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

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III. 1. Evaluation of Helium Effect on Candidate Structural Materials for Next Generation Long-life Nuclear Plant

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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 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.

Experimental

Material in this study is the 316FR steel and the HCM12A steel, which are 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^{2+} ion, about 550°C and about 50 appm, 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.

Tensile test at room temperature for the He implanted miniaturized tensile specimen was performed using an Instron-type multi-purpose testing machine (INTESCO Co., Ltd.) at Radio Isotope Laboratory of Tohoku University. The test environment and strain rate were in-air and about 6.7×10^{-4} s^{-1}, respectively.

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

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

Results

Figure 2 shows the results of the tensile test ((a) tensile strength, (b) yield stress, (c) uniform elongation, (d) total elongation) at about 550°C in 316FR and HCM12A implanted up to about 50 appm at about 550°C by Cyclotron[1)]. About 15% reduction of the tensile strength due to He implantation up to about 1 appm and almost no change of it due to He implantation from 1 to 50 appm were observed in both materials. Almost no change of the yield stress due to He implantation from 1 to 30 appm and slight increase of it due to He implantation up to about 50 appm was observed in 316FR. About 20% reduction of the yield stress due to He implantation up to 1 appm and almost no change of it due to He implantation from 1 to 50 appm was observed in HCM12A.

Figure 3 shows the results of the tensile test ((a) tensile strength, (b) yield stress, (c) uniform elongation, (d) total elongation) at room temperature in 316FR implanted up to about 50 appm and HCM12A implanted up to about 10 appm at about 550°C by Cyclotron[1)]. The tensile strength of 316FR gradually decreased with He concentration and about 17%

reduction of it due to He implantation up to about 50 appm was observed. The tensile strength of HCM12A also gradually decreased with He concentration and about 10% reduction of it due to He implantation up to about 10 appm was observed. About 18% reduction of the yield stress due to He implantation up to about 10 appm and almost no change of it due to He implantation from 10 to 50 appm were observed in 316FR. The yield stress of HCM12A also gradually decreased with He concentration and about 23% reduction of it due to He implantation up to about 10 appm was observed.

Figure 4. shows the Vickers hardness in 316FR and HCM12A implanted up to about 50 appm at about 550^{o}C by Cyclotron[1)]. Very small change of the hardness in 316FR was observed after He implantation from 1 to 50 appm. While, increment of the hardness by 20~30Hv due to He implantation up to 30 appm and reduction by 20~30Hv due to He implantation up to 50 appm were observed in HCM12A.

Summary

Evaluation of the short time mechanical properties such as the tensile property and the hardness for He implanted materials (316FR and HCM12A steel) using Cyclotron was carried out in order to clarify the relation between He and their changes due to He implantation. Table 2 is the summary of the database of thermal desorption spectrometry, microstructural observation, tensile test and Vickers hardness measurement for 316FR and HCM12A obtained using Cyclotron in 2006 to 2008 for the 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).

Acknowledgement

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References

1) Hasegawa A., Nogami S., Satou M., Wakai E., Aoto K., CYRIC Annual Report (2007) 25.
2) Hasegawa A., Nogami S., Satou M., Wakai E., Aoto K., CYRIC Annual Report (2006) 25.

Table 1. The chemical composition of the 316FR steel and the HCM12A steel..

	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
HCM12A	Bal.	0.11	0.27	0.64	0.016	0.002	1.02	0.39	1.89	10.83	0.30	0.19	0.054	0.063

Table 2. Summary of the database of thermal desorption spectrometry, microstructural observation, tensile test and Vickers hardness measurement for 316FR and HCM12A obtained in 2006 to 2008 in the 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).

Material	He conc. [appm]	TDS	TEM	Mechanical Properties		
				Tensile		Hardness
				550°C	R.T.	
316FR	0	—	2006-2007	2006-2007	2008	2006-2007
	1	2006-2007	2006-2007	2006-2007	—	2006-2007
	10	2006-2007	2006-2007	2006-2007	2008	2006-2007
	30	2006-2007	2006-2007	2006-2007	2008	2006-2007
	50	2008	2008	2008	2008	2008
	100	—	2008	—	—	—
HCM12A	0	—	2006-2007	2006-2007	2008	2006-2007
	1	2006-2007	2006-2007	2006-2007	2008	2006-2007
	10	2006-2007	2006-2007	2006-2007	2008	2006-2007
	30	2006-2007	2006-2007	2006-2007	—	2006-2007
	50	2008	2008	2008	—	2008
	100	—	2008	—	—	—

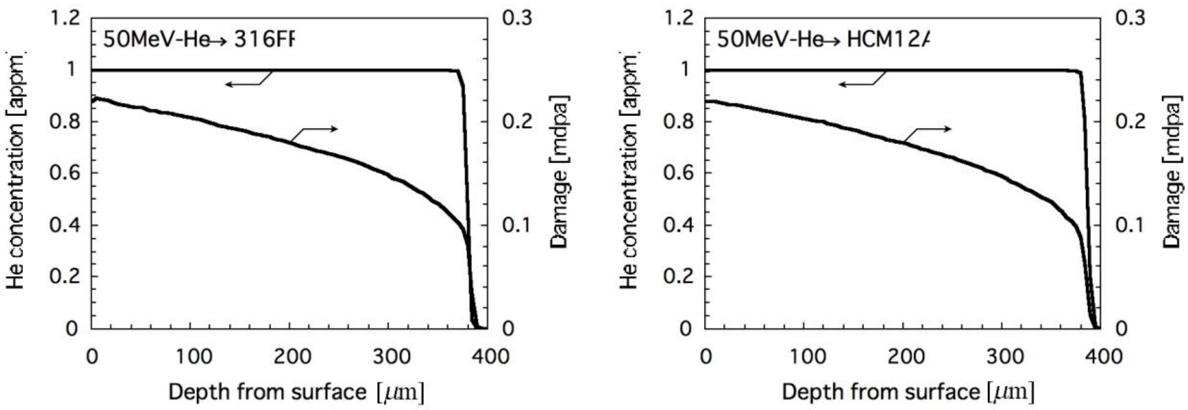

Figure 1. The depth distribution of He concentration and displacement damage in the 316FR steel and the HCM12A steel calculated by SRIM code.

Figure 2. The results of the tensile test ((a) tensile strength, (b) yield stress, (c) uniform elongation, (d) total elongation) at about 550^{o}C in 316FR and HCM12A implanted up to about 50 appm at about 550^{o}C by Cyclotron[1)].

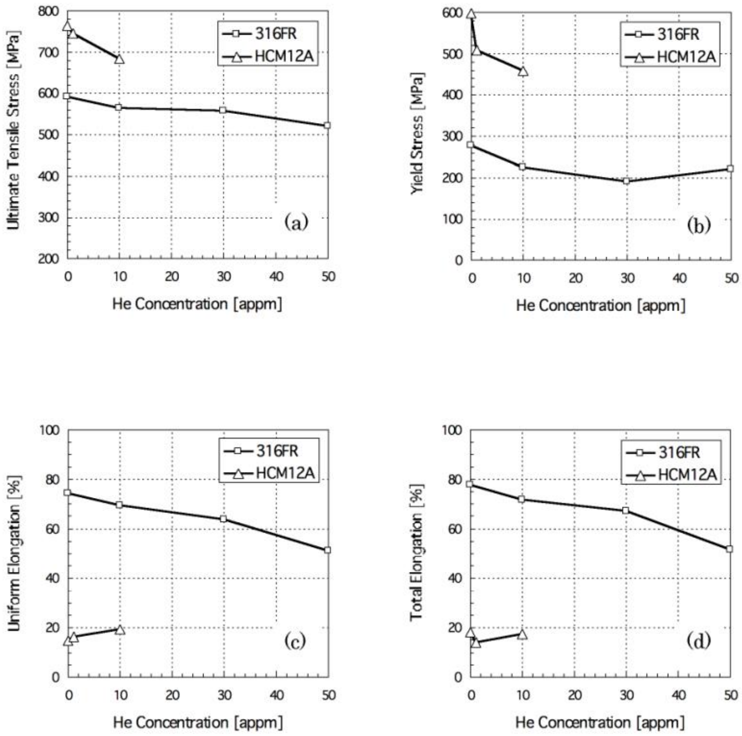

Figure 3. The results of the tensile test ((a) tensile strength, (b) yield stress, (c) uniform elongation, (d) total elongation) at room temperature in 316FR implanted up to about 50 appm and HCM12A implanted up to about 10 appm at about 550^{o}C by Cyclotron[1)].

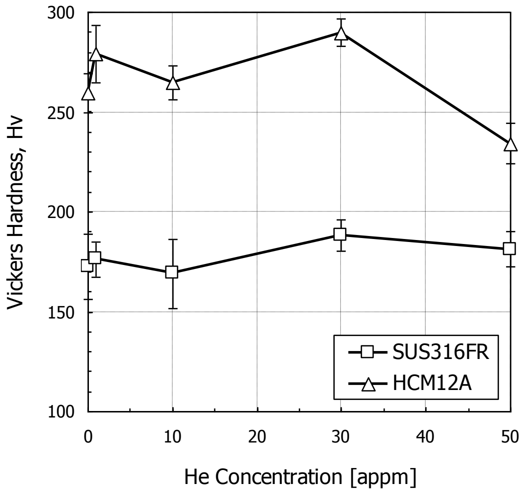

Figure 4.　Vickers hardness in 316FR and HCM12A implanted up to about 50 appm at about 550^{o}C by Cyclotron[1)].