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Low cycle fatigue of Alloy 690 and welds in a simulated PWR primary water environment

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1. Introduction

The reduction of low cycle fatigue life of metallic materials in the primary coolant water environments has been the subject of debate between the utility and regulator since 1980s. It became the significant licensing problem since the issue of RG-1.207 by U.S. NRC [1]. The statistical model for the environmental factor, Fen, specified in RG-1.207 was based on the extensive test results accumulated by the ANL and Japanese national program. Of the materials, the limited fatigue life data of Ni-Cr-Fe alloys were used to develop the Fen for the alloys [2-4]. Furthermore, test data for Alloy 690 and its weld are limited. Considering that Alloy 690 will be extensively used in the new nuclear power plants, additional effort to validate or improve current Fen model is required. In this study, environmental fatigue tests for these materials were performed and the new prediction model of fatigue life of Alloy 690 and weld in primary water condition was proposed.

2. Experimental

2.1 Test material

The test material used in this study was Alloy 690 and 52M weld. Forged Alloy 690, heat number 135264 from Goodman Alloys, was solution-annealed at 1060℃ for 3 hour followed by quenching in air. A 52M weld is fabricated by Doosan Heavy Ind. as a dissimilar weld joining SA 508.Gr.3. Cl.1 and STS 304. For LCF test, round bar type specimens with gauge length 19.05 mm and gauge diameter 9.63 mm according to ASTM E 606-92 [5], were used in this study.

2.2 Test system and conditions

The test system for LCF in primary water condition consists of servo-electric fatigue testing machine, an autoclave, and the water circulation loop, as shown Fig. 1. The test environment was simulated PWR water containing dissolved boric acid and lithium hydroxide at 310 ^{o}C and 15 MPa. The levels of DO, DH, conductivity and pH are monitored and controlled at room temperature. After the DO was reduced below 1 ppb, the concentration of dissolved hydrogen in the feedwater is maintained as 2.2ppm to simulate primary water condition.

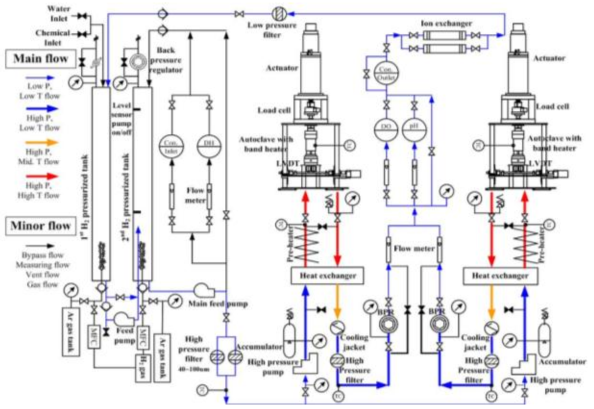

Fig. 1. The schematic diagram for low cycle fatigue test in primary water condition

The LCF tests were performed in strain control mode with a fully reversed (R=-1) triangular waveform. As summarized in Table 1, strain rates of 0.4%/s, 0.04%/s, and 0.004%/s and applied strain amplitudes of 0.4%, 0.6%, and 1.0% were used. The fatigue life, N_{25}, is defined as the number of cycles for the peak tensile stress to drop 25% from its initial value. To evaluate the environmental effect, tests were also conducted in room temperature air condition.

Table I: LCF test condition

Environment		RT Air, PWR
Waveform		Fully reversed triangular (R= -1)
Control		Strain control
Strain rate		0.4, 0.04, 0.004%/s
Strain amplitude		0.4, 0.6, 1.0%
Water chemistry	DO	<5ppb
	DH	~ 25cc/kg
	Conductivity	< 20~25 μ S/cm
	pH	6~7

3. Results and Discussion

3.1 Fatigue life of Alloy690/52M weld

The tested fatigue life data of Alloy 690 and 52M are presented in Fig. 2. For comparison, fatigue life model for Ni-base alloy of JSME, ASME code mean curve, and fatigue design curve as well as the prediction model of ANL for stainless steels are also shown. As shown in the figure, the fatigue lives of Alloy 690 and 52M in primary water environment are shorter than those in RT air condition, but the degree of reduction in fatigue life was smaller than other structural materials, such as LAS, and SSs. The general tendency, the fatigue life decreases with decreased strain rate, is confirmed for all strain rate tested, although there is some scatter on the data of 0.04%/s. Also, the overall trend is similar to published data on the NUREG report [4] and the test results data are in good agreement with existing prediction models by ANL and Higuchi.

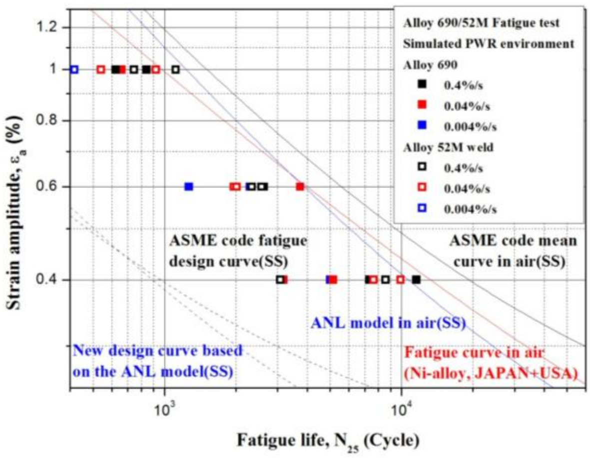

Fig. 2. Fatigue life of Alloy 690 and 52M weld in simulated PWR environment

3.2 Revised fatigue life prediction model for Alloy 690 and 52M

As mentioned before, the existing prediction models are based on the limited database mainly consists of Alloy 600 and its welds. We tried to develop a more reliable model for Alloy 690 and 52M by adding our data to the existing database. The revised prediction model consists of new fatigue curve in air condition and environmental correction factor. Fig. 3 shows the details of the revised prediction model considering parameters like strain rate, temperature, and dissolved hydrogen concentration. With the revised Fen model for Alloy 690 and 52M, the reliability of the fatigue life prediction has been improved as shown in Table II.

3. Conclusions

To evaluate the fatigue life of Alloy 690 and 52M in a PWR environment, low cycle fatigue tests were performed and revised fatigue life prediction models and environmental factor were proposed. With the revised Fen model for Alloy 690 and 52M, the reliability of the fatigue life prediction has been improved.

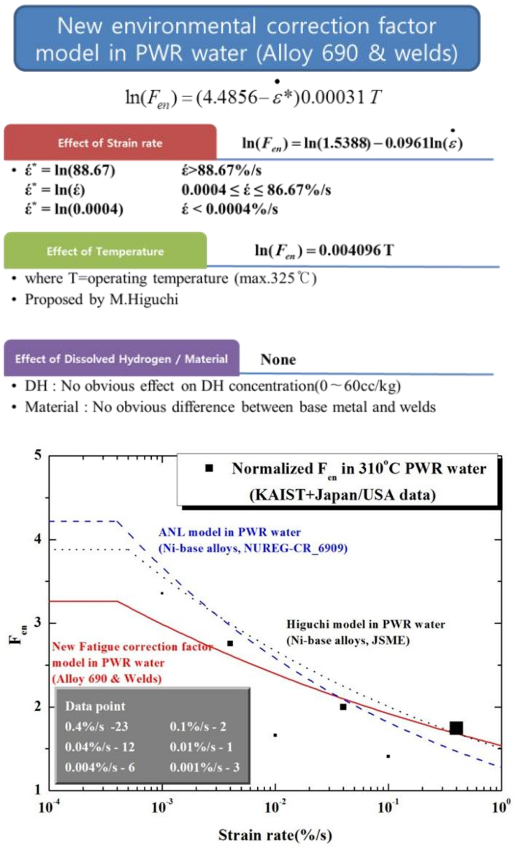

Fig. 3. Revised environmental correction factor model in PWR water for Alloy 690 and 52M weld

Table II: Estimated scatter of fatigue life prediction by various model

Model	Mean Square Error
KAIST	0.038435
ANL	0.076986
Higuchi	0.064417

REFERENCES

[1] US NRC, 2007, Regulatory Guide 1.207.
[2] Higuchi, M., K. Sakaguchi, A. Hirano, and Y. Nomura, “Revised and New Proposal of Environmental Fatigue Life Correction Factor (F_{en}) for Carbon and Low–Alloy Steels and Nickel Alloys in LWR Water Environments,” Proc. of the 2006 ASME PVP., July 23–27, 2006, Vancouver, BC, Canada, paper # PVP2006–ICPVT–93194.
[3] Van Der Sluys, W. A., B. A. Young, and D. Doyle, “Corrosion Fatigue Properties on Alloy 690 and Some Nickel–Based Weld Metals,” Assessment Methodologies for Preventing Failure: Service Experience and Environmental Considerations, PVP Vol. 410-2, R. Mohan, ed., ASME, New York, pp. 85–91, 2000.
[4] O. K. Chopra and W. J. Shack , "Effect of LWR Coolant Environments on the Fatigue Life of Reactor Materials", NUREG/CR-6909, 2007
[5] Standard Practice for Strain-Controlled Fatigue Testing, ASTM E 606-92 (1998).