Journal of Nuclear Materials 458 (2015) 253–263

Contents lists available at ScienceDirect

Journal of Nuclear Materials

journal homepage: www.elsevier.com/locate/jnucmat

Dependence of crack growth kinetics on dendrite orientation and water chemistry for Alloy 182 weld metal in high-temperature water

Zhanpeng Lu [a,b,*], Junjie Chen [a], Tetsuo Shoji [b], Fanjiang Meng [c]

[a] Institute of Materials Science, School of Materials Science and Engineering, Shanghai University, Shanghai 200072, China
[b] New Industry Creation Hatchery Center, Tohoku University, Sendai 980-8579, Japan
[c] Shanghai Nuclear Engineering Research & Design Institute, Shanghai 200233, China

HIGHLIGHTS

- SCC paths along dendrite directions in both T–S and T–L specimens of Alloy 182.
- Higher SCC growth rates in T–S orientation specimen than in T–L orientation specimen.
- CGR increased with increasing dissolved oxygen.
- Apparently negative *da*/*dt* curve by ACPD in hydrogen saturated water.

ARTICLE INFO

Article history:
Received 7 October 2014
Accepted 17 December 2014
Available online 27 December 2014

ABSTRACT

Stress corrosion cracking growth rates of Alloy 182 weld metals in T–S and T–L orientations in 288 °C pure water with various dissolved oxygen and hydrogen concentrations were measured. Extensive inter-dendritic stress corrosion cracking paths on the side surfaces and fracture surfaces were observed. The crack growth path in the T–S orientation specimen was perpendicular to the applied loading direction, and parallel to the loading direction in the T–L specimen. Crack growth rates of the T–S specimen were significantly higher than those of the T–L specimen under the same test conditions. The crack growth rate decreased significantly with decreasing dissolved oxygen concentration. Adding dissolved hydrogen in water caused an apparent decrease of the alternating current potential drop signal during crack growth monitoring.

1. Introduction

Ni-base alloy weld metals have been used in nuclear power plants. Stress corrosion cracking (SCC) of Ni-base weld metals such as Alloy 182 weld metal was observed in both boiling water reactors (BWRs) [1–8] and pressurized water reactors (PWRs) [9–13]. It has been found that water chemistry such as dissolved oxygen or dissolved hydrogen could have significant effects on SCC growth of Ni-base alloys such as Alloy 182 weld metal in high temperature water environments [4–7,9–13]. It was found that dendrite orientation of Ni-base weld metals had a strong effect on SCC growth in high temperature water. In the disposition equation proposed by MRP 115 [12–13] for SCC growth rates of nickel base alloys 182/132/82 in PWR primary water, a correction factor f_{orient} was used to account for the effect of crack growth direction vs. dendrite orientation. f_{orient} took 1 for crack growth along the dendrite direction and 0.5 for crack growth perpendicular to the dendrite direction. Modifying water chemistry is an effective way of mitigating SCC. In the present work, the effects of dendrite orientation and environmental parameters such as dissolved oxygen (DO) or dissolved hydrogen (DH) on SCC growth kinetics of Alloy 182 in high temperature pure water were investigated. The effects of loading mode and testing procedures were also studied. The cracking path and crack growth rates related to dendrite structure of Alloy 182 and notch direction were discussed.

2. Experimental procedures

Alloy 182 weld metal taken from an Alloy 182–Alloy 600 weld was used. The weld was post-weld heat treated at 615 °C for 15 h. The chemical compositions of Alloy 182 are shown in Table 1. Contoured double cantilever beam (CDCB) specimens, specimen T6122B (T–S orientation) and specimen T6121 (T–L orientation), were tested. The design of CDCB specimen were reported in previ-

---

* Corresponding author at: Institute of Materials Science, School of Materials Science and Engineering, Shanghai University, Shanghai 200072, China. Tel.: +86 21 56336107; fax: +86 21 56332475.

E-mail address: zplu@shu.edu.cn (Z. Lu).

http://dx.doi.org/10.1016/j.jnucmat.2014.12.083
0022-3115/

ous papers [14,15]. The thickness of the specimens was 16 mm. The locations and configurations of the SCC specimen T6122B (T–S orientation) and specimen T6121 (T–L orientation) are shown in Fig. 1. The direction of the applied loading during the SCC test was perpendicular to S direction in specimen T6122B, and perpendicular to L direction in specimen T6121. The specimen was first fatigue pre-cracked in air under a sine-wave loading at about 20 Hz and a maximum stress intensity factor (K_{max}) value of 15 MPa $m^{0.5}$, where the load-ratio (K_{min}/K_{max}) was $R = 0.2$. After pre-cracking in air, the specimens were side-grooved to 5% on each side. The specimens were ultrasonically cleaned in ethanol before the SCC test. After the water chemistry and temperature had reached their designed values, the specimens were at first pre-immersed for two days and then subjected to in-situ fatigue pre-cracking in high temperature water under a series of triangular (Tri.) wave loadings. The loading modes for in-situ pre-cracking were: f ~0.01 Hz, K_{max} of 30 MPa $m^{0.5}$, $R = 0.3$ (288 cycles), $R = 0.5$ (576 cycles), and $R = 0.7$ (864 cycles) respectively. After the in-situ pre-cracking, the specimens were subjected to a constant loading (CL) or trapezoidal (Trap.) wave loading at stress intensity factor of about 30 MPa $m^{0.5}$ in pure water at 288 °C. The crack-lengths were continuously monitored by using an alternating current potential drop (ACPD) machine equipped with a data-logging system. The crack length data by observations on the fracture surfaces were used to calibrate the ACDP data. The monitoring of crack growth by ACPD for various alloys such as stainless steels, stainless steel weld metals, Ni-base alloys in high temperature water environments has been proved to be effective [14–21]. The linearity between ACPD change and crack advance make it simple for the conversion of ACPD signal to crack length increment, especially for non-standard fracture mechanics specimens. The resolution of ACPD machine was found to be suitable for detecting the effects of various testing parameters.

The test matrix was summarized in Table 2. Grain boundary properties were evaluated by EBSD technique with Hitachi S-4300 FE-SEM, TSL solutions camera control system VIT 1000, image processing system DSP 2000, and interface controller MSC 2000. The EBSD patterns were analyzed using OIM-Analysis software provided by TSL, Co. Ltd.

More tests would provide better understanding of absolute values of crack growth rates of weld metals. In the present work, the main objective is to investigate the effects of water chemistry as well as weld dendrite orientation on crack growth rates. Two specimens taken from the same weld metal block were tested together

Table 1
Chemical composition (wt.%) of Alloy 182 weld metal.

C	Si	Mn	S	P	Fe	Cr	Ni	Mo	Nb	Ta
0.031	0.59	6.04	0.013	0.013	7.67	13.65	69	0.177	1.75	0.368

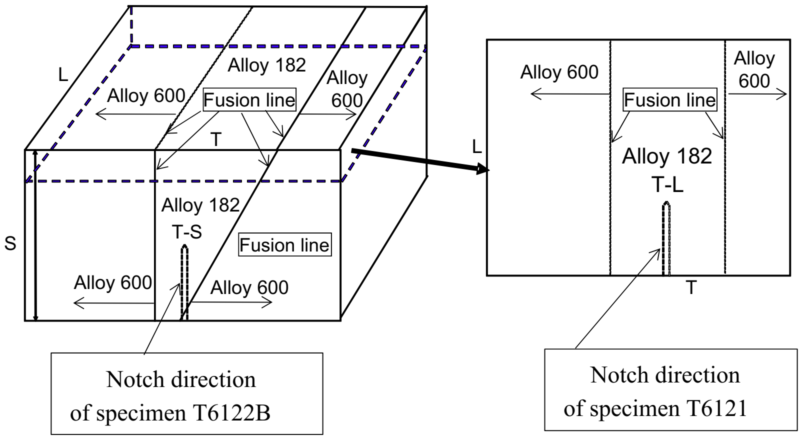

Fig. 1. Schematic of the weld block and the notch directions of specimen T6122B (T–S orientation) and specimen T6121 (T–L orientation) for SCC tests.

Table 2
Conditions and sequences for CGR tests of Alloy 182 specimens in 288 °C pure water with various DO and DH concentrations under various loading conditions. The value of K or K_{max} was about 30 MPa $m^{0.5}$.

Step no.		Dissolved oxygen (DO) (ppm)	Loading mode
Specimen T6122B (T–S)	Specimen T6121 (T–L)		
2BP1	21P1	2	Tri. loading, $R = 0.3$, ~0.01 Hz, 288 cycles
2BP2	21P2	2	Tri. loading, $R = 0.5$, ~0.01 Hz, 576cycles
2BP3	21P3	2	Tri. loading, $R = 0.7$, ~0.01 Hz, 864 cycles
2BS1	21S1	2	CL
2BS2	21S2	0.2	CL
2BS3	21S3	6.5	CL
2BS4	21S4	6.5	Trap. loading, $R = 0.7$/60 s, holding time = 3 h
2BS5	21S5	0.005 then 0.2	Trap. loading, $R = 0.7$/60 s, CL = 3 h
2BS6	21S6	<0.005	Trap. loading, $R = 0.7$/60 s, CL = 3 h
2BS7	21S7	<0.005, DH = 1.4 ppm	Trap. loading, $R = 0.7$/60 s, CL = 3 h
2BS8	21S8	6.5	Trap. loading, $R = 0.7$/60 s, CL = 3 h