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Effect of proton irradiation on irradiation assisted stress corrosion cracking in PWR

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1. Introduction

Irradiation assisted stress corrosion cracking (IASCC) involves the cracking and failure of materials under irradiation environment in nuclear power plant water environment. The major factors and processes governing an IASCC are suggested by others [1].

The IASCC of the reactor core internals due to the material degradation and the water chemistry change has been reported in high stress stainless steel components, such as fuel elements (Boiling Water Reactors) in the 1960s [1], a control rod in the 1970s, and a baffle former bolt in recent years of light water reactors (Pressurized Water Reactors). Many irradiated stainless steels that are resistant to inergranular cracking in 288 °C argon are susceptible to IG cracking in the simulated BWR environment at the same temperature [2].

Under the circumstances, a lot works have been performed on IASCC in BWR. Recent efforts have been devoted to investigate an IASCC in a PWR, but the mechanism in a PWR is not fully understood yet as compared with that in a BWR owing to a lack of data from laboratories and fields. Therefore, it is strongly necessary to review and analyze recent researches of an IASCC in both BWR and PWR for establishing a proactive management technology for the IASCC of core internals in Korean PWRs [3].

The objective of this research to find IASCC behavior of proton irradiated 316 stainless steels in a high-temperature water chemistry environment.

2. Experimental procedures

Type 316 austenite stainless steels were used in this study. The chemical compositions of the alloy are given in Table 1. Tensile specimens of which size 23 mm in gage length were fabricated using electric discharge machining, shown in Fig. 1.

Prior to proton irradiation, the surface of specimens was mechanically polished using #2400 grit SiC sand paper, and then electro-polished in a electrolyte solution for 50 % phosphoric acid, 25 % sulfuric acid, and 25 % Glycerol at room temperature.

Specimens were irradiated to 1, 3, 5 DPA at 360 °C using 2.0 MeV protons.

Slow strain rate test on proton irradiated samples were conducted in multi-specimen SSRT test system, which is able to strain four samples in parallel.

The SSRT test was performed in simulated PWR primary water (Table 2). The strain rate was $3.5 \times 10^{-7}\ s^{-1}$. After the SSRT testing, SEM observation was performed on gage and fracture surfaces to characterize cracking.

Table 1. Chemical compositions of tested alloy (wt%)

Fe	Ni	Cr	Mo	Mn
bal.	10.8	16.7	2.0	1.3
Si	P	C	S	
0.59	0.05	0.047	0.001	

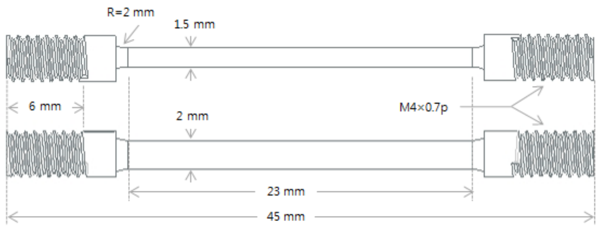

Fig. 1. Schematic of tensile specimen.

Table 2. Simulated PWR primary water

Strain rate	Temperature	pH	Conductivity
$3.5 \times 10^{-7}\ s^{-1}$	340 °C	6.35	21.12 μS/cm
Dissolved O_2	Dissolved H_2		
< 5 ppb	25 cc/kg		

3. Results and Discussions

Stress-strain curves for 1, 3, 5 DPA sample are shown Fig. 2. Evaluation of IASCC susceptibility was validated from percent IG cracking obtained from SEM analysis of fracture surface after SSRT experiments. SEM analysis of fracture surfaces is shown in Fig.3.

Each specimen showed mixed intergranular cracking and transgranular cracking, along with of ductile failure.

The term of %IG cracking is fraction area showing intergranular crack fracture of proton irradiated area. The test was conducted twice on 3 dpa samples, which showed 11% and 36% IASCC ratios, respectively. The SCC ratio, however, does not seem to be reproducible.

The other 1 dpa and 5 dpa samples showed a similar IASCC ratio of 37% with their different dose levels.

Fig. 4 shows cracking image on proton irradiated gage surface.

Another method of IASCC susceptibility evaluation was determined crack length of proton irradiated surface. Total length crack was summed crack length more than average grain size (100 µm).

Total crack length of 1 DPA specimen was 2345 µm. 3 DPA specimens have tested twice. Total crack length of them has obtained respectively 10,507 µm and 11,869 µm. Total crack length of 3 DPA was increased significantly compared with 1 DPA. Total crack length of 5DPA has obtained 13,112 µm.

Therefore, the higher proton dose seems to increase IASCC susceptibility.

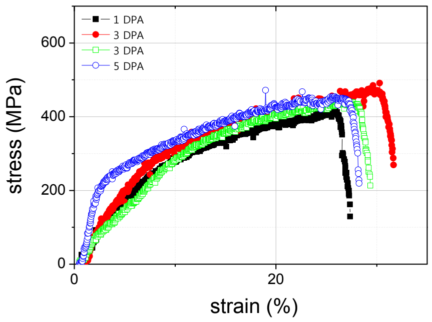

Fig. 2. Stress-strain curve for proton irradiated sample.

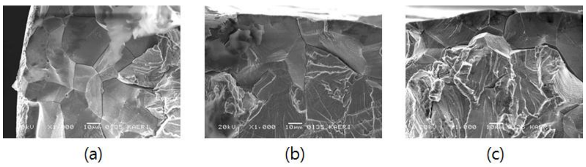

Fig. 3. SEM image on fracture surface for a) 1 DPA, b) 3 DAP and c) 5 DPA after SSRT test in PWR primary water.

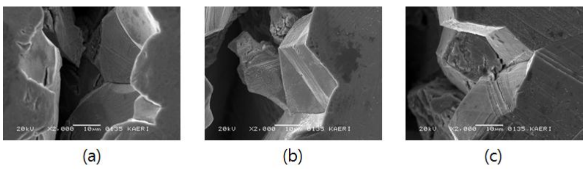

Fig. 4. SEM image on gage surface for a) 1 DPA, b) 3 DAP and c) 5 DPA after SSRT test in PWR primary water.

3. Conclusions

The IASCC initiation susceptibility on 1, 3, 5 DPA proton irradiated 316 austenite stainless steel was evaluated in PWR environment.

(1) SCC area ratio on the fracture surface was similar regardless of irradiation level.
(2) Total crack length on the irradiated surface increases in order of specimen 1, 3, 5 DPA.
(3) The total crack length at the side surface is a better measure in evaluating IASCC initiation susceptibility for proton-irradiated samples..

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