Mechanical property evaluation of proton irradiated Inconel X-750

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INTRODUCTION

The spacer, one of the fuel channel parts in the CANDU reactor, is made of high-strength nickel-based alloy, and serves to prevent the embrittlement of the pressure tube by suppressing the contact between the pressure tube the calandria tube. The X-750 alloy containing high density of nanometer sized gamma phase has been known to exhibit intergranular grain boundary failure because of high thermal neutron flux spectra and internal production of helium and hydrogen. Radiation-induced defects act as barriers to dislocation motion, and the inter-defect distance creates a new internal material length scale. This causes irradiation hardening and affect the mechanical properties of the material [1, 2]. The main purpose of this work is to evaluate the effect of irradiation on the strength of Inconel X-750 using micro hardness and micro-compression tests.

EXPERIMENTAL

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.

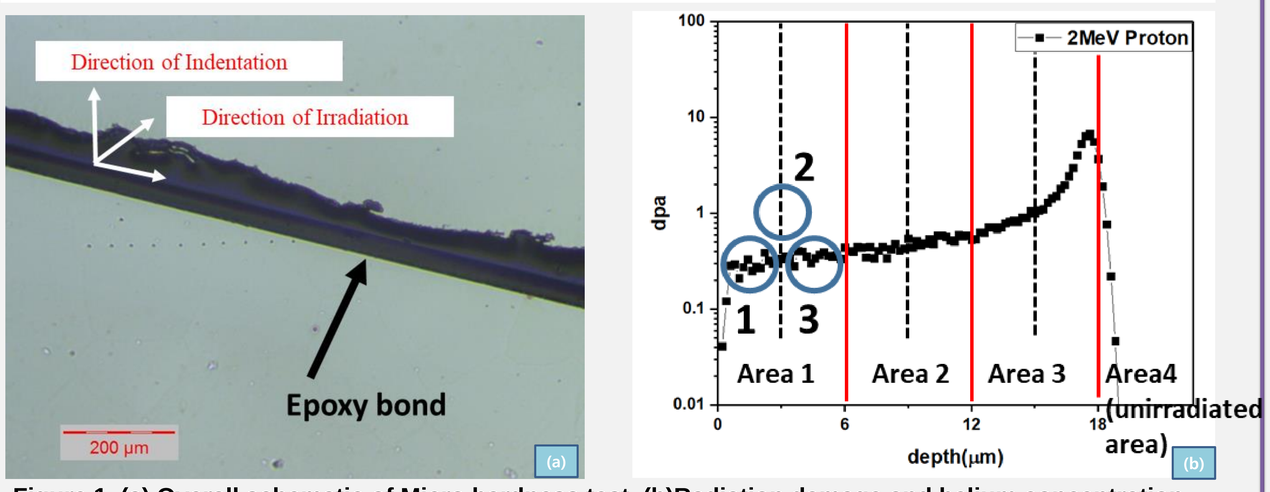
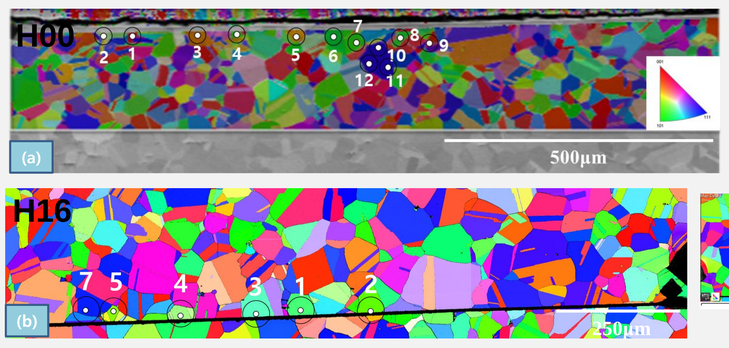


Figure 1. (a) Overall schematic of Micro hardness test, (b)Radiation damage and helium concentration calculated by SRIM (2 ~ 5 μm in depth)



Ion species	Proton
Energy	2MeV
Fluence	1.0×10^{19} ions/m^2
Temperature	733K (360℃)

Figure 2. EBSD maps of (a) H00 (as-received), and (b) H16 (heat-treated)

- **We prepared specimens H16 heat-treated at 730℃ for 16hours and H00 specimens that were no heat treated.**
- **The micro hardness test was conducted up to about 50μm with a load of 5mN on the surface perpendicular to the irradiation direction(figure 1(a)).**

- **We utilized mainly a focused ion beam (FIB) device for fabrication of micro-pillars. Three irradiated areas and one non-irradiated area were classified through SRIM data, and three micro pillars with a diameter of 3μm were fabricated in each area(figure 1(b)). also conducted crystal orientation analysis with electron backscattered diffraction (EBSD) equipped in SEM(figure 2).**

RESULT & DISCUSSION

➢ Micro hardness test

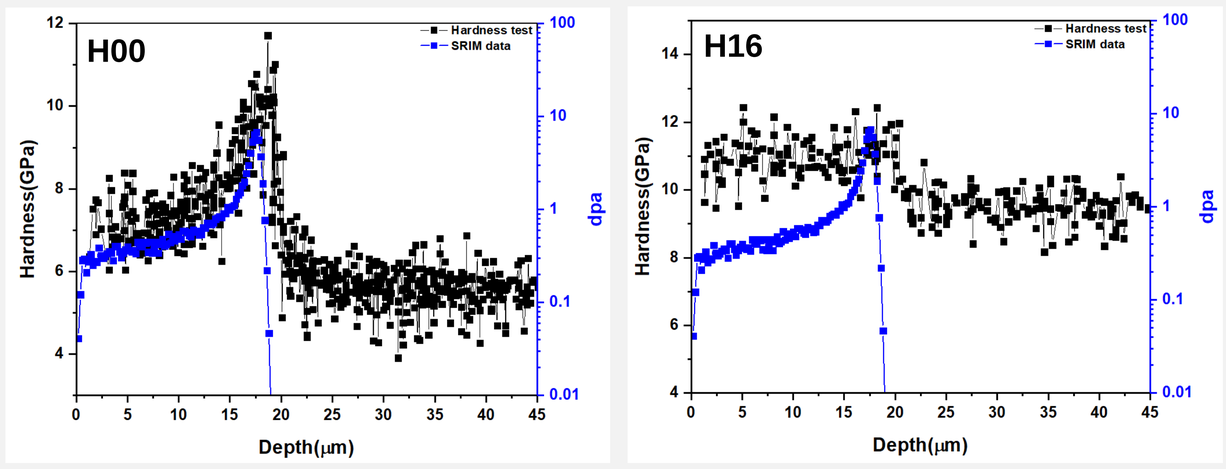


Figure 3. Comparison graph of SRIM data and micro hardness test

- **It was confirmed that irradiation hardening occurred due to proton irradiation.**
- **It was confirmed that H16 had a higher hardness value in the non-irradiated area than H00, and H00 had a value of 5.5GPa and H16 had a value of 9.46GPa, respectively.**

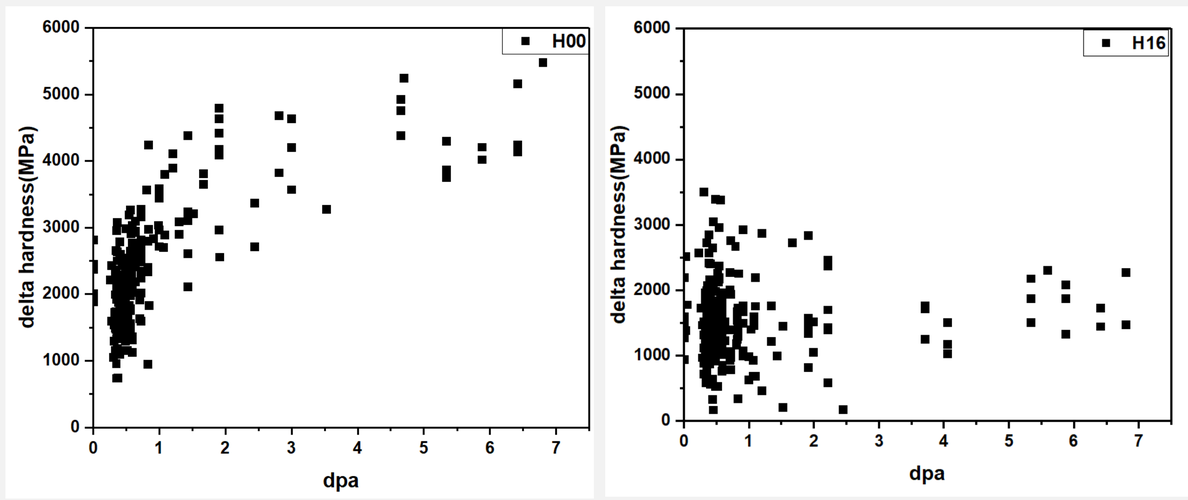


Figure 3. A graph represented by the dpa and the delta hardness obtained by subtracting the value of the non-irradiated area from the irradiated area.

- **In the case of H00, as dpa increases, the delta hardness value tends to increase. However, in the case of H16, even if dpa increases, there is no significant change in the delta hardness value.**

➢ Micro pillar test

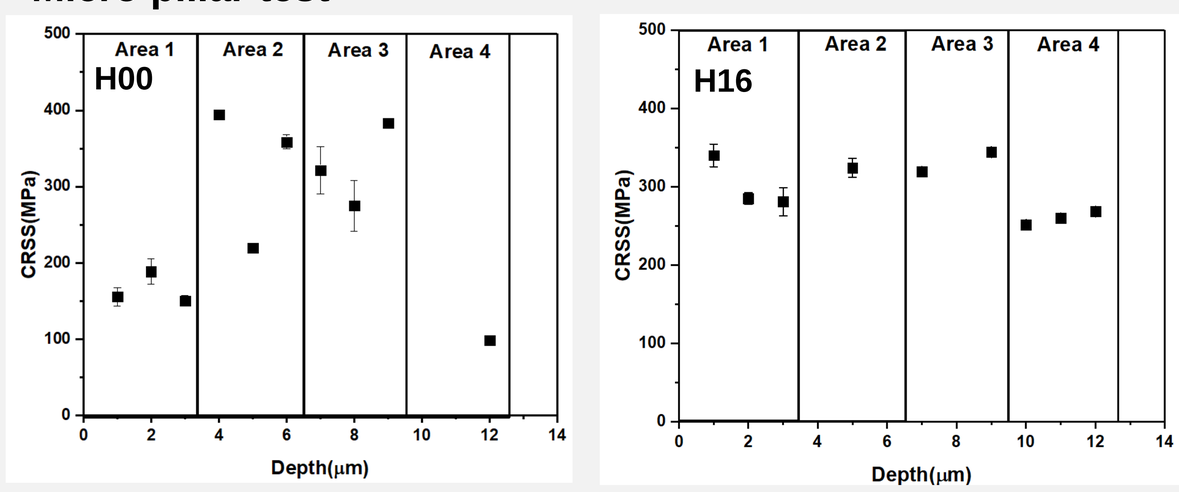


Figure 4. CRSS according to micro pillar position. Depth on the X-axis represents the center point of the micro pillar.

- **There was generally no significant difference in CRSS within each area. In the case of some pillars, bucking occurred due to contact misfit between the indenter and the surface, and was excluded**

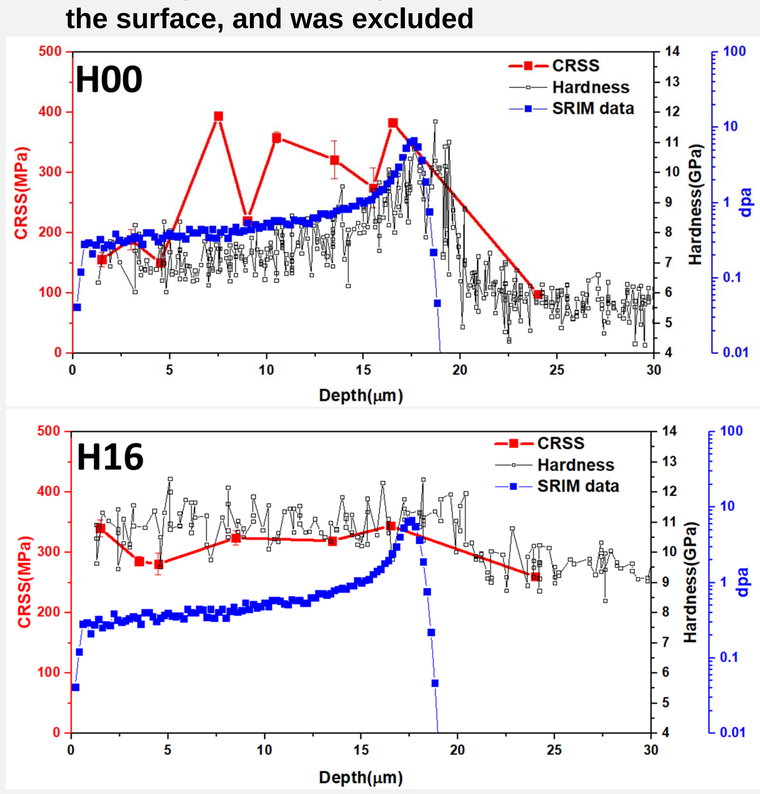


Figure 5. Results of SRIM data, micro hardness test and micro pillar test according to the irradiation depth.

- **In the case of H00, except for the 4th and 6th pillars, the trend is generally consistent with the SRIM data, and as dpa increases, the hardness and CRSS value increases.**
- **In the case of H16, no changes in hardness and CRSS values were observed with increasing dpa. This reason is considered to be due to the nano-sized γ` phase present inside H16.**
- **Area 2 and area 4 area of H00 are expected to undergo additional micro-pillar test .**

Conclusion

- **The irradiation hardening of Inconel X-750 alloy steel is evaluated by proton irradiation at 360℃. Through the micro-hardness test and micro-compression test, changes in mechanical properties due to proton irradiation of Inconel X-750(H00 and H16) was evaluated.**
- **In H00 and H16, irradiation hardening by proton irradiation was observed. However, in the case of H16, even when dpa increased, no significant change in hardness and CRSS value was observed. This is estimated by influence of the γ` phase inside H16.**

Reference
[1] C.D. Judge, The effect of irradiation on Inconel X-750, Department of materials science and engineering, McMaster University, 2015.
[2] M, Griffiths, CNL nuclear review 2 (1) pp 1-16 2013.