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Microstructure Characterization of Alloy 182 Weld Metal and Stress Corrosion Cracking in PWR Primary Water Environment

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1. Introduction

Primary water stress corrosion cracking (PWSCC) in reactor pressure vessel head penetration nozzles and their welded parts, composed of an Alloy 600 base metal and an Alloy 182 weld metal, have been found throughout the world [1,2]. Alloy 182 has a similar chemical composition to that of Alloy 600, and has been used widely as the filler or buffer for dissimilar metal welds joining Alloy 600, stainless steel and low alloy steel. Laboratory tests indicate that the SCC susceptibility of Alloy 182 might be greater than that of mill annealed Alloy 600 [3]. In the present study, the microstructure of a Alloy 182 weld was characterized using microscopic equipments, and PWSCC test was conducted in simulated PWR environments using small U-bend specimens. The cracking properties of the Alloy 182 weld were explained in terms of the microstructural aspects.

2. Methods and Results

2.1 Experimental conditions

Alloy 600 plates were prepared from an air melt, and were then cold worked for a 30% reduction through cross rolling. The plates were joined using shielded manual arc welding (SMAW). The machined groove of the plates was filled with an Alloy 182 (ENiCrFe-3) filler. A buttered layer of Alloy 82 (ERNiCr-3) was formed by gas tungsten arc welding before the SMAW with Alloy 182. During the welding process, a shielding gas of 99.99% Ar was blown on the welding material to protect it from oxidation. Test specimens were fabricated from the welds in an as-welded condition. The chemical compositions of the materials used in this study are given in Table I.

Table 1. Chemical compositions of the materials (wt%)

	Ni	Cr	Fe	C	S	P	Si	Mn	Mg	Al	Ti	Nb
Alloy 600	75.59	15.69	7.49	0.05	0.001	0.03	0.30	0.27	0.04	0.12	0.26	0.02
Alloy 182	66.09	14.60	7.48	0.07	0.005	0.54	0.68	7.82	N.D.	N.D.	0.52	2.02

The specimens for the optical microscope and SEM were prepared by chemical etching in a solution of 2 % bromine + 98 % methanol. Thin foil specimens for the TEM were prepared by grinding slabs to an approximately 60 ㎛ thickness, and then electro-jet polishing them into 3 mm diameter discs in a 7 % perchloric acid + 93 % methanol solution at -40 ℃ with a current of approximately 80 mA.

In the PWSCC test, small U-bend specimens were used and conducted under the simulated primary water environmental conditions, that is, 1200 ppm B + 2 ppm Li containing pure water at 325 ℃, dissolved oxygen content below 5 ppb, a hydrogen partial pressure of 14.3 psi, and an internal pressure of 2300 psi.

2.2 Microstructure of Alloy 182 weld

The Alloy 182 weld metal consisted of typical dendritic grains, as shown in Fig. 1. The observed plane in Fig. 1 is perpendicular to the welding direction and parallel with the direction of dendritic growth. The dendrites are generally oriented in the direction of the solidification of the weld. Each grain is formed by a colony of dendrites. All the cellular dendrites had a similar shape, demonstrating that they grew in a specific crystallographic orientation in the grain, i.e., <100> in cubic metals [4].

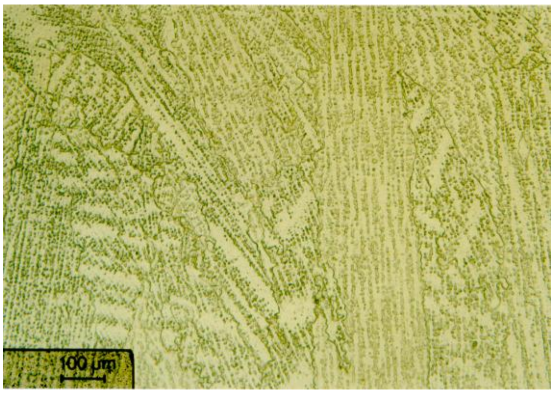

Fig. 1 Optical micrograph of the Alloy 182 weld metal

In the Alloy 182 weld metal, many types of precipitates were found, as shown in Fig. 2. They were mainly distributed on the dendritic interfaces. These precipitates were classified into three groups, depending on their locations and shapes; (1) tiny intergranular, (2) coarse faceted intragranular, and (3) small round intergranular precipitates. From the TEM analyses, the tiny intergranular precipitates were identified as Cr-rich $M_{23}C_6$, coarse faceted particles as (Nb,Ti) carbides, and small round precipitates as Al_2O_3 and TiO_2 type oxides. In many cases, the (Nb,Ti) carbides were nucleated and grew independently on the oxide surface at several locations, and then finally coalesced as a rim around the oxides.

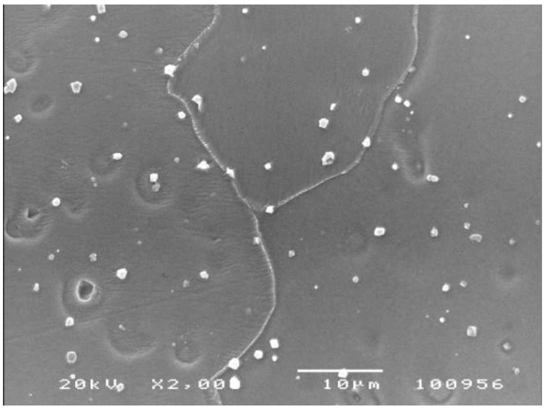

Fig. 3 SEM micrograph showing the precipitation distribution in Alloy 182 weld metal

2.3 PWSCC results

Crack initiation was judged from an optical microscopic observation with a x20 magnification. A noticeable crack was first found on the specimen tested for 208.3 days. This specimen consisted of all of the metallurgical parts generated during the welding process, that is, the Alloy 600 base metal, the Alloy 600 heat affected zone, and the Alloy 182 weld metal. However, the crack was located only in the Alloy 182 weld metal adjacent to the weld line. All the cracks in the Alloy 182 weld metal were initiated on the grain boundaries. Fig. 4 shows the crack initiation at the grain boundary on the surface of the Alloy 182 weld metal.

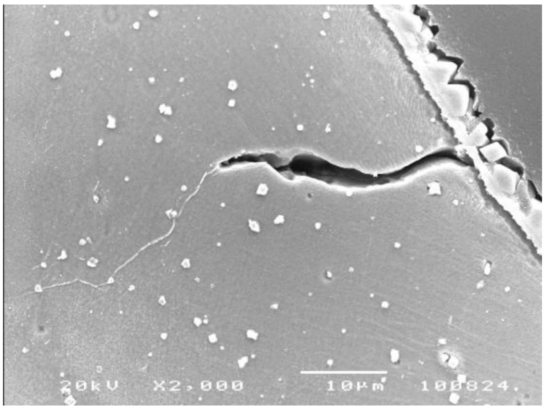

Fig. 3 SEM micrograph showing crack initiation in Alloy 182 weld metal

The crack initiated on a grain boundary also propagated along the boundary, as shown in Fig. 4. The types of grain boundaries can be distinguished according to the misorientation angle between adjacent grains, that is, a low angle grain boundary, a special boundary, and a random high angle (or, general) grain boundary [5]. From an electron-beam scattered diffraction analysis, it was found that the cracks in the Alloy 182 weld metal propagated along the random high angle grain boundaries.

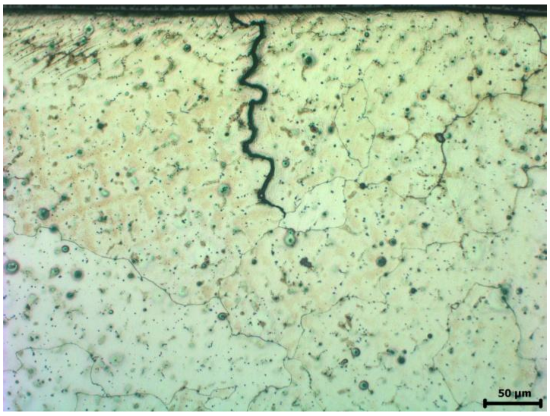

Fig. 4 Optical micrograph showing a crack propagation in Alloy 182 weld metal

3. Conclusions

The Alloy 182 weld metal showed a well developed dendritic solidification zone. Tiny intergranular Cr-rich $M_{23}C_6$ and Nb carbides were developed on the grain boundaries. The precipitates formed inside the grains were coarse faceted (Nb,Ti)C and small round-shaped precipitates of Al_2O_3 and TiO_2 type oxides. Frequently, the (Nb,Ti) carbides were precipitated on the oxide surface at several locations.

The cracks were found only in the Alloy 182 weld metal, which means that the PWSCC susceptibility of Alloy 182 is greater than that of Alloy 600. The cracks were initiated at the grain boundaries on the surface, and also propagated along the random high angle grain boundaries.

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