Stress Corrosion Cracking Properties of an Alloy 600/182 Weld in the Simulated Primary Side Water Environments

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1. Introduction

Recently, corrosion damages in the reactor pressure vessel head penetration nozzles and the welded parts around them at pressurized water reactors have been found throughout the world [1]. In the present work, the microstructure and a second phase precipitation in the Alloy 600/182 welds, used as the penetration nozzles, were investigated by a scanning electron microscope (SEM), and a transmission electron microscope (TEM) equipped with an energy-dispersive X-ray (EDX) spectrometer. The crack growth rate and the primary water stress corrosion cracking (PWSCC) properties of the Alloy 600 base metal and Alloy 182 fusion zone were studied by observing the fracture surfaces of the compact tension (CT) specimens after the test. Finally, the PWSCC behaviors of the alloys were explained in terms of their microstructures.

2. Methods

Alloy 600 was from an air melt, and cold worked at 30% by a cross rolling. The test specimens were taken from the welds, which were made by filling a machined groove in an Alloy 600 plate with a filler metal of Alloy 182. In all the cases the welds were made by qualified nuclear grade welders

TEM specimens were prepared by grinding slabs to approximately a 60 ㎛ thickness, and finally electropolishing the 3 mm discs. A 7 % perchloric acid + 93 % methanol solution cooled to -40 ℃ was used and a current of approximately 50 mA was applied for a jet polishing. TEM examination was carried out with a JEOL 2000 FXII (operating voltage 200 kV). Specimens for the optical and SEM examinations were made by a chemical etching with a solution of 2 % bromine + 98 % methanol. JEOL 5200 (operating voltage 25 kV) was used for the SEM observation.

The PWSCC test was conducted under a simulated primary water condition, in a 1200 ppm B + 2 ppm Li solution at 325 ℃. The CT specimens were machined from the weldment with several orientations. There is no standard terminology for the orientation of weld specimens, so the ASTM standard for plates [2] has been adapted. In the present experiment, the direction of the Alloy 182 weld has been used in a similar fashion to the rolling direction of the Alloy 600 plate, and this is shown in Fig. 1. Before the PWSCC test, a pre-crack was fabricated by a fatigue so that the stress intensity factor K would be 30 MPa√m at the pre-crack tip when the applied tensile load was 450 Kg. The test duration was 1,500 hours.

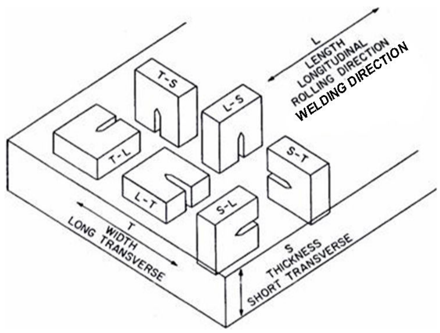

Fig. 1 Terminology used for orientations of cracking planes in the test specimens with respect to the rolling and welding.

3. Results and Discussion

3.1 Microstructure

The solidification morphology of the Alloy 182 fusion zone, on the other hand, had well developed dendrites. Within each grain, all the cellular dendrites had the same shape, demonstrating that they grew in a specific crystallographic direction in a grain, that is, <100> in cubic metals [3]. The microstructure of the Alloy 600 base metal was heavily deformed due to the cold working, and the majority of dislocations seemed to be arranged in complex cell walls separated by regions of a low dislocation density. In the Alloy 182 fusion zone, many dislocations were generated during the welding process mainly due to the thermal tensile stress originating from the volume contraction of the re-solidified region

3.2 Precipitation Behaviors

In the Alloy 600 base metal, needle-like precipitates were found inside some grains, and coarse ones were distributed along the grain boundaries. From an analysis of the diffraction patterns, all the precipitates found in the base metal were identified as Cr_7C_3, having a pseudo-hexagonal structure with a = 1.398 nm and c = 0.452 nm [4].

In the Alloy 182 fusion zone, on the other hand, three types of precipitates were found, that is, tiny precipitates on the grain boundaries, faceted and round ones in the dendritic interfaces. Tiny precipitates were densely distributed along the grain boundaries. They had a cube-

cube orientation relationship such as $\{100\}_{matrix}//\{100\}_{ppt}$, $<100>_{matrix}//<100>_{pot}$ with one grain, and their crystal structure was revealed to be face-centered-cubic (fcc) with a lattice parameter of 1.065 nm. From these results, it can be confirmed that they were Cr-rich $M_{23}C_6$ [5]. It is expected that the carbides were precipitated during the cooling process after a solidification of the matrix. It was revealed from the TEM analysis that the crystal structure of faceted precipates was fcc with a lattice parameter of ~ 0.448 nm. It consisted mainly of Nb and Ti as metallic elements without any O and N peaks. From these observations, it can be concluded that the faceted particles are (Nb,Ti)C. Finally, the small and round shaped precipitates were found to be Al-rich and Ti-rich oxides.

3.3 PWSCC

Fig. 2 shows a fracture surface of the Alloy 182 weld CT specimen with the T-S orientation of Fig. 1. From the figure, it can be seen that the cracks were propagated along the inter-dendritic interfaces, therefore, the cracking mode in the Alloy 182 weld was shown to be inter-dendritic.

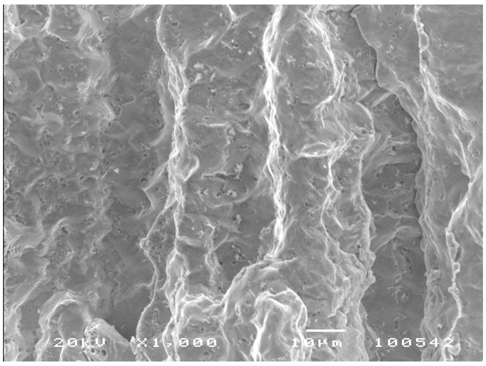

Fig. 2 SEM micrograph showing the fracture surface of the Alloy 182 weld CT specimen with T-S orientation.

On the other hand, the fracture morphologies of Alloy 600 showed that the cracks grew along the grain boundaries. Therefore, it is confirmed that the cracking mode was purely intergranular in this case. The predominant failure mode of Alloy 600 is well known to be intergranular in the primary and secondary water environment [6].

The crack growth rates of the Alloy 182 weld were found to be very high when the orientations of the cracking planes were T-S, T-L-L-S, and L-T in Fig. 1. When the cracking planes were S-T and S-L, however, PWSCC cracks were rarely found under the same test conditions. These results originate from the fact that the crack propagation direction was along the dendrites. The cracking planes of the S-T, and S-L specimens were perpendicular to the dendrites, therefore, the cracks could not be easily propagated in these circumstances. The cracking planes of the rest were more or less parallel to the dendrites. From the above results, therefore, it can be concluded that the crack growth rate has a maximum value if the cracking plane is parallel to the primary dendrites.

4. Conclusions

1) The microstructure of the Alloy 600 base metal was heavily deformed due to a cold work. The solidification morphology of the Alloy 182 fusion zone had well developed dendrites, and a high dislocation density was introduced into the fusion zone due to the thermal tensile stress originating from the volume contraction during a welding process.
2) The precipitates in the Alloy 600/182 weld were identified as:
   - intergranular/intragranular Cr_7C_3 in the base metal,
   - intergranular Cr-rich $M_{23}C_6$, (Nb,Ti)C and Al-rich and Ti-rich oxides in the fusion zone.
3) The PWSCC mode was an intergranular cracking in the Alloy 600 base metal and the heat affected zone. On the other hand, it was inter-dendritic in the Alloy 182 fusion zone, therefore, the crack growth rate has a maximum value when a cracking plane is parallel to the primary dendrites.

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