Radiation induced changes in austenitic stainless steel after He ion irradiation

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1. Introduction

Much attention has been paid to radiation induced phenomena in austenitic stainless steels used for internals in nuclear reactors since the phenomena are closely related with material degradation such as radiation hardening, radiation induced segregation and swelling. Neutron irradiation effect has been considered to be important for material degradation of nuclear internals. Effect of helium and hydrogen on the material degradation has been overlooked because of low production rate of helium and hydrogen during operation of PWR. However, recent researches revealed that large amounts of helium and hydrogen were generated in neutron irradiated reactor internals used for commercial PWR [1-3]. In this work, we are investigating on role of helium on radiation induced changes in austenitic stainless steel using He ion irradiation to have scientific knowledge regarding these phenomena.

2. Experimental

2.1 Preparation of Material

Table 1 Chemical composition (wt%) of material used in the present study

	Ni	Cr	Mo	Mn	Si	P	C	S
SA316_2	10.8	16.7	2.0	1.3	0.6	0.05	0.047	0.001

Table 1 indicates the chemical composition of experimental steels used for this work. We carried out fine polishing with a vibratory polisher. A colloidal silica suspension was used for the reduction of surface damage.

2.2 Ion irradiation

We performed He ion irradiation with various energies ranged from 50 keV to 490 keV. In order to produce uniform radiation damage, radiation doses for each energy level were determined through SRIM calculation [4]. In the calculation, we assumed average displacement threshold energy to be 40 eV [5]. To measure swelling property, Mo mesh grids were attached on the experimental samples during the ion irradiation.

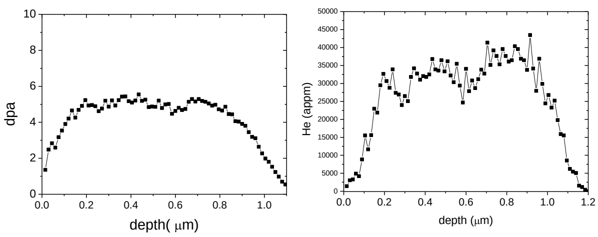

Fig.1 Radiation damage (dpa) and He ion concentration calculated by SRIM.

Matrix damage and ion concentration for the depth from the surface was calculated as shown in Fig. 1. The irradiation temperature was 400 ℃. According to the SRIM calculation, the damage layer was expected to be formed at 1 ㎛.

2.3 Characterization of radiation induced changes in the ion-irradiated austenitic stainless steel

Transmission electron microscope with field emission gun was used at 200 KeV to investigate microstructural changes caused by He ion irradiation. Cavity was observed by high magnification using under focus. For a chemical analysis at the grain boundary, we titled the TEM sample to set the GB plane parallel to the beam direction. When the GB plane is parallel to the beam direction, the interface fringes disappeared and a sharp contrast must be visible in the vicinity of GB. INCA system by Oxford Inc. was used for identification of the chemical compositions at GB using EDS. In a quantitative analysis, Cr, Ni, Mo, P, and Fe were only considered. Si was excluded in the analysis because of artifact phenomenon of EDS. Radiation hardening was measured by nano indentation test (CSM nano indenter) and swelling was measured by SPM (scanning probe microscope, Vecco).

3. Result

A low magnified TEM image in Fig. 2(a) presents clear radiation damage layer in the ion-irradiated austenitic stainless steels. Fig. 2(b) and 2(c) show the EDS results measured at a grain boundary in the experimental steel irradiated with He ions at 400℃. In the case of the steel irradiated at 400℃, radiation induced segregation and depletion developed at the grain boundary as shown in Fig. 2(b) and 2(c). The Cr element at the grain boundary was depleted significantly. Also, the elements of Ni, Si and P at the grain boundary were enriched considerably.

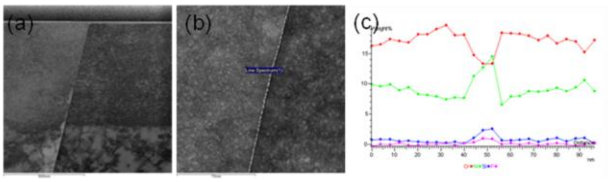

Fig. 2 (a) low magnified TEM image of He ion irradiated austenitic stainless steel, (b-c) STEM image and EDS results at grain boundary in the irradiated layer.

Fig. 3 TEM images showing Frank loops (a), cavities in the matrix (b) and at the grain boundary (c) in He ion irradiated austenitic stainless steel.

A number of cavities and frank loops were observed in the radiation damage layer as shown in Fig. 3(a) and 3(b). In addition, it was observed that the cavities were concentrated on grain boundary as shown in Fig. 3 (c). The RIS phenomena also happened at the frank loops. Analyses using OM and SPM showed that swelling developed on the irradiated area as shown in Fig. 4. The swelling is expected to be due to high density of cavities in the radiation damage layer. In nano indentation result, nano-hardness on the irradiation area is 4.4 GPa while nano hardness is measured to be about 3.1 GPa at unirradiated area. High density of frank loops and cavities lead to significant hardening at irradiation area.

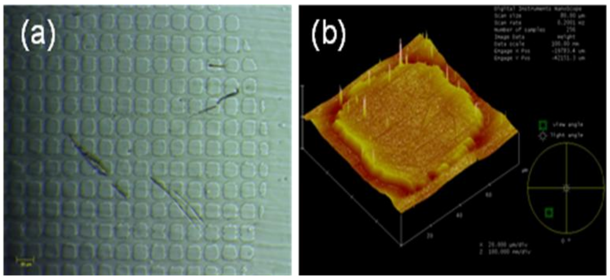

Fig. 4 Swelling pattern observed by optical microscope (a) and measured by SPM (b)

We compared the experimental data of the ion-irradiated stainless steel at 400℃ with previous data on Fe ion irradiated austenitic stainless steel. RIS of Cr and Ni in the ion-irradiated stainless steel irradiated at 400℃ is similar with that of Fe ion irradiated steel. Different feature between both the ion irradiation experiments is to formation of the cavity after He ion irradiation.

4. Conclusions

A TEM observation was performed to investigate radiation induced changes in austenitic stainless steel after He ion irradiation. Under He ion irradiation, RIS was detected in the ion-irradiated stainless steel. The tendency of RIS of Cr and Ni in ion-irradiated stainless steel irradiated at 400℃ is similar with that in Fe ion irradiated stainless steel. He implantation effect lead to high density of cavity, which is closely related with swelling and radiation hardening in the irradiated austenitic stainless steel.

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