

Effect of ion irradiation and implantation of H and He on the corrosion behavior of austenitic stainless steel

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Abstract

It is important to evaluate the effect of irradiation on the corrosion behavior of materials to be used in spallation neutron sources. Solution annealed high purity Fe–18Cr–12Ni specimens were used in this study. Ni³⁺ and H⁺ or He²⁺ ions were injected at 473–773 K. After corrosion test, the specimens were examined with atomic force microscope (AFM) to evaluate the corrosion behavior. It was shown that the corrosion rate of the irradiated area increased with increasing dose and temperature. H implantation accelerated corrosion. On the other hand, He implantation seemed to suppress corrosion. Mechanisms for these effects of the different irradiation conditions on the corrosion behavior are discussed.

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PACS: 28.50.Ft; 61.80.–x; 41.75.Ak; 82.45.Bb; 68.37.Ps; 25.55.–e

1. Introduction

Liquid metals are expected to be used as neutron spallation targets, i.e. mercury for intensive neutron sources and lead–bismuth for accelerator-driven systems (ADSs) [1–3]. Candidate structural materials for the target are type316 austenitic stainless steel and F82H ferritic steel. In the case of the target assembly concept for the J. PARC project, target vessel will be cooled by heavy water or light water [4]. Therefore, corrosion resistance of these materials after irradiation needs to be addressed. Moreover, high energy protons and neu-

trons will irradiate the structural materials in or close to the proton beam [5]. It is known that radiation damage such as radiation-induced segregation, dislocation loops, precipitates, etc. may cause a degradation of the corrosion resistance of materials [6–16]. However, there were not enough studies about the corrosion behavior of the candidate structural materials after irradiation.

The aim of this work is to study the effects of different irradiation condition on the corrosion behavior on stainless steel. It was difficult to evaluate corrosion behavior on irradiated materials by conventional techniques such as electrochemical potential reactivation (EPR) method [14], therefore, the authors developed a new evaluation method using atomic force microscope (AFM) in previous studies [15–18]. The AFM method succeeded to obtain quantitative results relative to the corrosion behavior of ion irradiated materials. Therefore, it was applied to the study of the corrosion

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behavior of materials after ion irradiations, which simulate the irradiation conditions of structural materials in a spallation neutron source. The operating temperature is expected to be about 473 K or below [5]. Radiation damage would amount to 35 dpa per year [4]. Moreover, considerable quantities of transmutation products, particularly hydrogen and helium, will be generated due to the exposure to a high flux of 1 GeV protons and associated neutrons at rate of 500–1000 appm H/dpa and 50–200 appm He/dpa [5,19]. Therefore, the effects of radiation damage, irradiation temperature, H and He on the corrosion behavior was studied in this work.

2. Experimental

Chemical composition of the stainless steel used in this study is listed in Table 1. The stainless steel was high purity Fe–18Cr–12Ni alloy that was solution annealed at 1323 K for 30 min. Specimens 6 mm in length, 3 mm in width and 0.3 mm in thickness was fabricated. The surface of the specimens was mechanically polished with emery papers and diamond paste of 0.3 μm diameter, then electrochemically polished in a solution with H_3PO_4 54%, H_2SO_4 36%, CH_3OH 10% at about 280 K with a potential of 18 V for 5 s.

Ion irradiation experiments of these specimens were conducted at Takasaki Ion Accelerators for Advanced Radiation Application (TIARA) of Japan Atomic Energy Research Institute (JAERI). Twelve mega-electron volt 12 MeV Ni^{3+} ions were injected in order to produce radiation damage, and H^+ or He^{2+} ions were synergistically implanted in the specimens. The defect production rate by Ni^{3+} ion irradiation was about 9.2×10^{-4} dpa/s. Irradiation conditions are listed in Table 2. Radiation damage and ion concentration in this list were estimated at the position of the gas atoms concentration. Irradiation for the specimens was conducted at the side of sheet. Depth profiles of radiation damage and contents of implanted atoms were calculated by TRIM85 code, and typical implant concentration and depth profiles are shown in Fig. 1. The depth profile was almost the same for every irradiation conditions. H^+ and He^{2+} ions were implanted at depth of about 1.5 μm which does not correspond to the peak-damage region. Near the peak-damage region, implanted Ni^{3+} ion may affect radiation damage [7]. Therefore, the peak-damage region was avoided for H^+ and He^{2+} ion implantation.

Table 2
Irradiation conditions

Radiation damage (dpa)	Irradiation temperature (K)	Ratio of H/dpa (appm/dpa)	Ratio of He/dpa (appm/dpa)
5	473	0	0
5	573	0	0
5	673	0	0
5	773	0	0
35	473	0	0
35	573	0	0
35	673	0	0
70	573	0	0
35	473	50	0
35	573	50	0
35	573	500	0
35	473	0	50
35	573	0	50
35	673	0	50
35	573	0	500
35	673	0	500

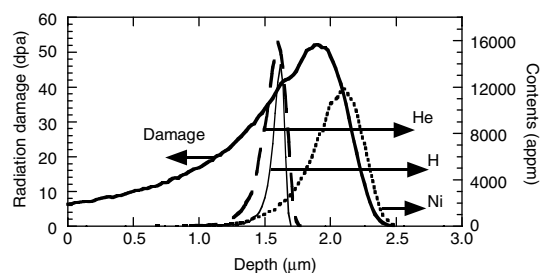


Fig. 1. Typical distributions of radiation damage and ion contents as function of the depth in specimens (35 dpa, 673 K, 500 H/dpa, 500 He/dpa). Major radiation damage was given by Ni^{3+} irradiation, and the damage given by gas atoms can be neglected.

To protect the irradiated surface during corrosion test, a copper film was plated on the irradiated specimens. The aqueous solution for Cu plating contains CuSO_4 90 g, H_2SO_4 15 ml and pure water 475 ml. Plating was performed with a current density of about 0.03 A/cm², at ambient temperature with anode metal of pure Cu. After plating, side of specimens was mechanically polished as smooth as possible with alumina powder of 0.3 μm in diameter. Fig. 2 shows a sketch of the specimen after polishing. Corrosion test

Table 1
Chemical composition (wt%)

Cr	Ni	C	Si	Mn	P	S	Ti	N	Fe
18.17	12.27	0.003	0.01	1.36	0.001	0.0014	0.01	0.0014	Bal.

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