANL report LAUR-99-4175, 1999.

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