Micro-Hardness Measurement of Proton Irradiated Type 316 Stainless Steel

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1. Introduction

Irradiation assisted stress corrosion cracking (IASCC) has been recognized to be a potentially critical phenomenon for core internals in pressurized water reactors over decades. Though the IASCC mechanism is not fully understood because of its complexity, it is widely accepted that IASCC can be affected by the water environment and the irradiation-induced material properties [1]. The compositional change at grain boundary, especially the depletion of Cr, radiation-induced segregation, and/or localized deformation due to irradiation [2,3] can considerably contribute to IASCC. In the present study, microscopic examination of the type 316 stainless steel (SS) was firstly done, and then the micro-hardness test was preformed to find out the changes of its mechanical properties due to a proton irradiation.

2. Methods and Results

2.1 Proton Irradiation and micro-hardness test

In the experiment, type 316 SS plates were used in the solution-annealed condition, and their chemical composition is shown in Table 1. The specimens with dimensions of 2 mm x 15 mm x 1.5 mm were ground/polished to a final finish of 0.3 ㎛ alumina powder, and then electropolished in a 10 % perchloric acid + 90 % methanol for about 10 seconds at 50 V at –50 ℃ to get clean surfaces prior to the proton irradiation. 2 MeV protons were irradiated on the front surface of the specimen at 1, 3, 5 displacements per atom (DPA), respectively. The specimen temperature was maintained at 360 ℃ during the irradiation.

Table 1 Chemical composition of the type 316 SS

Fe	Cr	Ni	C	Si	Mn	Mo	P	S
bal.	16.93	10.44	0.57	0.53	1.03	2.07	0.0026	0.001

The proton irradiation depth is very small, normally several tens of ㎛ order, under the present irradiation conditions. Therefore, the irradiated specimens were electroplated with Ni to protect their edges before the micro-hardness test. The micro-hardness test was performed using a Nano Indentation System (Nano Indenter XP, MTS) with the maximum load of 15 g

2.2 Microstructure of the un-irradiated type 316 SS

The specimen used in this study was identified to be an austenitic phase having an fcc structure with a lattice constant of 0.3597 nm. The OM image of the un-irradiated type 316 SS is shown in Fig. 1. The microstructure was homogeneous without any abnormal grain growth and texture. Any intergranular and intragranular precipitations were hardly found. String-like ferrites were often found in the austenitic matrix.

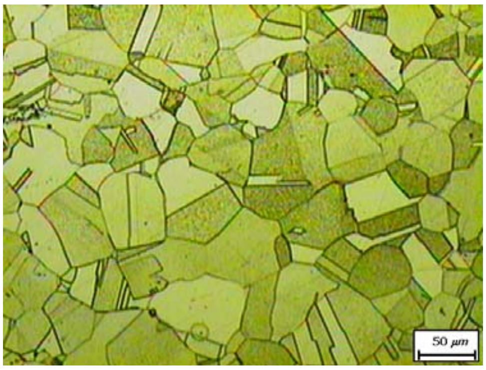

Fig. 1 OM image of the un-irradiated specimen.

The compositional changes of Fe, Cr, Ni, Mo and Mn, which are main metallic elements of type 316 SS, across a grain boundary in the un-irradiated specimen are shown in Fig. 2. As expected, noticeable compositional variations around the grain boundary were not found since the microstructure of the specimen was homogeneous because of the solution annealing treatment.

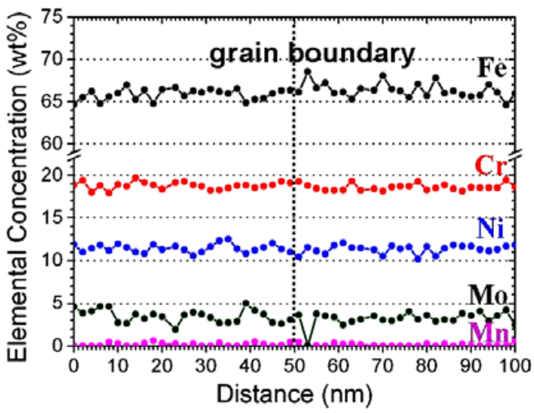

Fig. 2 Compositional changes across a grain boundary in the un-irradiated specimen.

A TEM image of the defects taken under a two-beam condition in the un-irradiated specimen is shown in Fig.

3. The number density of dislocation was relatively low, and they were mainly arranged on the {111} slip planes. Stacking fault images were frequently found due to its low stacking fault energy [4].

Fig. 3 TEM bright image of the un-irradiated specimen

2.3 Results on the micro-hardness test

Fig. 4 is a cross sectional view taken from the specimen irradiated by protons at 5 DPA. The upper part of the figure shows a Ni layer electroplated to protect the edge of the specimen. Since the proton irradiation depth was relatively small, approximately 50 ㎛, the micro-hardness measurement was made in the diagonal direction from the surface. The tracks of indentation are clearly seen just below the surface of the specimen.

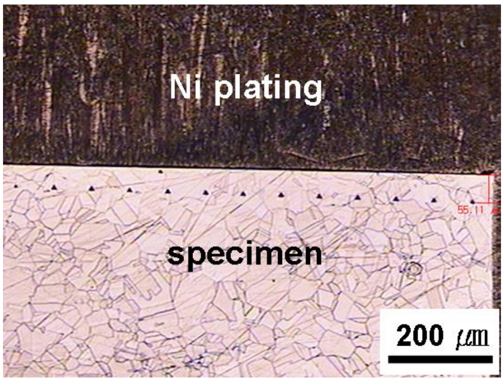

Fig. 4 OM image on the cross section of the specimen irradiated by protons at a 5 DPA.

The result of micro-hardness test on the proton irradiated specimen at 5 DPA is shown in Fig. 5. The value was highest at the surface and gradually decreased as went into the inside. At about 30 ㎛ from the surface, the micro-hardness value was suddenly changed and then maintained a constant value on the average. This fact means that the specimen was hardened by the proton irradiation to this depth. From the above result, it is believed that the proton irradiation depth was approximately 30 ㎛ under the proton irradiation conditions, and this result agreed well with others [5].

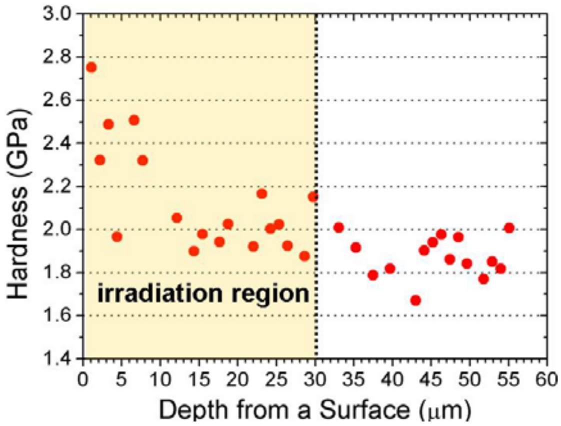

Fig. 5 Variation of the micro-hardness values depending on the depth from the surface of the specimen irradiated by protons at 5 DPA.

3. Conclusions

The microstructure of the un-irradiated type 316 SS was a homogeneous austenitic phase with some string-like delta ferrites, and no other intergranular/ intragranular precipitates were found. The number density of dislocation was relatively small, and stacking fault images were frequently observed due to its low stacking fault energy.

Due to the proton irradiation at 5 DPA, the micro-hardness values were increased, which means that the specimen was hardened by the proton irradiation. The irradiation depth was estimated to be about 30 ㎛ from the surface, and this result agreed well with others.

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