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Measurement of PWSCC CGR vs. K in the CRDM 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 measurement of a crack length during PWSCC is recognized as a key parameter to properly assess the reliability/integrity of nuclear core components in primary water environments. In this presentation, the crack growth rates (CGRs) depending on the stress intensity factor (K) of Alloy 600 used as a CRDM nozzle material were precisely determined by the DCPD (direct current potential drop) method.

2. Methods and Results

2.1 DCPD voltage measurement

In the experiment, a 1/2 CT (compact tension) specimen was used, 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 the material's resistivity change occurred after the long term operation at high temperature.

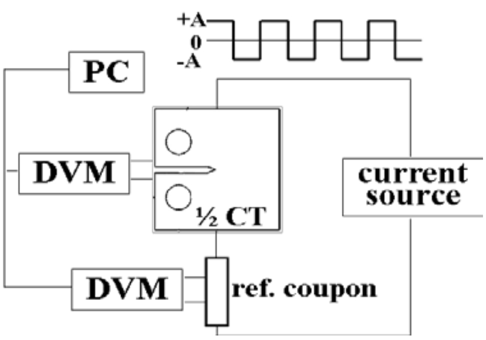

Fig. 1. Schematic configuration of the DCPD system.

2.2 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 stress intensity factor at a crack tip was controlled by the applied load. During the test, the applied load was gradually increased to change the stress intensity factor. On the upper head of an autoclave, a part of the PWSCC loop system, 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 oxidized zirconium tubes. Major test parameters such as temperature, load, displacement, pH, conductivity, ECP and D.O. were being monitored and collected by PC through an A/D converter. The schematic diagram of the test loop is shown in Fig. 2.

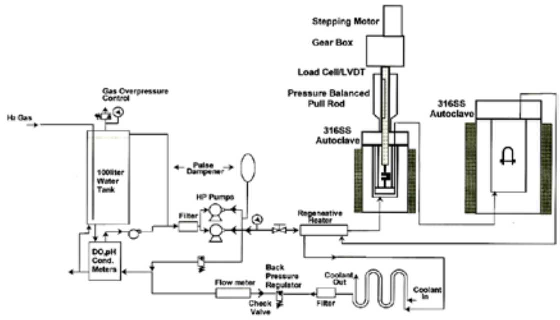

Fig. 2. Schematic diagram of the PWSCC test loop.

2.3 Microstructure of the test specimen

An SEM micrograph of the test specimen is shown in Fig. 3. Needle-shaped particles were precipitated inside the grains, and coarse precipitates are densely distributed on the grain boundaries. TEM analysis of the diffraction patterns identified that the needle-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 can be 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].

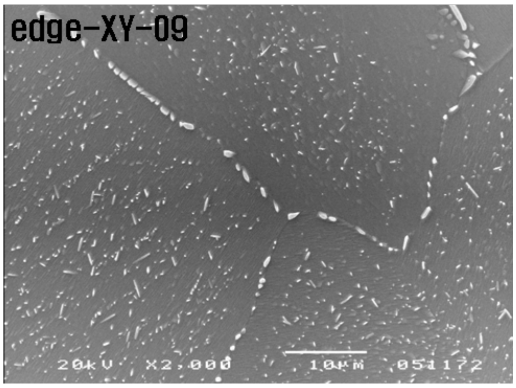

Fig. 3. SEM micrograph showing a precipitation morphology in the test specimen.

2.4 Results of CGR test

The variations of crack length of CRDM Alloy 600 depending on time under the specific applied load are shown in Fig. 4. The test was conducted for about 7 months. The CGR and K calculated from the crack length variation and the applied load were also included in the figure. As expected, the CGR increased as the K increased.

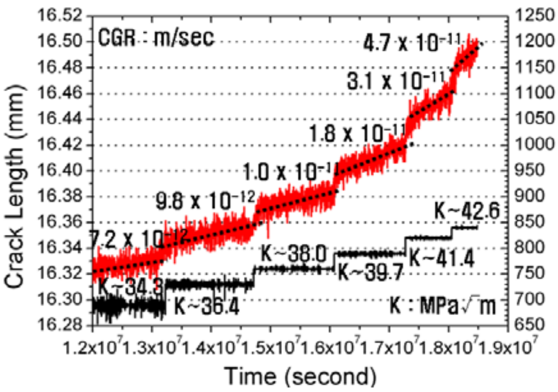

Fig.4 The variation of crack length of CRDM Alloy 600 depending on time under the specific applied load.

The results obtained in the present study were displayed on the previous report [5] in Fig. 5 to compare with others. In the figure, the present data were indicated by red dots. As shown in the figure, the results were reasonably well matched with others within the error range. On the other hand, the CGRs obtained in the present study were somewhat smaller than other's results, which means that the PWSCC resistance of Alloy 600 used in the present study is higher than those of the comparative materials. It is believed that the main reason for this is to originate from the microsstructural differences, especially from the differences in the grain boundary properties of the materials.

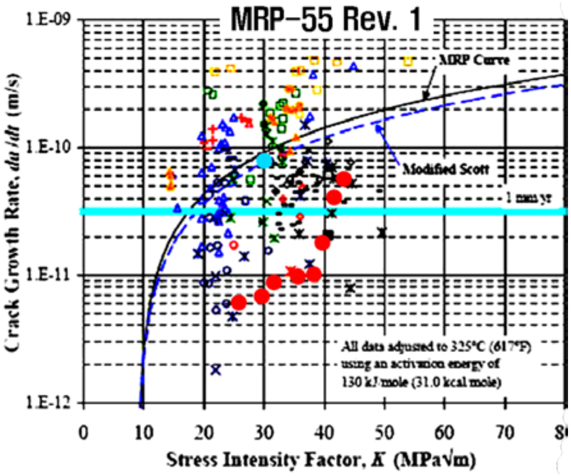

Fig. 5 The CGR values obtained in the present study and the other's previous ones.

3. Conclusions

An in-situ measurement technique for a PWSCC crack length determination was developed, and it was found that the crack growth rates depending on the stress intensity factor obtained from the DCPD voltage measurement in the present study agreed well with the previously reported ones. PWSCC test with CT specimens at high values of stress intensity factor is now in progress with acquisition of the major experimental parameters.

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