Comparison of the ASME Environmental Fatigue Design Curve with the Leax' Low Bound Model

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1. Introduction

Environmental fatigue issue long time argued between industry and regulator. The issues of the debates are about environmental fatigue data only from experiment laboratories, no evidences in fields, and over conservatism [1]. However, NRC issued the requirement to implement it to the construction design prior to industry practical design code [2,3]. American Society of Mechanical Engineers (ASME) determined to issue non-mandatory code cases of environmental fatigue design. This paper evaluated the conservatism of the ASME proposed environmental fatigue design curve in comparison with the Leax' low bound approach model of environmental fatigue curve. A group of CF8M cast austenitic stainless steel (CASS) produced in KEPCO Research Center was introduced in the evaluation.

2. ASME Environmental Fatigue Design Curve

ASME BPV (Boiler and Pressure Vessel) III Standards Committee approved the proposal to issue Code Case N-X-0, "Fatigue Evaluations Including Environmental Effects, Section III Division I" this year. The Code Case includes environmental fatigue design curves of carbon steel, low alloy steel, austenitic stainless steel, and Ni-Cr-Fe steel in the environments of the light water reactors. Fig. 1 shows the ASME environmental fatigue curves for the austenitic stainless steels. The lowest environmental fatigue curve B can be used in design of the pressure boundary components of nuclear power plants.

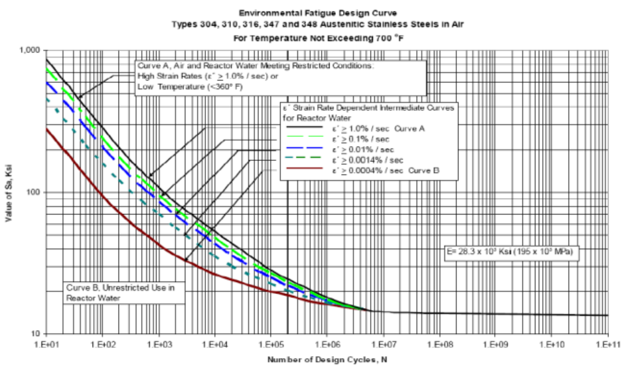

Fig. 1 ASME Environmental Design Fatigue Curve for Austenitic Stainless Steels [4]

3. Leax' Low Bound Model

Leax proposed an environmental fatigue fracture life N_f with the low bound curve approach; equation (1) for the environmental design fatigue curve based on the test data collected worldwide (383 failure points) [5].

The best fit curve equation from the test data was adjusted to compensate the gap of experiments from real component environments and give the margin of fatigue design. The coefficients of equation (1) were derived from the specific test conditions of this study and substituted in equation (2) which is drawn in Fig. 2. The coefficients of equation (1) used in this study are as follows [6]:

A=1.87x10-2 (for the CASS in the pressurized water reactor (PWR) environment), $\varepsilon_{SWT}=\varepsilon_a^{0.7}(\sigma_{MAX}/E)^{0.3}$ (modified Smith-Watson Topper coefficient), ε_a is the strain amplitude(10^{-2}%/s), σ_{MAX} is the maximum stress in the cycles (38ksi at 315.5℃), E is the elastic modulus (28.3×10^3ksi), $\varepsilon_0 = 9.068\times10^{-4}$, b=-2.09, P=0.0286 (for the cast stainless steel), k=149.0 (PWR environment), Z=(dε/dt)exp[Q/(RT)] (Zener-Hollomon coefficient), dε/dt is the strain rate (10^{-2}%/s), Q=35.170cal/mol, T is the absolute temperature (588K), R is the gas constant (1.987cal/mol-K), and m=-0.2233.

$$N_f = A\cdot(\epsilon_{SWT}-\epsilon_0)^b\cdot[P+(1-P)\cdot exp(-kZ^m)] \quad (1)$$

$$N_f = (2.377\times10^{-4}\epsilon_a^{0.7}-2.156)\cdot[0.0286+0.9714exp(-0.1798\dot{\epsilon})] \quad (2)$$

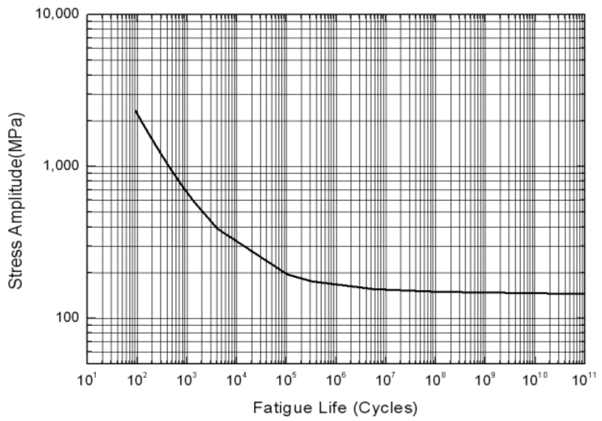

Fig. 2 Leax' Low Bound Curve with the CF8M Environmental Fatigue Test Conditions

4. Comparison

The Fatigue limit of Fig. 2 was modified by reducing strain amplitude 20% at the cycle 10^6 and fit to the one of the ASME. Fig. 3 compares the modified Leax' low bound fatigue curve and environmental fatigue test data of CF8M cast stainless steel produced in the operating environment of PWR. Most test data are above the modified low bound curve which means that the Leax' curve predicts well the environmental fatigue phenomenon.

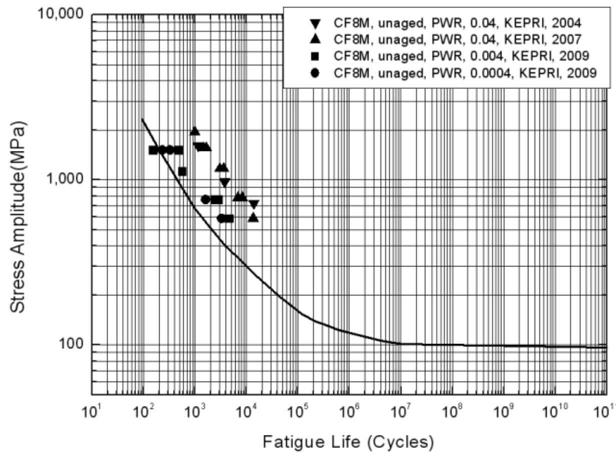

Fig. 3 Comparison of the Modified Leax' Low Bound Model with the CF8M Environmental Fatigue Test Data

The curve of Fig. 3 was adjusted in life by applying factor of 2.5 to balance with the ASME curves. The adjusted Leax' low bound limit curve at the strain rate 0.0004%/s is plotted with the ASME proposed curves in Fig. 4. The Leax' limit curve is less conservative than the ASME environmental fatigue curve at the stain rate 0.0004%/s on left side in estimating fatigue life.

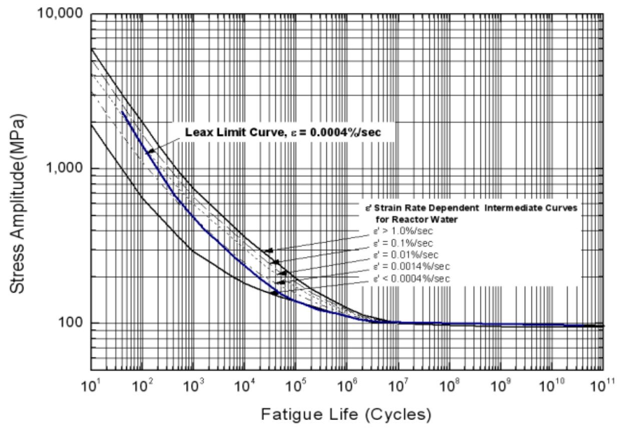

Fig. 4 Comparison of the Modified Leax' Limit Curve with the ASME Environmental Fatigue Curves

5. Discussions

Leax' low bound model limits well the lowest environmental fatigue life test data of the CF8M CASS material and is less conservative than the ASME proposed environmental fatigue life curves. This can shows that the ASME proposed environmental design fatigue curve can predict the environmental fatigue life of CF8M CASS.

The conservatism of the ASME proposed environmental fatigue curve is confirmed by comparing with the Leax' limit curve that is bounding the environmental fatigue test data. The more conservatism is better in designing components integrity and safety as long as it is economical.

However, it could be a burden to have a heavy conservatism in estimating fatigue life when utility plan to have nuclear power plants in long term operation beyond design life. An optimizing technology for counting environmental fatigue phenomena in structural integrity assessment of in-operation components is asked to be developed in near future.

6. Conclusions

The conservatism of the ASME proposed environmental fatigue design curve was evaluated in comparison with the Leax' low bound approach model of environmental fatigue curve.

The ASME proposed environmental fatigue design curve was compared with the Leax' limit curve that is bounding the environmental fatigue test data.

The conservatism of the ASME curves is so heavy that its application to the field for the long term operation is a burden.

An optimizing technology of smoothing the conservatism will be very welcomed to the nuclear industry in near future.

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