Comparative Study of Fatigue Life of Type 316LN Austenitic Stainless Steel in 310°C Low Oxygen-containing Water with Prediction Models

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1. Introduction

Austenitic stainless steels (SSs), such as type 304 and 316, are widely used as structural materials of nuclear power plants. Since nuclear power plants are operated in high-temperature water, components are exposed to corrosive environments. Therefore, the combination of mechanical vibration and corrosive environments can induce the enhancement of fatigue damage [1]. Although the ASME Boiler and Pressure Vessel Code Section III specified the design fatigue curves for structural materials used in nuclear power plants, these curves did not address exactly the effects of corrosive environments on the fatigue lives of structural materials because the ASME design fatigue curves were based on data tested in room temperature (R.T.) air [2]. Thus far, researchers have suggested some models for prediction of the fatigue lives of structural materials in light water reactor (LWR) environments [3-5]. The Argonne National Laboratory (ANL)'s statistical models [3] and the fatigue life reduction correction factor suggested by M. Higuchi et al. [4] were representative. In this regard, this study was aimed at providing strain-fatigue life data of type 316LN SS in 310°C low oxygen-containing water and at comparing the experimental data generated in this study with other researchers' models.

2. Experimental Details

The test material used in this study was ASME SA312 type 316LN SS. The test material was heat treated at 1065.56°C for 1 hour, followed by quenching in water. The low cycle fatigue (LCF) test specimens were of round bar type, with a gauge section of 9.63 mm in diameter and 19.05 mm in length.

The low cycle fatigue (LCF) tests were performed in a symmetric uniaxial push-pull mode in 310°C low oxygen-contained water. The strain rates were 0.4, 0.04, and 0.008 %/s, and the applied strain amplitude were varied from 0.4 to 1.0 %. The DO level of the test water was kept to less than 1 ppb, and the conductivity was maintained under 0.1 μS/cm. Fatigue life, N_{25}, was defined as the number of cycles at which the tensile stress drops 25 % from its peak.

3. Results and Discussion

Figure 1 shows the fatigue lives of type 316LN SS with various strain rates in air and 310°C low oxygen-containing water. The LCF tests in air were conducted for the purpose of comparison with those in 310°C water. In Figure 1, the ASME design fatigue curve and mean curve in air for austenitic SS is also presented for comparison [2]. As shown in Figure 1, the fatigue lives of type 316LN SS in 310°C low oxygen-containing water was shorter than those in air. The reduction in the fatigue life in 310°C low oxygen-containing water was enhanced with a decreasing strain rate.

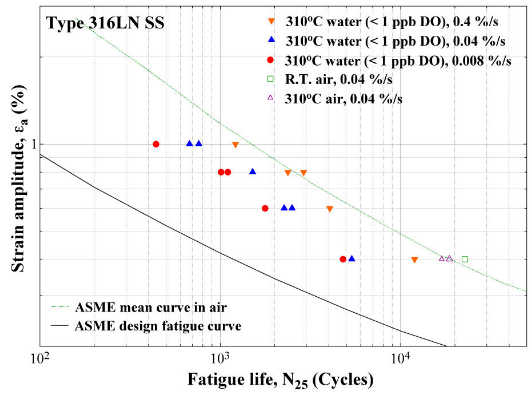
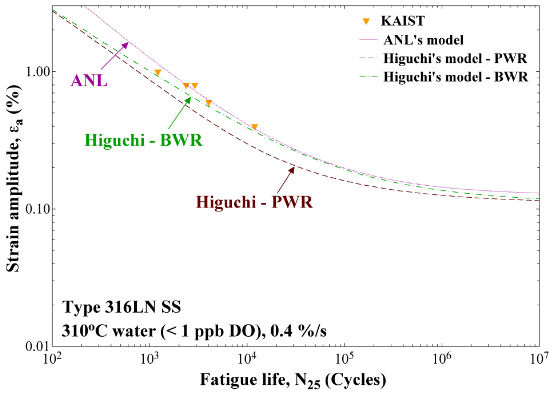


Figure 1. Fatigue lives of type 316LN SS with various strain rates in air and 310°C low oxygen-containing water.

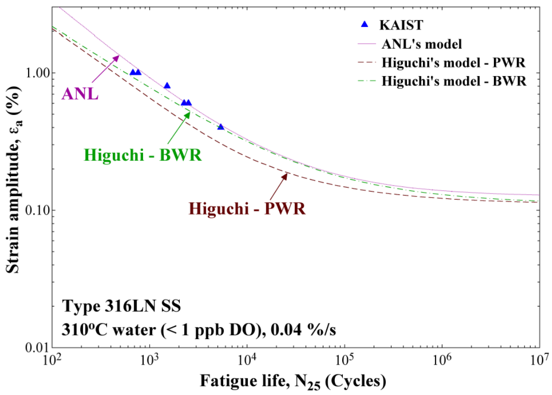
We compared our test results with other researcher's models, such as those of the ANL [3] and M. Higuchi [4]. The ANL's model for type 316NG SS was chosen for comparison with our data, because the chemical composition and heat treatment of our test material are very similar to those of type 316NG SS [3]. The fatigue lives predicted from the ANL's model was determined by using the transformed parameters (temperature, strain rate, and DO level) calculated from our test conditions. In ANL's models, the fatigue live equations are presented for several groups of materials.

Higuchi et al. [4] suggested the fatigue life correction factor (F_{en} was defined as the ratio of fatigue life in air and fatigue life in water). The fatigue lives predicted from the Higuchi's models were determined by multiplying the curve in air by F_{en} as calculated from our conditions. The best fitting curve in air was proposed by Tsutsumi et al. [5]. The Higuchi's models were divided with the reactor type (boiling water reactor (BWR) and pressurized water reactor (PWR)).

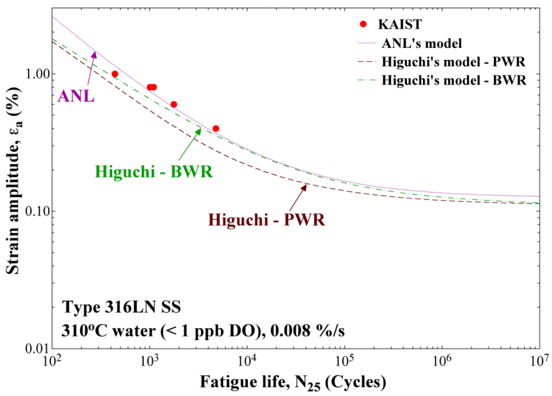
Figure 2 compares the test results of current study with other researchers' models. As shown in Figure 2, the ANL's model shows good agreement with the fatigue lives generated in this study for all testing strain rates. The ratio of predicted lives from the ANL's model and the experimental date produced in this study is a factor of 0.7-1.2. The effect of conductivity of the water on the fatigue life of austenitic SSs in LWR environment was not addressed explicitly in the ANL's model. Therefore, it can be considered that the difference between the fatigue lives predicted from the ANL's model and the test results generated in this study is induced by the absence of the conductivity term in the fatigue life in the ANL's model.



(a)



(b)



(c)

Figure 2. Comparison of the fatigue lives generated in this study and other researchers' models: (a) 0.4, (b) 0.04, and (c) 0.008 %/s.

In contrast, the fatigue lives of current study were a factor of 2.5 higher than the predicted lives from the Higuchi's PWR model. The Higuchi's models described that the fatigue lives of austenitic SSs in LWR environments reduce with a increasing electrical conductivity. The Higuchi's model for PWR was based on the experimental data of austenitic SSs generated in PWR water (conductivity ~ 22 μS/cm at R.T.); however, the fatigue lives of type 316LN SS in this study were produced in high-temperature deionized water (< 1 μS/cm at R.T.). Furthermore, the Higuchi's models did not include the effect of the material variability on fatigue lives of austenitic SSs in LWR environments. In a consequence, the Higuchi's PWR model shows poor agreement with the fatigue lives generated in this study due to the two reasons described previously. The predicted lives from the Higuchi's BWR model were a factor of 1.7 lower than those produced in this study. The Higuchi's BWR model shows a little difference from the test results, relative to PWR model. The conductivity of BWR water is very similar to that of the test water used in this study. Hence, this difference between the fatigue lives predicted from the Higuchi's BWR model and the experimental data generated in this study can be explained by the absence of the effect of the material variability on the fatigue life in the Higuchi's BWR model. Therefore, the ANL's statistical model does the best job of describing the fatigue lives generated in this study, relative to other models.

4. Conclusion

The fatigue lives of current study show good agreement with the ANL's statistical model. The Higuchi's PWR model showed poor agreement with the experimental data produced in this study because of the low conductivity of the test water and the absence of the effect of the material variability in the Higuchi's models. The gap between the fatigue lives produced in this study and those predicted from the ANL's model is narrow, relative to the Higuchi's models. Therefore, it can be considered that the effect of material variability on the fatigue life is more significant than the effect of conductivity.

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