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Fatigue and Oxidation Property of P92 Steel according to the Microstructure

Si-Yeon Bae
KEPCO Research Institute, 103-16 Munji-Dong, Yuseong-Gu, Daejeon, 305-380, Korea

1. Introduction

The fatigue strength and fatigue life of weldment at high temperature are important for high temperature component materials used in power plants. Mechanical components and structures are frequently fractured by fatigue at high temperature.[1~2] It is well known that the fatigue crack growth rate is accelerated by oxidation and the high temperature fatigue life is also influenced by oxidation. Particularly, the welded joints suffer from Type IV cracking, which initiates fracture at the fine-grain heat affected zone (FGHAZ) under the fatigue or creep load conditions at high temperature. Generally, HAZ in welded joints is weak part with low toughness, and serves as frequent crack initiating sites.[3~5] Hence, the welded joints require careful examination. In this study, the fatigue crack growth rate in low ΔK range were measured and the effect of oxidation on fatigue crack growth behavior were investigated for P92 steels that are W-strengthened high-Cr ferritic steels used as main stream pipe materials in power plants.

2. Experimental Procedures

2.1 Test material

The material used in this study was obtained from main steam pipe in the ultra super-critical power plant. Table 1 lists the chemical composition of the P92 alloy steel.

Table 1. Chemical composition of P92 (wt.%)

C	Si	Mn	P	S	Al	Cr
0.10	0.22	0.48	0.017	0.0006	0.01	9.11
Ni	Mo	V	Nb	N	W	B
0.18	0.47	0.18	0.056	0.0405	1.71	0.0029

2.2 Fatigue crack growth test and oxidation test

Fatigue crack growth tests were conducted in accordance with ASTM E 647. The crack length was measured by a traveling microscope and the DCPD (Direct Current Potential Drop) method. The samples for oxidation tests were cut to a size of 3x5x7mm with the electrodischarge machine from the weld metal, the base metal and HAZ of the P92 alloy. They were ground to a 2000-grit emery paper, cleaned in acetone, and oxidized at 550, 600, 650 and 700^{o}C up to 500 hr in air in an electrical furnace.

3. Results and Discussion

3.1 Test results of microstructure observation and oxidation

Fig. 1 shows the microstructures of the base metal, weld metal, and HAZ of P92 alloy. The base metal displays the acicular ferritic structure, where the intersecting laths are observed (Fig. 1(a)). The weld metal displays similar acicular structure, which resulted from the rapid cooling after welding process (Fig. 1(b)). Laths are observed to intersect randomly. The HAZ near the base metal consisted of FGHAZ (Fig. 1(c)), where Widmanstätten structure like laths were observed. The HAZ near the weld metal consisted of CGHAZ (Fig. 1(d)), where Widmanstätten structure like laths were also observed.

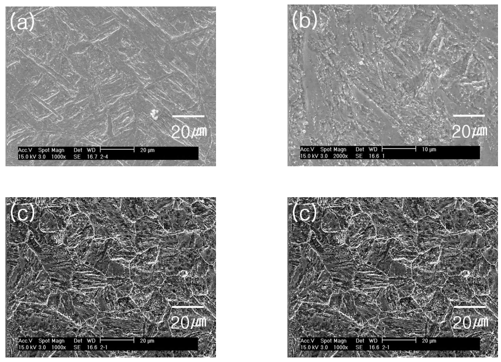

Fig. 1. The etched SEM microstructures of P92 steel. (a) base metal (b) weld metal (c) fine-grain HAZ (d) coarse-grain HAZ.

Fig. 2 shows the weight gain versus oxidation time curves obtained from the samples oxidized at 700^{o}C in air. As expected, more weight gains were recorded with an increase of oxidation time. The oxidation resistance increased in the order of HAZ, base metal and weld metal. In the HAZ, grain boundaries were clearly recognizable (Figs. 1(a) and (b)). The presence of such short-circuit diffusion paths results in the fast oxidation especially in FGHAZ.

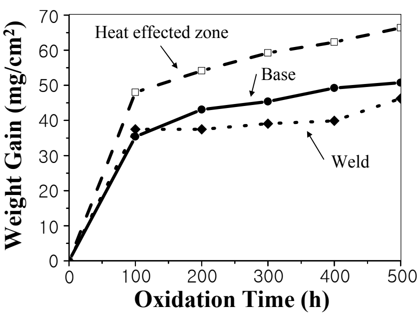

Fig. 2. Weight gain versus oxidation time curves of base metal, weld metal, and HAZ during oxidation at 700^{o}C in air.

Probably, excess dislocations and fine $M_{23}C_6$ precipitates in the HAZ[1~2] may promote oxidation by acting as heterogeneous nucleation sites for oxides. The exhibition of lower weight gains in the weld compared with the base metal may be due mainly to the rapidly solidified microstructure of the weld.

Fig. 3 shows the cross-sectional SEM images and the corresponding EDS line profiles of the oxidized P92 samples. After oxidation at 700°C for 500hrs, The oxide layer thickness were found to be 140μm for HAZ, 120 μm for base metal and 75 μm for weld metal. All scales were found to be porous and prone to cracking (Figs. 3(a)-(c)). The EDS analyses indicated that the scales consisted of the outer Fe_2O_3 layer and the inner (Fe_2O_3, Cr_2O_3)-mixed layer, as typically shown in Fig. 3(d). Iron oxidized preferentially at the outer layer, and Cr was mainly segregated at the inner oxide layer due to its comparative thermodynamic inertness.

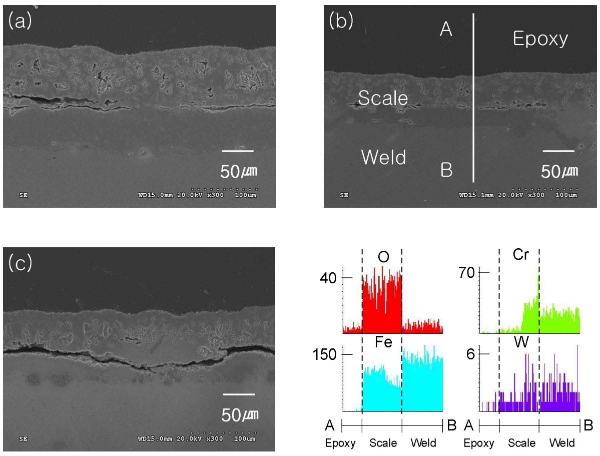

Fig. 3. Cross-sectional SEM images and EDS line profile of P92 steel after oxidation for 500hr at 700°C. (a) base metal image, (b) weld metal image, (c) HAZ image, (d) EDS of (b)

3.2 Test results of fatigue test and oxide layer

The results are represented by fatigue crack growth rate (da/dN) vs. stress intensity factor range (ΔK) curves in Fig. 4. The fatigue crack growth rates in the low ΔK range of all materials increased as the temperature increased. The fatigue crack growth rate of weld metal was the lowest among three different microstructures. The carbide precipitates in the fine lath of weld metal is thought to decrease the fatigue crack growth rate. The fatigue crack growth rates of HAZ was the highest at all test temperatures, because HAZ is reported to contain the softened Type IV zone with low fracture toughness resulting from the reduced fractional amount of tempered martensite even though grain is fine.[6] From the respect of oxidation, the crack velocity increased with the oxide layer thickness, supporting the fact that the oxidation embrittlement effect in oxide layer accelerates the crack propagation.

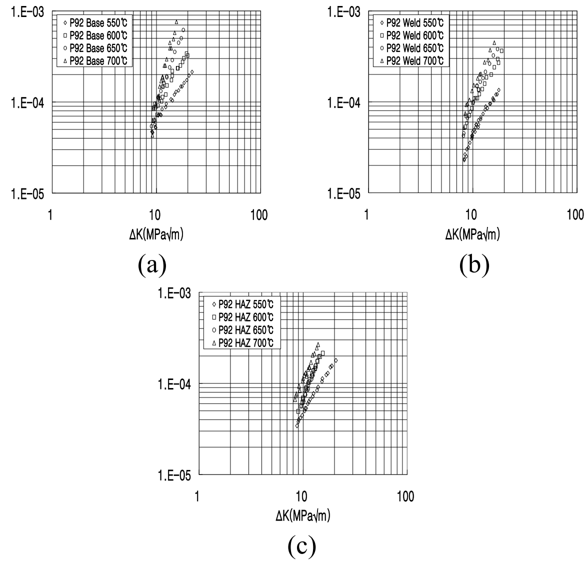

Fig. 4. da/dN vs. ΔK curves in low ΔK range (a) base metal (b) weld metal (c) HAZ.

4. Conclusions

From the experimental results following conclusions were obtained.

The oxides formed on the base metal, weld metal, and HAZ of the P92 alloy were mostly Fe_2O_3. The oxidation resistance was lowest at HAZ and increased in the order of base metal and weld metal. The fatigue crack growth rates in the low ΔK range for all three specimens increased as the test temperature increased. For all test temperatures, the fatigue crack propagation velocity for HAZ was the greatest while it was the lowest for the weld metal.

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