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Measurement of PWSCC Growth Rates vs. K in the Alloy 600/182 Weld

Yun Soo Lim*, Hong Pyo Kim, Sung Sik Hwang
Nuclear Materials Development Division, Korea Atomic Energy Research Institute
1045 Daeduk-daero, Yuseong, Daejeon,305-353, Korea
**Corresponding author: yslim@kaeri.re.kr*

1. Introduction

Primary water stress corrosion cracking (PWSCC) of the Alloy 600/182 welded parts in reactor pressure vessel head penetration nozzles at pressurized water reactors has been found in many countries [1]. It is recognized that a precise and non-destructive measurement of the crack length variation during PWSCC is necessary to properly assess the reliability/integrity of nuclear core components. In the present study, the crack growth rates (CGRs) depending on the stress intensity factor (K) of Alloy 600 base metal and the Alloy 182 weld metal around a CRDM penetration nozzle were precisely determined using a direct current potential drop method. The cracking behaviors of the Alloy 600/182 weld were also examined using various microscopic equipments.

2. Methods and Results

2.1 PWSCC test

In the present experiment, 1/2 CT (compact tension) specimens were used. A direct current of 5 A was applied to the CT specimen, and the current was periodically reversed via a programmed current source. At the same time, the voltage drops were measured from the CT specimen and a reference coupon through digital voltmeters, and the crack length was then calculated using 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 was equipped to calibrate the material's resistivity changes occurring after long term operation at high temperature.

The PWSCC test was conducted under simulated primary water conditions, that is, 1200 ppm B + 2 ppm Li containing pure water at 325 ℃, 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 the crack tip was controlled by the externally applied load. During the test, the applied load was gradually increased to change the stress intensity factor at the crack tip. On the upper head of the autoclave, which was 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 monitored and collected using a PC through an A/D converter. A schematic diagram of the test loop is shown in Fig. 1.

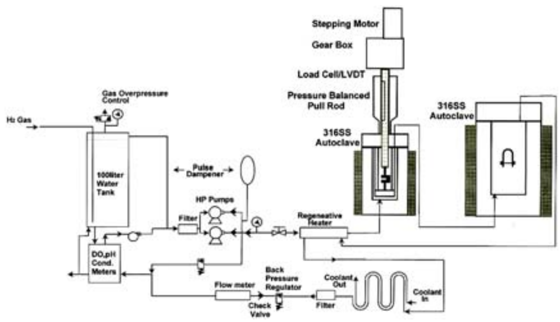

Fig. 1 Schematic diagram of the PWSCC test loop.

2.2 Microstructure of the test specimen

The grains in the Alloy 600 base metal were distributed equi-axially without any preferred orientation, and the average grain size was measured as ~ 200 ㎛. Needle-shaped particles were precipitated inside the grains, and coarse precipitates were densely distributed on the grain boundaries. A TEM analysis of the diffraction patterns identified that all the precipitates found were Cr_7C_3 of a pseudo-hexagonal structure with a = 1.398 nm and c = 0.452 nm. The Alloy 182 weld metal, on the other hand, showed a rapidly solidified microstructure, as shown in Fig. 2. All the (cellular-) dendrites inside a grain had a same shape, which means that they grew in the same crystallographic direction.

Fig. 2 Optical micrograph taken in the Alloy 182 weld metal.

2.3 Results of CGR test

The results obtained in the present study are summarized in Fig. 3. In the figure, the data from the Alloy 600 base metal were indicated by red dots and those from the Alloy 182 weld metal were blue dots. As shown in the figure, the CGR values of Alloy 182 weld metal were about 10 times higher than those of the Alloy 600 base metal, which means that the PWSCC susceptibility of the Alloy 182 weld metal is much larger than that of the Alloy 600 base metal. It is believed that the main reason for the difference originates from microstructural differences, especially from the differences in the grain boundary properties of the two materials.

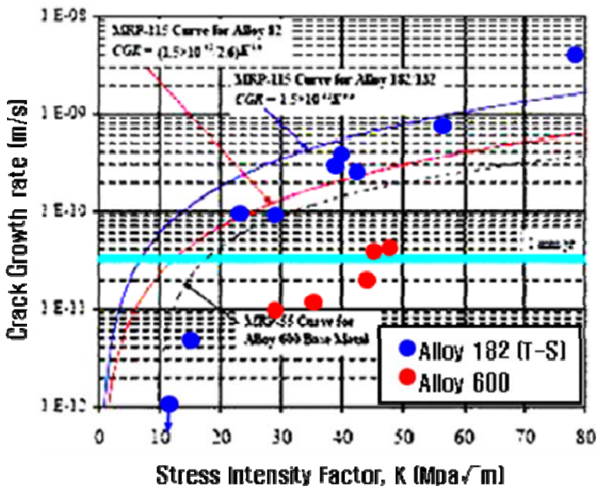

Fig. 3 The CGR values of the Alloy 600 base metal and the Alloy 182 weld metal, depending on the stress intensity factor.

2.4 Cracking properties in the Alloy 600/182 weld

Fig. 4 shows the fracture morphologies of the Alloy 600 base metal and the Alloy 182 weld metal. From the figure, it can be seen that the cracking mode of the Alloy 600 base metal was completely intergranular. The predominant failure mode of Alloy 600 is well known to be intergranular in the primary and secondary water environments [4]. In the case of the Alloy 182 weld metal, however, the cracking morphology showed a dendritic shape, which means that the crack propagated along the dendritic interfaces.

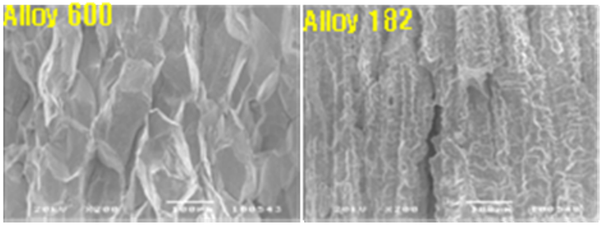

Fig. 4 Fracture surfaces of the Alloy 600 base metal and the Alloy 182 weld metal.

From an SEM/EBSD analysis, it was found that in both metals the cracks propagated along the random high angle grain boundaries, which had misorientation angles over 15 degrees between the adjacent grains without any coincidence site lattice (CSL) specialty. It is well known that the random high angle grain boundaries have a higher energy than the low angle and/or CSL special grain boundaries do.

3. Conclusions

The crack growth rates of the Alloy 182 weld metal were about 10 times higher than those of the Alloy 600 base metal because of the microstructural differences under the same experimental conditions. The cracking mode of Alloy 600 in a simulated primary water environment was completely intergranular, however, Alloy 182 showed an inter-dendritic cracking property. The cracks in both alloys were propagated along the random high angle grain boundaries, which have high grain boundary energies.

REFERENCES

[1] W. Bamford, Service Experience of PWSCC Alloy 600 Small Bore, WH-ICONE12-49520, 2004

[2] E647-00, Standard Test Method for Measurement of Fatigue Crack Growth Rates, ASTM International, PO Box C700, West Conshohocken, PA 19428, 2000

[3] M. A. Hicks and A. C. Pickard, A Comparison of Theoretical and Experimental Methods of Calibrating the Electrical Potential Drop Technique for Crack Length Determination, Int. J. of Fracture, Vol. 20, p. 91, 1982

[4] EPRI, Materials Reliability Program (MRP), Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Thick Wall Alloy 600 Materials, MRP-55 Rev. 1, Final Report, 1006695, Nov. 2002