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Low Cycle Fatigue Behavior of Dissimilar Metal Weld of Alloy 152, 52M in High Temperature Air and 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 52/152 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 behavior of dissimilar metal weld composed of Alloy 152 and 52M.

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. 3 Cl. 1 with Alloy 152 and Alloy 52 was prepared. Detailed chemical compositions are shown in table 1. Alloy 152 was named as A152, Alloy 52 as A52 and A508 Gr. 3 Cl. 1 to A508.

Then, specimen was fabricated to evaluate fatigue behavior of Alloy 152 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.

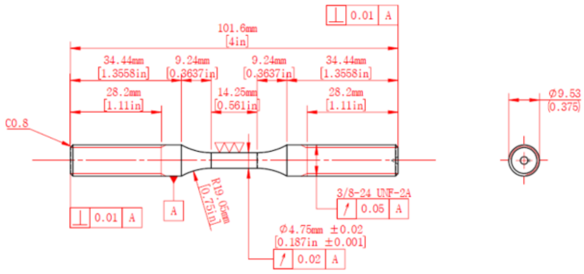

Figure 1. Schematic drawing of fatigue specimen used in this study

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.

Table 2. Test matrix of low cycle fatigue test

Test	Environment	Strain
MAH51	Air 300 ℃	0.5 %
BAH51	Air 300 ℃	0.5 %
JAH51	Air 300 ℃	0.5 %
MPH51	PWR water 300 ℃	0.5 %
BAH71	Air 300 ℃	0.7 %
JAH71	Air 300 ℃	0.7 %

Every tests were conducted in constant strain rate of 0.1 %/s to compare the results of this study with preceding research [2,3]. Test matrix is shown in table 2. Specimen name was defined by the combination of letters stands for material (M: A52M, B: A152, J: Joint weld of 52M and 152) and test condition (AH51: 0.5 %

Table 1. Chemical composition of alloys used to fabricate dissimilar metal weldment (w.t. %)

	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	
A52M	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

of strain in air, AH71: 0.7% of strain in air, PH51: 0.5% of strain in simulated PWR water).

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 and table 3. Each maximum and minimum stress was plotted for each cycles. Almost similar behavior of stress by cycle were observed in other specimen. Fatigue life of Alloy 152 was longer than those of Alloy 52M and joint weld of Alloy 152/52M in 0.5% of strain. Meanwhile, the difference between fatigue life was almost negligible in 0.7% of strain.

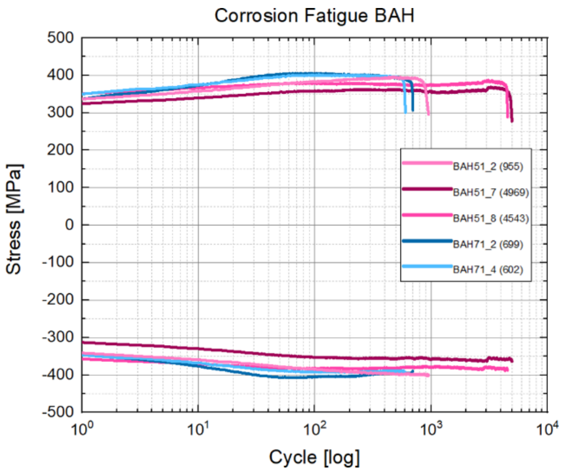

Figure 2. Maximum and minimum stress for each cycles

Table 3. Results of low cycle fatigue test

Test	Fatigue life (cycle)	Standard deviation
MAH51	3328	675
BAH51	4756	213
JAH51	1222	190
BAH71	651	49
JAH71	767	66
MPH51	3191	1187

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 152 weld metal.

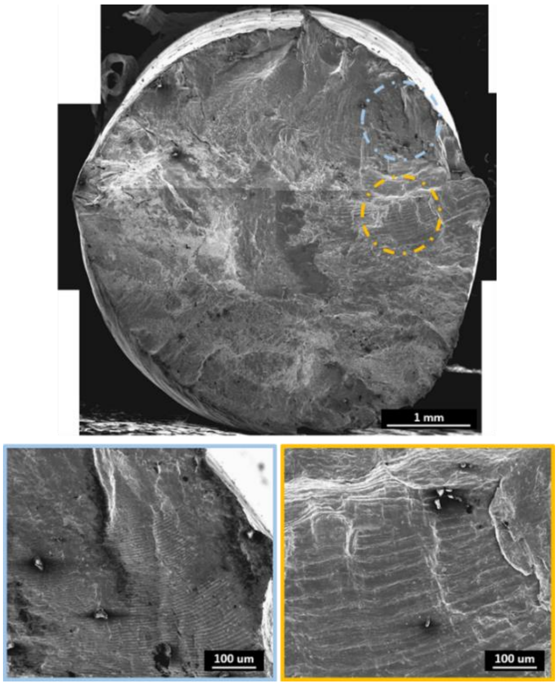

Figure 3. Fracture surface analysis result of PH51

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 materials covered in this study.

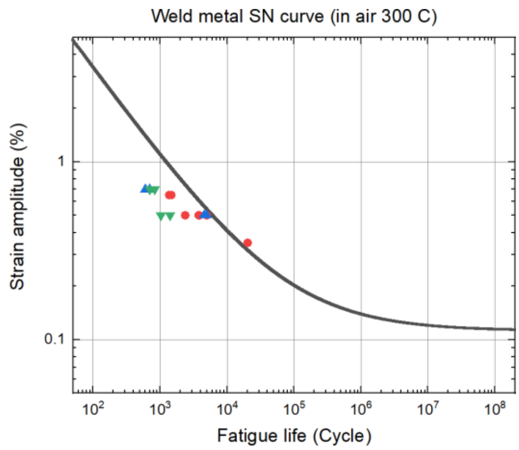

Figure 4. Comparison of test results achieved in this study with ASME fatigue life curve from NUREG/CR-6909

4. Conclusion

Low cycle fatigue behavior of dissimilar metal weld composed of Alloy 152 and 52M was investigated in air and simulated PWR environment varying the strain amplitude. According to the results, fatigue life of every specimen was decreased as increasing the strain amplitude. Also, every samples were hardened at the early cycle and some of them were softened before failure. Fatigue life of Alloy 152 was longer than those of Alloy 52M and joint weld of Alloy 152/52M in 0.5% of strain. 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. To figure out the effect of strain rate and material variety to fatigue life of specimen, further microstructural investigation is on going.

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