Transactions of the Korean Nuclear Society Autumn Meeting
Goyang, Korea, October 24-25, 2019

Evaluation of mechanical properties using micro bending test of helium implanted Inconel X-750

Sangeun Kim, Hyung-Ha Jin, I Seul Ryu, Gyeong Geon Lee*

Nuclear Materials Research, Korea Atomic Energy Research Institute,
111, 989 Beon-gil Daedoek-daero, Yuseoung-gu, Daejeon

**Corresponding author: kse91@kaeri.re.kr*

1. Introduction

Heavy water CANDU reactors use Inconel X-750 as internal spacers to maintain a gap between the hot Zr-2.5wt%Nb pressure tube and the cool Zircaloy-2 calandria tube. The CANDU reactor has an extremely high thermal neutron flux spectra and internal production of helium and hydrogen. Helium will act to stabilize small vacancy clusters to form bubbles and/or cavities, the void swelling which could contribute to a form of grain boundary embrittlement [1].

This work focus on mechanical properties change of X-750 alloys after the helium implantation through micro cantilever bending test.

2. Experimental

The experimental material in this study is a solution annealed nickel based alloy (Inconel X-750) plate. The chemical compositions of the experimental sample are given in Table 1. Some of X-750 alloy were heat-treated at 730℃ for 16 hours to emulate one of typical microstructures (the formation of γ\`) of the annular garter spring spacer component.

Table 1 Chemical composition of experimental sample

Al	**C**	**Co**	**Cr**	**Cu**	**Fe**	
0.72	**0.05**	**0.09**	**14.85**	**0.01**	**6.80**	
Mn	**Nb**	**S**	**Si**	**Ta**	**Ti**	**Ni**
0.09	**1.03**	**0.003**	**0.18**	**0.01**	**2.61**	**Bal**

The experimental specimens (as-received and heat-treated) for the helium implantation were prepared by mechanical polishing. The surface of specimens was mechanically wet-polished using SiC sand papers. Fine mechanical polishing was performed with a fine-sized diamond suspension (3um and 0.25um) and a colloidal silica suspension (0.1um).

Helium implantation on the Inconel X-750 alloys was performed in the Michigan Ion beam laboratory. Helium ions were used in multiple energies ranges, from 1420 keV to 2820 keV, for the development of uniform radiation damage and implanted ion in the ion-implanted samples. The displacement damage was calculated using the SRIM code [2]. The calculated peak damage was 0.1dpa at a depth of 2~5μm and the implanted He concentration is also estimated to be approximately 1000, 3000 and 6000appm in the layer as shown in Fig. 1.

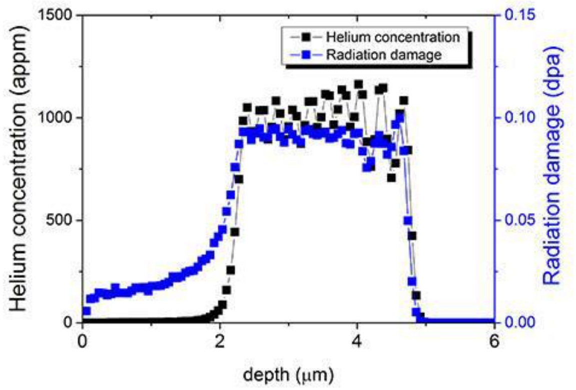

Fig 1. Radiation damage and helium concentration calculated by SRIM

We utilized mainly a focused ion beam (FIB) device for fabrication of micro-cantilevers near edge region of the experimental samples. We obtained the geometric information of the micro-cantilevers through SEM imaging and also conducted crystal orientation analysis with EBSD equipped in SEM (as shown in Fig 2).

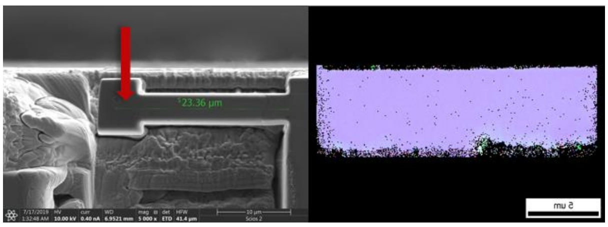

Fig 2. SEM image and EBSD map of cantilever

Micro bending of the micro-cantilevers in the experimental sample was carried out with a nano indenter (UNHT, CSM instruments). A berkovich tip was used for the bending test. Loading rate for the micro bending test was set to be 0.5mN/min. The indentation displacement was limited to be 1-2 um.

3. Result and discussion

The cantilevers for the micro bending test were fabricated with uniform implanted layer ranging from 2 um to 5 um in depth. Load to displacement data of the helium implanted X-750 alloys were obtained by micro-bending test. The applied load obtained from the data was used to calculate the engineering stress (σ) [3].

$$\sigma = \frac{4Fy}{wh^2} \quad \text{(eq.1)}$$

Where F is the applied load, y is the distance to indenting point (moment arm), w is the width of cantilever beam, and h is its thickness. The resolved shear stresses are estimated using the maximum Schmid factors.

Table 2. CRSS and ΔCRSS according to helium implantation

	1000appm		3000appm	6000appm	
	H00	H16	H00	H00	H16
CRSS(Mpa)	506.23	592.44	728.17	1447.69	1434.56
ΔCRSS(Mpa)	202.23±36.5	92.44±24.08	424.17±84.7	1143.69±84.77	934.56±147.28

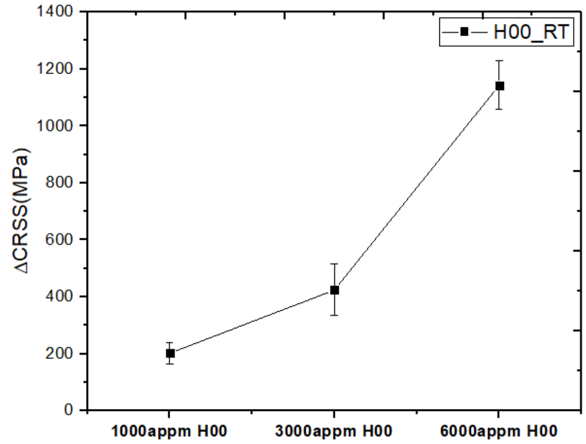

Fig 3. ΔCRSS – displacement profiles of X-750 alloys after helium implantation

Fig 3 shows ΔCRSS (CRSS of irradiated X750 - CRSS of unirradiated X-750) – displacement profiles of helium implanted X-750 alloys by micro bending test. The ΔCRSS of micro-cantilever samples was measured to be 202MPa(1000appm), 424 MPa(3000appm), 1143 MPa(6000appm) for helium implanted X-750 alloy respectively. It is expected that the significant hardening is caused by helium bubble formation in the matrix.

Fig 4 shows the change of ΔCRSS of X-750 samples after heat treatment. Note that the ΔCRSS of the micro-cantilever samples was measured to be 200 MPa (1143MPa) for as-received X-750 alloy and, 92 MPa (934MPa) for heat-treated X-750 alloy respectively. The hardening of the heat-treated X-750 alloy is measured to be lower. The low hardening phenomenon seems to be due to the disordering process of γ` [4].

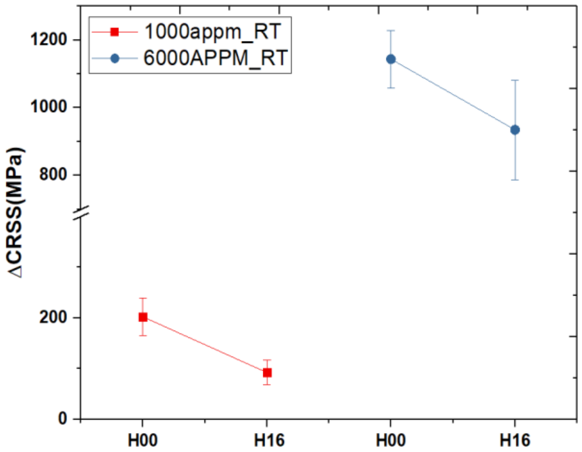

Fig 4. Change of ΔCRSS by heat treatment of X-750

3. Conclusion

We performed the micro bending test for evaluation of mechanical properties change of Inconel X-750 alloy after helium ion irradiation. The micro bending test indicates that the helium implantation cause significant hardening. Heat-treated X-750 alloys has a smaller helium ion irradiation effect than as-received sample. It seems to be due to the disordering process of gamma prime, γ`.

REFERENCES

[1] C.D. Judge, The effect of irradiation on Inconel X-750, Department of materials science and engineering, McMaster University, 2015.

[2] J.F.Ziegler, J.P.Biersack, U.Littmark, The Stopping and Range of Ions in Solids, Pergamon Press, New York, 1985.

[3] C. Motz, T.Schoberl, R. Pippan, Acta Mater 53 pp 4269-4279 2005

[4] H.K Zhang, Z. Yao, M A. Kirk, M R. Daymond, Metal Mater Trans. A 45(8) pp 3422-3428 2014.