

# Evaluation of Helium Effect on Candidate Structural Materials for Next Generation Long-Life Nuclear Plant

著者	Hasegawa A, Nogami S, Satou M, Wakai E, Aoto K
journal or publication title	CYRIC annual report
volume	2007
page range	25-29
year	2007
URL	<a href="http://hdl.handle.net/10097/44381">http://hdl.handle.net/10097/44381</a>

## III. 2. Evaluation of Helium Effect on Candidate Structural Materials for Next Generation Long-life Nuclear Plant

*Hasegawa A.<sup>1</sup>, Nogami S.<sup>1</sup>, Satou M.<sup>1</sup>, Wakai E.<sup>1</sup>, and Aoto K.<sup>2</sup>*

<sup>1</sup>*Department of Quantum Science and Energy Engineering, Tohoku University*  
<sup>2</sup>*Japan Atomic Energy Agency*

### Introduction

For development of the next generation long-life nuclear plant, precise prediction of the irradiation damage to reactor vessel and in-core component during operation is necessary. This study focuses on the developing the index for evaluation of the irradiation damage for the candidate structural materials of the next generation long-life nuclear plant such as SUS304 steel, SUS316FR steel and 12Cr steel (HCM12A), which can be applied to reactor design method considering irradiation environment effect. This study also focuses on the developing the non-destructive inspection technique for precise understanding of irradiation damage progress during operation based on the index.

The amount of generated helium (He) is recognized as one of the promising index in this study. The database of mechanical property change for those materials due to He implantation should be established in order to verify whether He generation amount is adequate as the index for evaluation of the irradiation damage. Therefore, short time mechanical properties such as the tensile property (tensile strength and yield stress) and the hardness were evaluated in order to clarify the relation between He and their changes. Microstructure observation was also performed for analysis of the microstructure change due to He implantation.

### Experimental

#### (1) He Implantation using Cyclotron

Material in this study is the 316FR steel, which is the candidate structural material for next generation nuclear plants. The chemical composition of these materials is shown in Table 1. The specimen shape was a miniaturized tensile specimen and a rectangular

specimen with geometry of 5 mm×16 mm×0.3 mm. The specimen surface was mechanically and electrically polished into mirror state.

The He implantation test was carried out using the AVF Cyclotron accelerator of Cyclotron and Radioisotope Center of Tohoku University. The implanted particle, implantation temperature and He concentration were 50 MeV He<sup>2+</sup> ion, about 550°C and about 10 appm (implantation rate: about 0.3 appm/h), respectively. Helium was uniformly implanted from the specimen surface to about 400 μm in thickness by using a rotating energy degrader consisting of Al foils. Figure 1 shows the depth distribution of He concentration and displacement damage in the specimen calculated by SRIM code. The displacement damage in an iron produced by 50 MeV He<sup>2+</sup> ion was about  $2 \times 10^{-4}$  dpa per 1 appm-He. The implantation temperature was measured using a thermocouple during implantation test, which was spot-welded to one of the implanted specimens.

## **(2) Tensile Test**

Tensile test for the He implanted tensile specimen was performed using an Instron-type multi-purpose testing machine (INTESCO Co., Ltd.) at Radio Isotope Laboratory of Tohoku University. The test temperature, test environment and strain rate were about 550°C, vacuum below  $1 \times 10^{-3}$  Pa and about  $6.7 \times 10^{-4}$  s<sup>-1</sup>, respectively.

## **(3) Hardness Measurement**

The Vickers hardness measurement was performed using a Vickers hardness tester (Shimadzu Corp., Micro Hardness Tester type M) at Radio Isotope Laboratory of Tohoku University. The number of the test was 10 for each specimen. The test temperature, indentation load and dwell time was room temperature, 200 gf and 15 sec, respectively.

## **(4) Microstructure Observation by TEM**

Microstructural observation for the He implanted specimen was performed using a transmission electron microscope (TEM, JEOL Ltd., JEM-2000FX) at International Research Center for Nuclear Materials Science of Tohoku University. Thin foil preparation for TEM observation was performed by electro-polishing using electrolyte solution with acetic acid and perchloric acid.

## **Results and Discussion**

### *(1) Tensile Test*

Figure 2 and Table 2 show the stress-strain curves for the miniaturized tensile specimen He-implanted up to about 10 appm (about 0.3 appm/h and about 1.7 appm/h<sup>1</sup>) and the summary of the yield stress, tensile strength, uniform elongation, total elongation and reduction in area, respectively. Almost no effect of implantation rate on the tensile strength was observed. While, clear effect on the yield stress, uniform elongation, total elongation and reduction in area was observed. About 37% increment of the yield stress, about 25% reduction of the uniform elongation, about 33% reduction of the total elongation, and about 11% reduction of the reduction in area occurred by reducing the implantation rate from about 1.7 appm/h to about 0.3 appm/h.

### *(2) Hardness Measurement*

Table 3 shows the summary of the Vickers hardness for the He-implanted specimen up to about 10 appm (about 0.3 appm/h and about 1.7 appm/h<sup>1</sup>). Almost no effect of implantation rate on the Vickers hardness was observed. The results also showed that the hardness change due to He implantation was very small for both implantation rates.

### *(3) Microstructure Observation by TEM*

Figure 3 shows the typical microstructure for the He-implanted specimen up to about 10 appm (about 0.3 appm/h and about 1.7 appm/h<sup>1</sup>). Almost no effect of implantation rate on the Vickers hardness was observed. No He bubbles were observed both in the matrix and in the grain boundary.

## **Summary**

Evaluation of the short time mechanical properties such as the tensile property and the hardness and observation of microstructure for He implanted 316FR by using Cyclotron was carried out in order to clarify the relation between He and their changes due to He implantation. The database of these properties was established for the He implanted specimen up to about 10 appm at about 0.3 appm/h and about 1.7 appm/h under the implantation temperature of 550°C.

## **Acknowledgement**

Present study is the result of R&D Project on Irradiation Damage Management

Technology for Structural Materials of Long-life Nuclear Plant entrusted to Japan Atomic Energy Agency (JAEA) by the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT). The authors are grateful to the staffs of CYRIC of Tohoku University relating to the accelerator operation and our irradiation experiments.

## References

- 1) Hasegawa A., Nogami S., Satou M., Wakai E., Aoto K., CYRIC Annual Report (2006) 25.

Table 1. The chemical composition of the 316FR steel (mass%).

	Fe	C	Si	Mn	P	S	Cu	Ni	W	Cr	Mo	V	Nb	N
316FR	Bal.	0.01	0.59	0.84	0.026	0.003	0.26	11.19	-	16.87	2.23	0.08	-	0.08

Table 2. The summary of the yield stress, tensile strength, uniform elongation, total elongation and reduction in area.

Material	He Concentration [appm]	He Implantation rate [appm/h]	Yield Stress [MPa]	Tensile Strength [MPa]	Uniform Elongation [%]	Total Elongation [%]	Reduction in area [%]	Ref.
316FR	0	—	139.8	368.0	31.6	34.8	99.5	1)
	10	1.7	91.8	354.7	40.8	46.1	95.3	1)
	10	0.3	125.5	345.7	30.7	31.0	85.0	—

Table 3. The summary of the Vickers hardness.

Material	He Concentration [appm]	He Implantation rate [appm/h]	Vickers hardness Hv		Ref.
			Average	Std. Dev.	
316FR	0	—	172.7	16.3	1)
	10	1.7	169.0	17.2	1)
	10	0.3	175.1	4.5	—

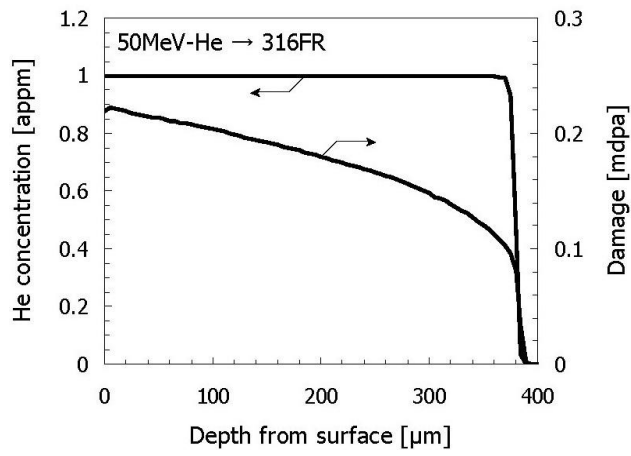


Figure 1. The depth distribution of He concentration and displacement damage, calculated by SRIM code.

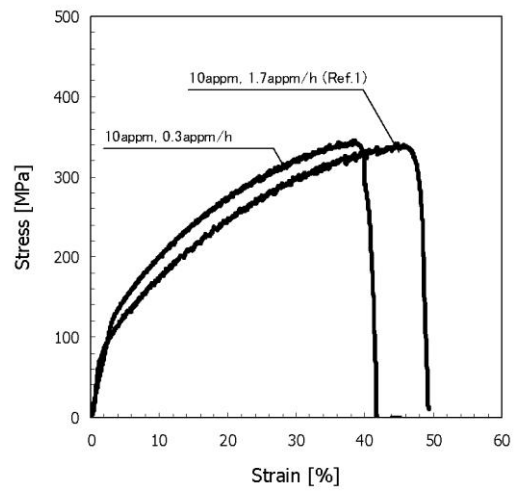


Figure 2. The stress-strain curves for the He implanted miniaturized tensile specimen.

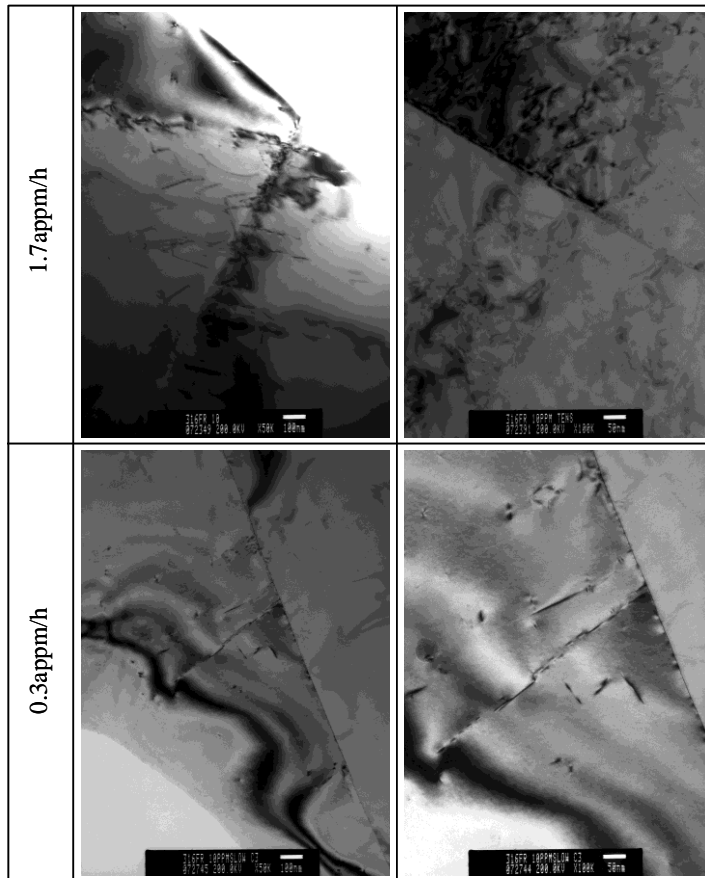


Figure 3. The microstructure of the He implanted 316FR steel up to about 10 appm.