Grain Boundary Properties of PWSCC Cracks in Alloy 600

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1. Introduction

Primary water stress corrosion cracking (PWSCC) in reactor pressure vessel head penetration nozzles, their welded parts, and steam generator tubes at pressurized water reactors have been found in many countries [1]. Several models have been reported for the PWSCC phenomena [2,3], however, the exact failure mechanisms have not been fully understood up to now. In the present study, PWSCC cracking properties of Alloy 600 used as the CRDM nozzle material were investigated through microscopic equipments. Especially, the microstructural and chemical changes around a crack tip during PWSCC were studied using TEM specimens fabricated by a focused ion beam (FIB) method.

2. Methods and Results

2.1 PWSCC experiment

In the test, a 1/2 CT (compact tension) specimen was used. Before the PWSCC test, the CT specimen was fatigue pre-cracked in a length of about 2 mm in the air. The PWSCC test was conducted under the simulated primary water environmental conditions, that is, 1200 ppm B + 2 ppm Li containing pure water at 340 ℃, dissolved oxygen contents below 5 ppb, hydrogen partial pressure of 14.3 psi, and an internal pressure of 2300 psi. The maximum stress intensity factor at a crack tip was maintained at 30 MPa√ m. Major experimental parameters such as the temperature, load, displacement, pH, electric conductivity, ECP and D.O. were being monitored and collected by PC through an A/D converter. The upper head of an autoclave, a part of the PWSCC loop system, is shown in Fig. 1.

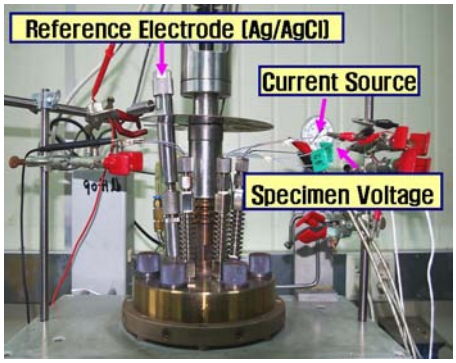
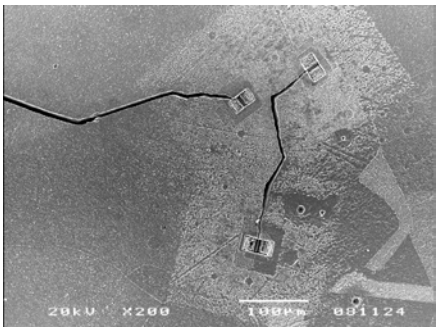


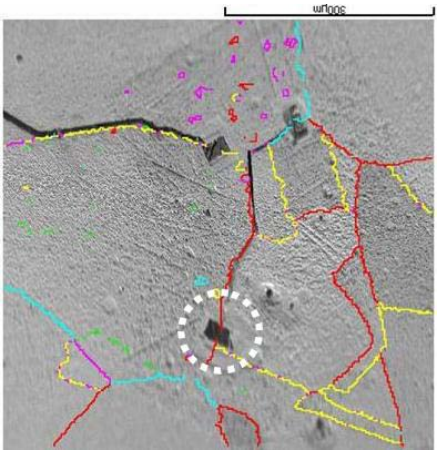
Fig. 1 Photo showing the upper head of an autoclave.

2.2 SEM/EBSD results

Fig. 2(a) shows an SEM image of the PWSCC cracks, and Fig. 2(b) is the SEM/EBSD result on the grain boundaries of Fig. 2(a). In Fig. 2(b), the grain boundaries are denoted by lines with different colors, depending on the degree of misorientation between the adjoining grains. From the SEM/EBSD analysis, it was found that the cracks propagated along the random high angle grain boundaries, which have a higher energy than the low angle and/or CSL special grain boundaries do. Also, it was confirmed that the cracking mode was completely intergranular under the present experimental conditions. The predominant failure mode of Alloy 600 has been well known to be intergranular in the primary and secondary water environments [4].



(a)

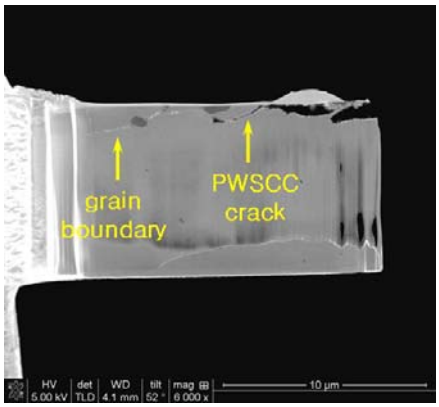


(b)

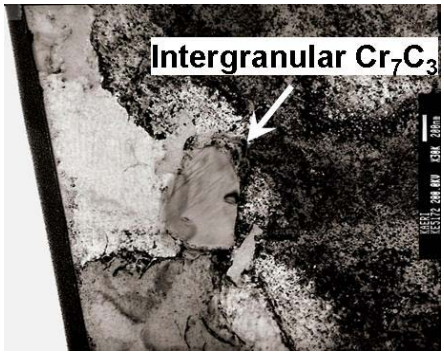
Fig. 2 (a) SEM image and (b) SEM/EBSD result around the crack tips of the CT specimen.

2.3 TEM results

An SEM image of the TEM specimen taken from the circled region in Fig. 2(b) is shown in Fig. 3(a). In the figure, the propagating crack is clearly seen. The grain boundary is also seen away from the crack tip. The precipitates on the grain boundary, as shown in Fig. 3(b), were identified as Cr_7C_3 from the TEM analysis. From the TEM/EDS measurement, oxygen was detected around the grain boundary. Since the bare metal had no oxygen content in the beginning, it is reasonable to assume that the oxygen diffused into the grain boundary/matrix from the environment during the test. This experimental result strongly supports that the internal oxidation model [2] is valid to some extent as the PWSCC failure mechanism.



(a)



(b)

Fig. 3 (a) SEM image of the TEM specimen and (b) bright field image of an precipitate on the grain boundary.

3. Conclusions

The cracking mode of Alloy 600 in a simulated primary water environment was completely intergranular, and the cracks were propagated along the random high angle grain boundaries. Intergranular Cr_7C_3 carbides were observed on the grain boundaries. In the base metal away from the crack tip, oxygen was detected. The existence of oxygen in the bare metal supports the fact that the internal oxidation model is valid to some extent as a PWSCC mechanism.

REFERENCES

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[4] G.S. Was, Corrosion, 1990, 46, 319.