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Low Cycle Fatigue Life of Alloy 52M Weld Metal in Simulated PWR Environment

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1. Introduction

ASME code contains rules for the design of 'class 1' components for nuclear power plants, recognizes fatigue as a possible mode of failure in pressure vessel steels and piping materials. However, the ASME code did not consider the effect of light water reactor (LWR) environment including pressurized water reactor (PWR) on the material fatigue.

According to the preceding research, LWR environment have a negative effect on the fatigue resistance of the structural material [1-5]. Therefore, for the long-term plant operation over 60 years, environmental corrosion fatigue effect on the structural material should be done. Furthermore, several fatigue experiments were conducted only for the base metal. So that, other materials, especially, weld metal such as Alloy 52M/152 should be studied to overcome the problems related to environmental corrosion fatigue.

In this work various strain amplitude was applied to figure out the fatigue properties of Alloy 52M weld and strain rate will be fixed as 0.1 %/s in cases following preceding research [2,3]

2. Experimental

2.1 Material Preparation

To investigate the low cycle fatigue behavior of Alloy 152 weld metal, dissimilar metal weldment joining SS316L and A508 Gr. B with Alloy 152 and Alloy 52M was prepared. Detailed chemical compositions are shown in table 1. Alloy 152 was named as A152, Alloy 52M as A52 and A508 Gr. B to A508.

Then, specimen was fabricated to evaluate fatigue behavior of Alloy 52M as shown in figure 1. Gage section of specimen was 14.25 mm (0.561 in) and total length was 101.6 mm (4 in). Specimen was designed based on ASTM E8-E8m.

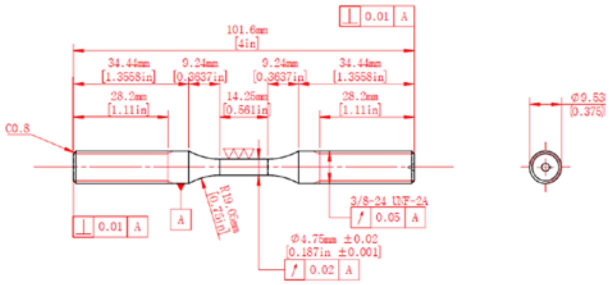

Figure 1. Schematic drawing of fatigue specimen used in this study

2.2 Low Cycle Fatigue Test

Low cycle fatigue tests were conducted in both air and water environment. Temperature was controlled to 300 ℃, and PWR water chemistry was simulated with 1000 ppm of boron, 2 ppm of lithium, 25 cm^3/kg of dissolved hydrogen concentration and dissolved oxygen concentration controlled below 5 ppb.

Every test was conducted in constant strain rate of 0.1 %/s. Test matrix is shown in table 2. Strain amplitude was 0.35, 0.5 and 0.65% for air environment and 0.5% was selected in simulated PWR environment.

Table 2. Test matrix of low cycle fatigue test

Test	Environment	Test condition
AH31	In-air 300 ℃	0.35 %, 0.1 %/s
AH61	In-air 300 ℃	0.65 %, 0.1 %/s
AH51	In-air 300 ℃	0.5 %, 0.1 %/s
PH51	PWR water 300 ℃	0.5 %, 0.1 %/s

Table 1. Chemical composition of alloys used to fabricate dissimilar metal weldment

	C	Si	Mn	P	S	Cr	Ni	Mo	N	Al	Co	Cu	Fe	Ti	Nb+Ta	V
SS316L	0.018	0.55	1.26	0.03	0.002	16.66	10.09	2.05	0.068		0.21	0.27	68.792			
A152	0.038	0.545	3.952	0.0105	0.0058	29.90	54.04					0.026	9.67	0.078	1.64	
A52	0.018	0.17	0.39	0.006	<0.001	29.56	59.7	<0.01		0.28	0.01	<0.002	8.51	0.45	0.762	
A508	0.19	0.21	1.32	0.008	0.002	0.19	0.91	0.48		0.02		0.02				0.003

There exist several methods to define failure criteria of low cycle fatigue test. ASTM Standard E606-04, ‘Standard Practice for Strain-controlled Fatigue Testing’, states that the definition of failure may vary with the ultimate use of the fatigue life information. In the fatigue tests performed during the last four decades, failure was defined according to the force (stress) drop method. In most of these tests, fatigue life was defined in terms of the number of cycles for the tensile stress to decrease 25% from its peak or steady-state value. And this criterion was selected also in this study.

3. Results and discussions

Results achieved from low cycle fatigue test are summarized in figure 2. Each maximum and minimum stress was plotted for each cycles. Fatigue life of strain amplitude of 0.35 % (AH31) had the longest life of 20,282 cycles. And the fatigue life decreases as strain amplitude increased. In every tests, hardening was observed in early stage of fatigue. In case of AH31, specimen was hardened up to 352 MPa for 6,492 cycle. Test conducted with strain amplitude of 0.5% (AH51) shows hardening behavior up to 408 MPa for 1,513 cycles in average.

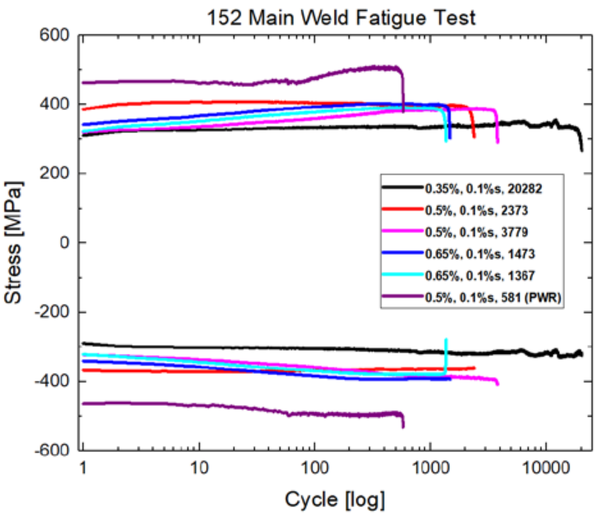

Figure 2. Maximum and minimum stress for each cycles

In the fracture surface of specimen tested in simulated PWR environment, several precipitates were observed. Those precipitates could be formed during solidification and cooling sequence during welding. And this could do a role as barrier for dislocation movement and could increase the tensile properties of material. Also, typical ‘bench marks’ were observed in fracture surface. Further tests are ongoing to verify reproducibility and to investigate the effect of stain rate on fatigue life of Alloy 52M weld metal.

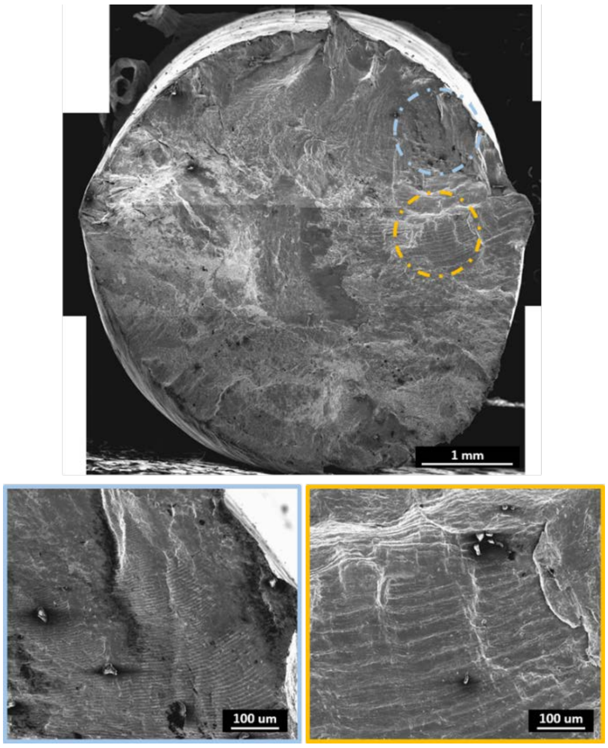

Figure 3. Fracture surface analysis result of PH51

Results were plotted in figure 4 to compare with ASME fatigue life curve from NUREG/CR-6909 [2]. As shown in figure 4, results are well matched with the curve. However, still test results are not enough. More experiment will be conducted with various environmental factors to reveal the effect of those to low cycle fatigue life of Alloy 52M weld metal.

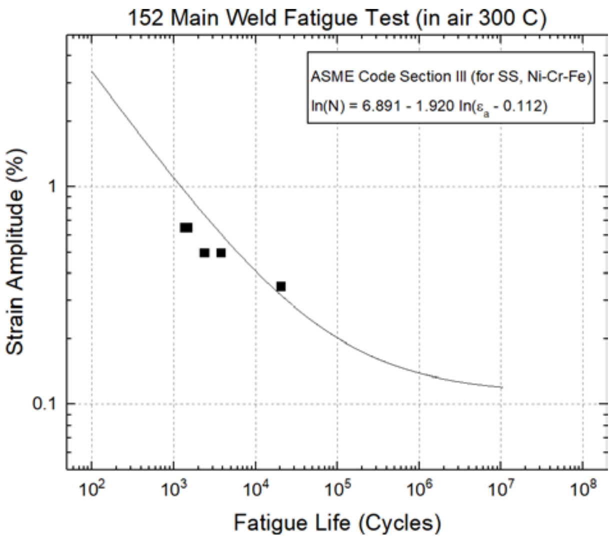

Figure 4. Comparison of test results achieved in this study with ASME fatigue life curve from NUREG/CR-6909

4. Conclusion

Low cycle fatigue behavior of Alloy 52M weld metal was investigated in air and simulated PWR environment varying the strain amplitude. According to the results, fatigue life of Alloy 52M was decreased as increasing the strain amplitude. Also, every samples were hardened at the early cycle and some of them were softened before failure Strain amplitude and fatigue life datum fit well with ASME code section II, but more data points should be added on it to make sure the agreement. In future, various test conditions will be tried to determine the agreement between the low cycle fatigue data at high temperature using alloy 52M and ASME design fatigue curve. Also, tests will be conducted in simulated PWR environment with changing strain rate to reveal the effect of environmental factors on fatigue behavior.

ACKNOWLEDGMENTS

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