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PWSCC crack growth rate and cracking properties of 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]. Their failure mechanisms have not been fully understood up to now, however, a precise and non-destructive measurements of a crack length and its resultant crack growth rate during PWSCC are recognized as key parameters to properly assess the reliability/integrity of nuclear core components. In the present study, an in-situ measurement technique using the DCPD (direct current potential drop) method is described, and some results on the crack growth rate test of Alloy 600 using the DCPD method are given.

2. Methods and Results

2.1 DCPD measurement method

1/2 CT (compact tension) specimens fabricated from Alloy 600 plates were used in the present experiment, and the schematic configuration of the DCPD system is shown in Fig. 1. Direct current of 5 A is applied to the CT specimen, and the current is periodically reversed via programmed current source. At the same time, the voltage drops are measured from the CT specimen and a reference coupon through digital voltmeters (DVMs), and then the crack length is calculated by the Hicks and Pichard (H&P) equation on the basis of the measured voltages [2,3]. The reference coupon prepared with the same material as the CT specimen is equipped to calibrate a material's resistivity change occurring after a long term operation at a high temperature.

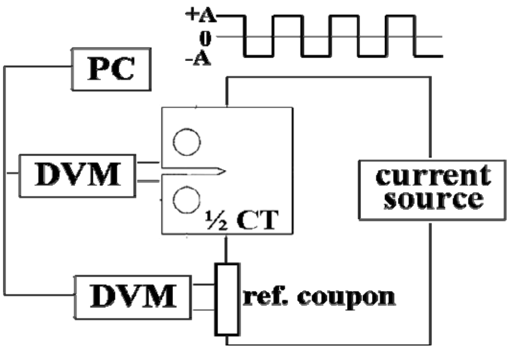

Fig. 1. Schematic configuration of the DCPD system.

2.2 Sep up for PWSCC test

The PWSCC test was conducted under the simulated primary water 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. The upper head of an autoclave, a part of the PWSCC loop system, is shown in Fig. 2. In the figure, current and voltage lead wires were prepared with Pt, and Ag/AgCl was used as a reference electrode to measure the electrochemical potential (ECP) of the specimen. All the lead wires inside the autoclave were electrically insulated with alumina tubes. Major test parameters such as the temperature, load, displacement, pH, conductivity, ECP and D.O. were being monitored and collected by PC through an A/D converter.

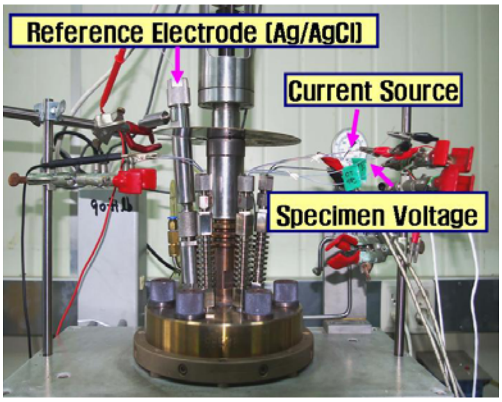

Fig. 2. Photo showing the upper head of an autoclave.

2.3 Microstructure

The average grain size was measured to be 50.9 ㎛. An SEM micrograph of the test specimen is shown in Fig. 1. Rod-shaped particles were precipitated inside the grains, and coarse precipitates are discretely distributed on the grain boundaries. TEM analysis of the diffraction patterns identified that the rod-shaped precipitates inside a grain of Alloy 600 were Cr_7C_3 of a pseudo-hexagonal structure with a = 1.398 nm and c = 0.452 nm. The grain boundary precipitates were also identified to be Cr_7C_3. Stacking faults on the planes perpendicular to the basal plane of a hexagonal structure were clearly seen, and some streaks due to staking faults were also visible in the diffraction patterns, which are a characteristic of Cr_7C_3 precipitated in Ni-base and Fe-base alloys [4].

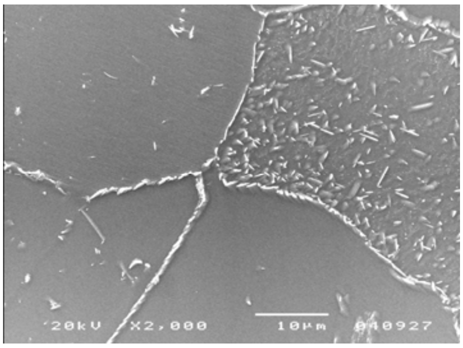

Fig. 3. SEM micrograph showing a precipitation morphology in the Alloy 600 test specimen.

2.4 PWSCC test results

The crack growth behavior of the CT specimen depending on time is shown in Fig. 3. The initial crack length before the test was calculated to be 12.507 mm. During the test, a triangular-wave load was applied on the specimen with a period of 2000 sec. and a load ratio of R = 0.7, as shown in Fig. 5. From Fig. 4, the average crack growth rate was measured to be 4.436 x 10^{-8} mm/s.

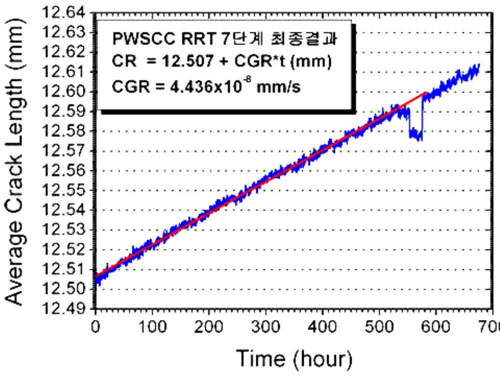

Fig. 4 Variation of the crack length depending on time during the PWSCC test.

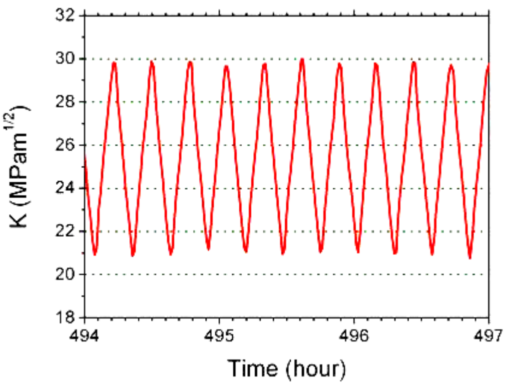

Fig. 5 Triangular-wave load applied on the specimen during the PWSCC test.

The fracture morphology of a specimen after the PWSCC test is shown in Fig. 6. In the figure, the area enclosed with a yellow line shows a cracked region during the PWSCC test. In the figure, faceted surfaces of the grains are clearly seen, which means that the cracks propagated along the grain boundaries. From this result, it can be concluded that the cracking mode of Alloy 600 under the present experiment conditions was intergranular.

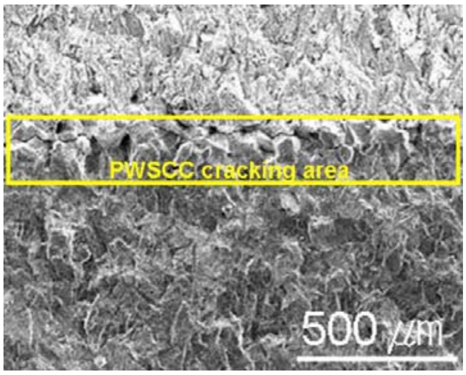

Fig. 6 SEM micrograph showing the fracture morphology of the CT specimen after PWSCC test..

3. Conclusions

An in-situ measurement technique for a PWSCC crack length and crack growth rate determination was developed. The average crack growth rate of Alloy 600 was measured to be 4.436 x 10^{-8} mm/s. under a triangular-wave load and the simulated primary water conditions. The cracks propagated along the grain boundaries, which means that the cracking mode was intergranular.

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