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Microstructural change of proton irradiated 316 stainless steels

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1. Introduction

Irradiation assisted stress corrosion cracking (IASCC) of the internals in a pressurized water reactor (PWR) has been considered critical for long-term operation. Some cracking of the internals (guide tube support pin, baffle former bolt) in European plants has already been identified since 1985. The cracking mechanism is not fully understood, however, it seems to be related with radiation assisted cracking under a high fluence, stress, and temperature environment. The effect of dissolved hydrogen (DH) concentration on the IASCC propagation has been studied [1-4]. It was noted that DH with 0 to 50 cc/kg accelerated the SCC in PWR environments. SCC was observed at up to 100 cc/kg of dissolved hydrogen [1]. The crack growth rate was not increased at high dissolved hydrogen level, but a significant decrease of the average crack growth rate was observed for the lowest dissolved hydrogen. Frutani [2] and Arioka [3, 4] also showed the same trend of DH effect of the SCC growth of stainless steel in a PWR environment.

On the contrary, the effect of DH concentration on IASCC initiation has not been studied much. Stephenson observed high crack initiation density in a primary water (PW) environment than normal water chemistry (NWC)[5]. This means that the low electrochemical potential in hydrogenated water chemistry (HWC) or PWR primary water suppresses the crack initiation. This behavior was also observed by other researchers [6, 7].

It may be controversial to say that, regarding the effect of DH on the crack growth and crack initiation, a low DH decreases the crack growth, but a high DH suppresses the crack initiation. An study on the effect of dissolved hydrogen concentration on the IASCC initiation behavior of 316 stainless steels in PWR water is necessary for operating PWRs.

As a prerequisite study about the effect of DH on the irradiated stainless steels, this paper aims to verify microstructural change of proton irradiated 316 stainless steels.

2. Experimental

To simulate the reactor internal materials in a PWR, type 316L stainless steel was used for this work. The compositions of the alloy and the proton doses are given in Table 1.

Figure 1 shows a microstructure of the test alloy non-irradiated condition. It shows a low dislocation density and little grain boundary precipitates.

Table 1 Chemical compositions of the test alloy (wt%) and proton dose levels

Material	Cr	Ni	P	Mo	Mn	Proton Doses(dpa)
316 SS	16.7	10.8	0.1	2.0	1.3	
	Si	S	C	Fe		1,3,5,10
	0.59	0.001	0.047	Bal.		

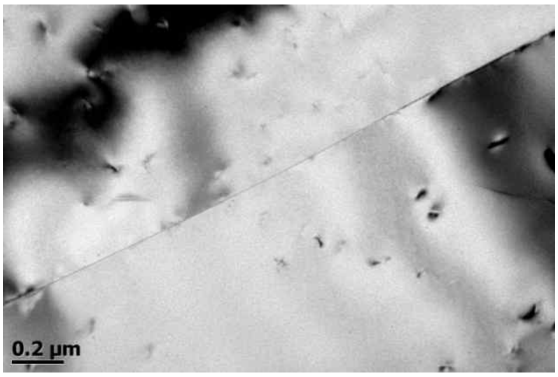

Figure 1 Microstructure of the test alloy non-irradiated sample

The specimens were fabricated with a gage length of 23 mm by electric discharge machining. A schematic of the sample is shown in Fig. 2. The surfaces of the specimens were mechanically wet-polished using #400 to #2400 SiC emery papers, and then electro-polished for 15 to 30 seconds in a 50% phosphoric acid, 25% sulfuric acid, and 25 % glycerol at room temperature.

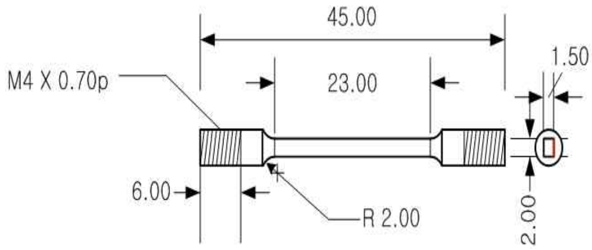

Figure 2 Schematic of IASCC initiation test specimen

Proton irradiation was performed using the General Ionex Tandetron accelerator at the Michigan Ion Beam Laboratory in the University of Michigan. Irradiations were conducted using 2.0 MeV protons at a current range of 40 μA. Four level irradiations (1,3,5,10 dpa) were conducted on the 316 stainless steel at 360 ^{o}C followed by 'cool' for 3 to 7 days at room temperature to permit the short-lived isotopes to decay. Details of the irradiation procedure can be found in Ref. [8]. The fluence and dose rate were calculated from the irradiation conditions using the SRIM code (see Figure 3). With peaks at around 2.5 μm deep for each sample, the dose profiles show a plateau of up to 20 μm deep.

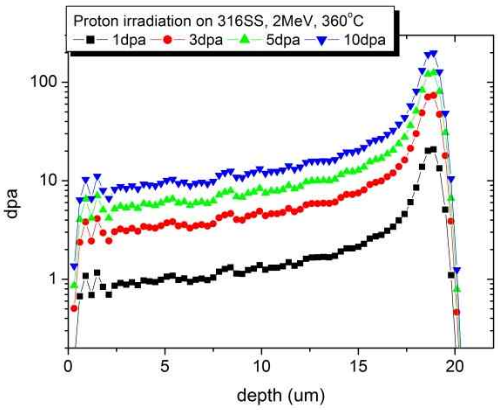

Figure 3 Calculation of proton irradiation profile on 316 SS

3. Results and discussion

Figure 4 shows a microstructure of 1 dpa proton irradiated sample. A micro void or pore, the size of which is less 10 nm in diameter, is shown in this sample. No voids or pores were observed in 3, 5 and 10 dpa samples, which should be clarified in a further analysis.

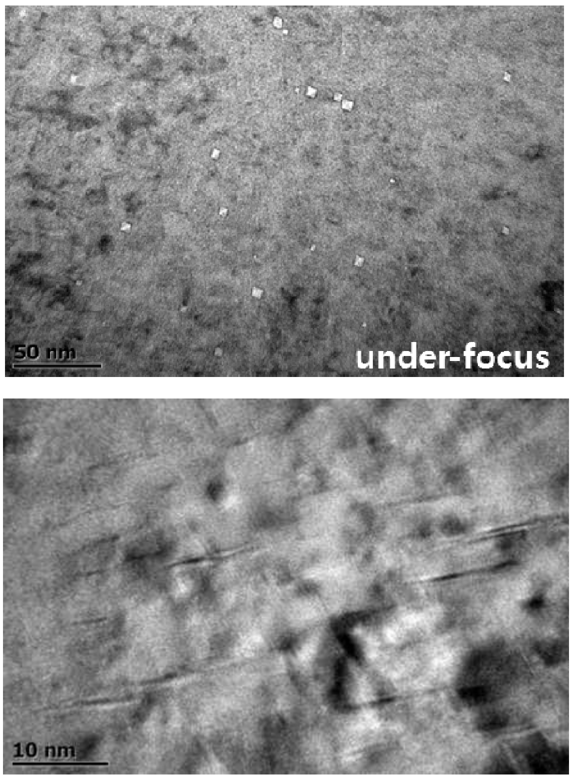

Figure 5 Plate-like precipitates on a 5 dpa proton irradiated sample

As shown in Figure 5, plate-like precipitates from a 5 dpa proton irradiated sample were observed. It seems that precipitates are faulted loops (1/3<111> lying on {110} planes, then it should be clarified in a further analysis also.

Preliminary results for evaluating the DH effect on the IASCC initiation under PWR conditions have been obtained. Some results on the tests will be described in the future.

4. Conclusions

(1) IASCC initiation behavior of 316 stainless steel in PWR water was studied.
(2) The fluence and dose rates were calculated from the irradiation conditions using the SRIM code. With peaks at around 2.5 μm deep for each sample, the dose profiles show a plateau up to 20 μm deep.
(3) Micro void or pores less than 10 nm in diameter were seen in the irradiated samples. Characteristic defects depending on dpa in each sample should be clarified in further analysis.

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