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Crack Density Analysis of 35% Cold Rolled Type 304 SS Specimen according to Slow Strain Rate Test using IASCC Test Facility (ITF) Mock-up

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1. Introduction

Irradiation Assisted Stress Corrosion Cracking (IASCC) is a phenomenon in which SCC is promoted when fast neutrons are irradiated in addition to the three major combinations of materials, environment, and stress, which are known to be conditions for general SCC to be generated. In Pressurized Water Reactor (PWR), IASCC is mainly reported in the Baffle Former Bolt (BFB) of Nuclear Power Plants (NPP) that have long operating experience. IASCC has also emerged as a major damage mechanism to be considered at the end of life of NPP and when extending its life [1]. In Korea, the soundness of the reactor's internal structure has been raised as a pending issue due to cracks occurring in the BFB of Kori Unit 1, which has been decided to be decommissioned by government. The regulatory agency is also demanding an investigation into the cause of the defect. The NPP decommissioning materials have a long-term operating history, so the technological ripple effect can be considered very significant in that it allows for preliminary evaluation of material deterioration that may occur within the design life of an operating NPP. Kori Unit 1 has experienced a high usage rate worldwide and has a very high utilization value. Therefore, it has become important to secure a foundation for demonstration test technology in high-temperature and high-pressure environments for low and intermediate level irradiation materials that can conduct utilization research using this material.

Based on the status of IASCC construction at home and abroad, the Korea Atomic Energy Research Institute (KAERI) is carrying out a project to build a nuclear power system soundness advancement system. In addition, the KAERI is also establishing a reliability verification system for NPP structural materials and components and building a demonstration test facility for neutron irradiation materials. Currently, the IASCC Test Facility (ITF) mock-up equipment is being built in the Materials Research Building and is being used for education and testing before the lead hot cell is built in the 2nd Research Building [2].

2. Experimental

In this study, we conducted a slow strain rate test (SSRT) on small, plate-shaped Type 304 SS specimens under high-temperature and high-pressure conditions using ITF equipment. We also then observed cracks in the specimens using an optical and scanning electron microscope (SEM). In this test, the Triangle Pattern was used as a representative of several patterns using the control panel of the SSRT program. After completing the corrosion crack test, cracks were observed using an optical and SEM to measure the defect length. Then, we determined how much density the specimen defects occupied by dividing the total crack defect length by a certain area [3].

A slow strain rate tester, including an autoclave, from Toshin Kogyo, Japan was manufactured. One of the features of this equipment is that it can display two loads: An internal load and an external load. Among these, the internal load was used, which has the characteristics of being able to measure more accurate values. The specimen used in the test was a small, plate-shaped tensile specimen manufactured separately considering the possibility of installation inside the installed autoclave. The test was also conducted under high-temperature and high-pressure conditions of 325 °C and 15 MPa, respectively, inside the autoclave.

2.1 Composition of Equipment

The ITF facility was used to evaluate the stress corrosion cracking characteristics of nickel alloy and stainless steel in an environment that simulated the PWR primary water system. The test equipment consisted of 1) a primary water circulation system that simulated the primary water system of the NPP and measured and controlled the water quality, 2) an autoclave, which was a high-temperature and high-pressure reactor, and 3) a slow strain rate tester that applied and controlled stress to the specimen.

2.2 Mechanical Properties of Type 304 SS

Table I summarizes the mechanical characteristics of the 35% CW Type 304 SS specimen.

Table I: Mechanical properties of type 304 SS

Specimen	CW (%)	Heat treatment condition	0.2% YS (MPa)	UTS (MPa)	El (%)	HRB
SS 304 H	35	Min. 1040℃, WQ	235.8	710.4	53.4	83.1

2.3 Flow of Primary Cooling Water

Fig. 1 is a flow chart of the primary water circulation loop representing the chemical solution flow path in the IASCC test facility. The chemical water in the solution storage tank is recycled to the solution storage tank through an autoclave.

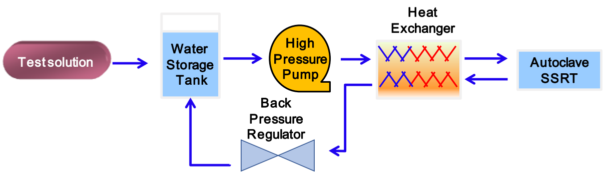

Fig.1. Flow chart of primary water loop system in ITF

3. Discussion and Results

The test period was approximately 5.25 days, and the test ended when 0.9mm tension, which was 10% of the gauge length, was completed. Fig. 2 is a graph showing the change in load and displacement of the SS 304 specimen after completion of the IASCC test. The blue line is the internal load, and the light green line is the displacement.

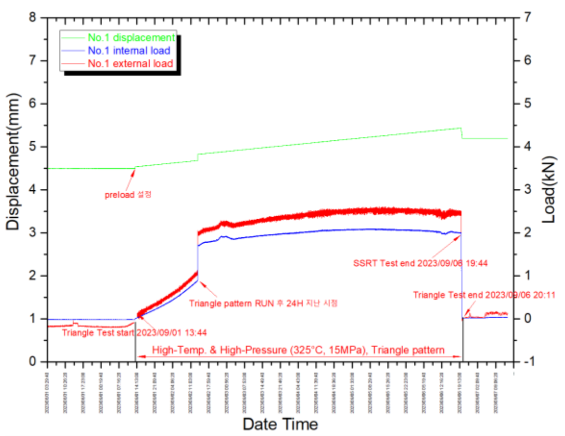

Fig. 2. Internal/external load & displacement of tensile specimen SS 304 (Triangle pattern, target value △disp. 0.9mm)

When the initial temperature and pressure reached the test conditions of 325 ℃ and 15 MPa, the initial displacement was 4.535 mm, the load was 0.014 kN, and the test was terminated at 5.438 mm after the final tension of 0.9 mm. At this time, the internal load value was 2.003 kN. After deformation up to 10% at an initiation strain of 1.85 x 10^{-7}/s in the primary coolant at 325°C, the test was stopped, and the test loop was cooled to atmospheric temperature. Table II shows the defect length measured using SEM photos and expresses the defect length as density per area. The crack area on the SEM photo was expressed as TCD (Total Crack Density) for the entire defect length, and the average TCDA (Total Crack Density Average) of the five photos of the L and C parts was about 3.82mm^{-1} and 7.43mm^{-1}, respectively. SEM photos that measured the crack defect length were taken at 200x magnification of the area with many cracks based on the center of the specimen.

Table II: Measuring TCDA (Total Crack Density Average) of defect crack length in 35% CW SS 304 specimen after the test

	L					C				Unit: µm
Positon & Magnification	L-X200 -01	L-X200 -02	L-X200 -03	L-X200 -04	L-X200 -05	C-X200 -01	C-X200 -02	C-X200 -03	C-X200 -04	C-X200 -05
Sum	927.93	1108.19	869.16	1282.12	529.23	1744.00	2605.94	2705.61	2358.21	240.77
Total	4716.6					9654.5				
Area	284800	307200	307200	307200	101120	288000	307200	307200	307200	39040
TCD(mm-1)	3.2582	3.6074	2.8293	4.1736	5.2337	6.0556	8.4829	8.8073	7.6765	6.1673
TCDA(mm-1)	**3.8204**					**7.4379**				

Figs. 3-4 are images taken at 1000x magnification using SEM at the LL and RR positions. It can be seen that white oxides appeared in the form of small grains between the cracks. After removal by selecting a chemical that can be removed later, we closely observed how much density the total crack length occupied relative to the area.

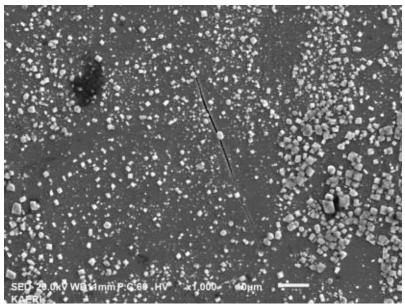

Fig. 3. Defect crack detail of SS304 specimen in SEM (LL, X1000)

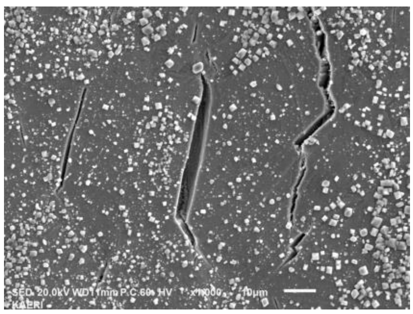

Fig. 4. Defect crack detail of SS304 specimen in SEM (RR, X1000)

4. Conclusions

In this study, a slow strain rate test was conducted on small plate-shaped Type 304 SS specimens using ITF equipment at 0.0001 mm/min under the conditions of temperature and pressure of approximately 325 ℃ and 15 MPa. Then, the microcracks generated in large quantities in this specimen were observed using SEM. Most of the defects observed here were judged to be IGSCC defects. Crack initiation occurred at grain boundaries between the austenite grains and at phase boundaries between the austenite and ferrite grains. The initiation path varied depending on the microstructure, and it was confirmed that small grains such as oxide were placed between cracks. We plan to measure the crack density in detail after removing the oxide in the future. In addition, we plan to secure Type 304 SS specimens of various materials such as welds and bends. With this specimen, we intend to obtain a lot of data on the IASCC initiation and growth characteristics of NPP internal structures through the slow strain rate test and use it to prevent damage to NPP components.

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