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Study of Stress Corrosion Cracking nucleation of Alloy 600 in primary water environment by EBSD and DIC

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1. Introduction

Nuclear power plant structural materials are exposed to high-temperature and high-pressure conditions, which are primary water environments and neutrons generated by the reaction of nuclear fuel during operation. Thus, the structural materials are fabricated using corrosion-resistant nickel alloys and stainless steel. However, several corrosion phenomena, such as stress corrosion cracking (SCC) still exist [1]. Several studies have been conducted on SCC generators to mitigate this damage and maintain structural health [2]. However, conventional ex-situ analysis methods are insufficient to study the exact mechanism of SCC under high-temperature and high-pressure environments.

the present study examined the early stage of SCC nucleation on the smooth surface of an Alloy 600 sample from a microstructural viewpoint. Tensile loading corresponding to an initial strain of 5% was applied to the specimen and this load was maintained while the metal was in a primary water solution. During the tensile test, the deformation of the surface was observed for digital image correlation (DIC) analysis. Electron backscatter diffraction (EBSD) analysis was performed to investigate the effect of metal microstructure on SCC nucleation.

2. Experimental

2.1 Material, specimen, and testing environment

Alloy 600 (Heat No. 49318, solution annealed 950°C/water) was used. Its chemical composition and mechanical properties are listed in Table 1.

Table I : The elemental composition (mass%) and mechanical properties of alloy 600 used in the present work.

C	Si	Mn	P	S	Cr	Ni	Cu	Fe
0.062	0.34	0.26	0.005	0.001	16.11	Bal.	0.02	8.83
0.2% offset stress, Mpa			Tensile strength, Mpa			Elongation, %		
259			643			48.6		

Fig. 1 shows the dimensions of the tensile specimen, and the reduced gage section was ground with abrasive paper up to #2000 and mirror-polished with diamond paste and colloidal silica for EBSD analysis.

The test solution was the simulated primary water used in typical PWR operating conditions at 300°C.

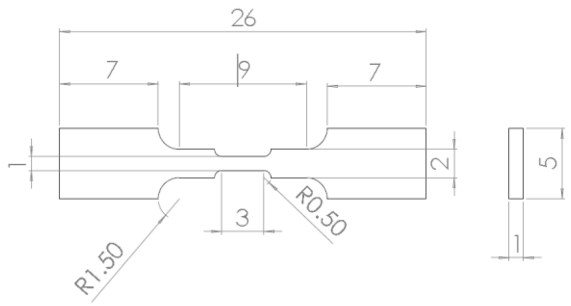

Fig. 1. Dimensions of a tensile specimen(mm).

2.2 EBSD analysis

Crystal orientation was measured with a field-emission SEM (Quattro S, FEI Ltd.) with an EBSD system (TSL Solutions), and analyzed with the OIM data collection and analysis software (TexSEM Labs).

2.3 SCC testing apparatus

The slow strain rate tensile test (SSRT) is a common means to investigate stress corrosion cracking (SCC).In addition, we have developed a device that can observe the SCC of the specimen in in-situ by installing a diamond window view cell. Fig. 2 is a specimen observed through a diamond window view cell.

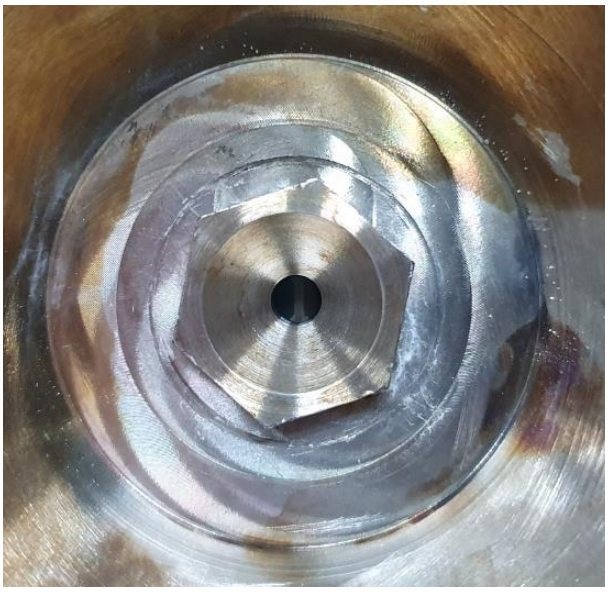

Fig. 2. Experimental specimens were observed through a diamond window view cell.

2.3 Experimental conditions

The DIC technique was used to characterize the initiation of intergranular corrosion cracks based on strains at the surface. Applying the DIC technique requires a random (speckle) pattern much smaller than the grain size to be formed on a specimen surface [3].

We solved this problem by separating the SCC testing procedure into two steps, strain measurement and crack observation. In the first step, a corrosion test was performed to create a speckle pattern on the surface of the specimen. Before and after the tension, images of the observation area were taken in the atmosphere with Laser Confocal Microscopes (LCM), and strain distributions were calculated via DIC. Then, the specimen was unloaded. In the second step, corrosion tests were conducted in a high-temperature and high-pressure primary water environment for 20 days, and the initiation of cracks on the surface was observed in-situ with LCM.

3. Results and discussion

3.1 location of cracks and strain analysis

Fig. 3 shows the location of the SCC displayed in the LCM image. Like the well-known phenomena IGSCC behavior of Alloy 600, it shows that cracks occurred along the SGs perpendicular to the tensile stress direction [4].

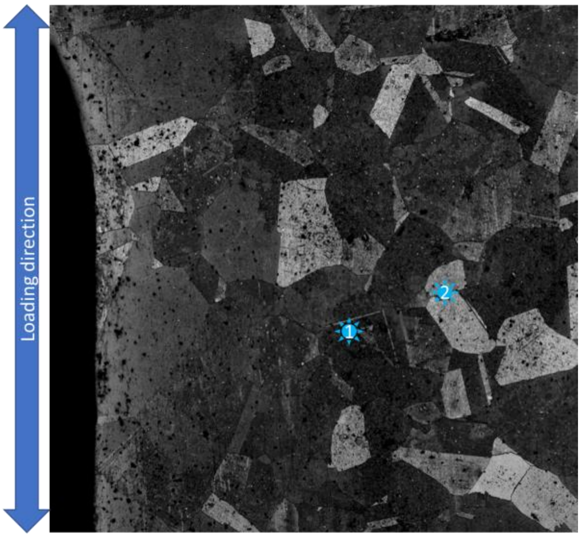

Fig. 3. The location of the SCC is shown in the LCM image.

Fig. 4 is an SEM image of cracks 1 and 2 after the experiment in Fig. 3. spinel oxide is developed on the surface, and slip bands are observed. The shape of the crack represents a typical IGSCC shape.

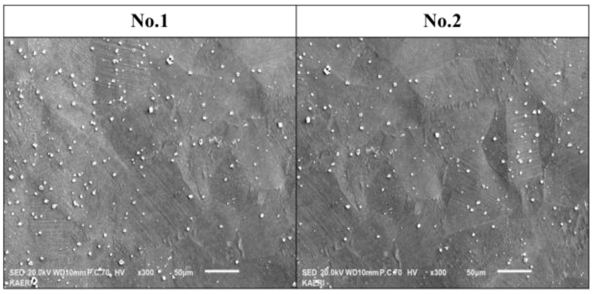

Fig. 4. The location of the SCC is shown in the LCM image.

Fig. 5 shows the strain distributions measured by DIC in the observation area. Although a uniform tensile strain was applied, microscopic strains were distributed heterogeneously due to anisotropic grain deformation. Crack No. 1 occurred near a place with severe deformation, while Crack No. 2 occurred at a place where deformation was not severe.

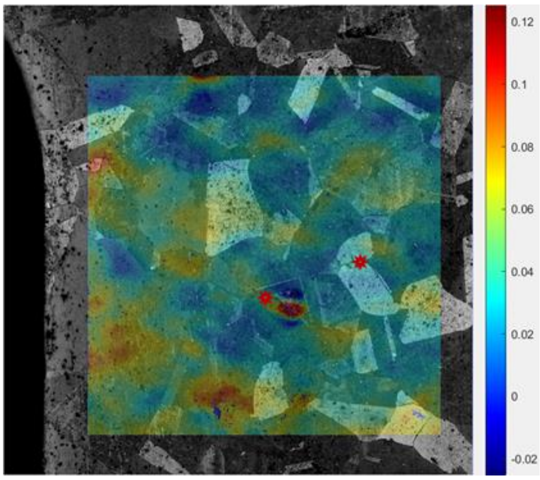

Fig. 5. Strain distributions in the observation area.

Fig. 6 is the EBSD grain boundary maps of the cracks. In both cracks 1 and 2, cracks occurred in the high-angle grain boundaries (HAGB).

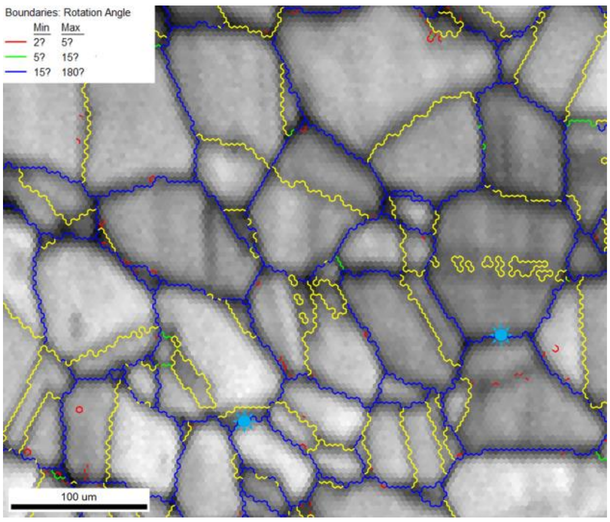

Fig. 6. EBSD grain boundary maps.

4. Conclusions

After applying a load to Alloy 600, cracks were observed in the test results for 20 days in the primary water environment. The type of crack is IGSCC. Crack No. 1 occurred near a place with severe deformation, while Crack No. 2 occurred at a place where deformation was not severe. Cracks were observed in HAGB as a result of the EBSD study.

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