Low Cycle Fatigue Behaviors of Type 316 Stainless Steel in 310 °C Water Environment

Byoung Koo Kim, a Hyunchul Cho, a In Sup Kim, a Chang Heui Jang
A Department of Nuclear and Quantum Engineering, KAIST, 373-1 Guseung-dong, Yuseong-gu, Daejeon 305-701, Republic of Korea
Bung_kim@kaist.ac.kr

a Dae Yul Jung, b Seong Cheol Byeon
b KHNP Co., LTD.
Yuseong Post Office Box(No.) 149, Yuseong-gu, Daejeon 305-605, Republic of Korea

1. Introduction

For the license renewal of power plant, safety analysis of main life determining parts for the extended life period is needed. Fatigue is one of the important degradation mechanism of reactor coolant pressure boundary (RCPB). And because of it's time dependency, fatigue is getting more important as the time goes. Fatigue is caused by stress gradient during heat up and cool down. It's range belongs to low cycle fatigue in RCPB. ASME made design fatigue curve of fatigue. But the curve dose not contain temperature and water environment effects. So fatigue test in primary coolant condition is need to generate more reasonable design curve. Type 316 stainless steel is material for surge line pipe. And it is thought to be the weakest part for fatigue in RCPB. So, fatigue tests of Type 316 stainless steel in 310 °C water were conducted.

2. Experiment

2.1 Test material and Specimen

Test material is SA312-92 Type 316 stainless steel produced by Wyman-Gordon Forgings. Chemical compositions are C:0.018, MN:1.84, P:0.022, S:0.016, SI:0.46, CR:16.37, NI:11.30, MO:2.11, N:0.096, B:0.0015, CO:0.10, CU:0.28. and tensile properties are Y.S.:294 MPa, U.T.S:577.1 MPa, Elong:67.7 %, Red. In Area:78.6 %. Heat treatment was conducted at 1065.5 °C for one hour and water quenched. Microstructure is an austenite structure and average grain size is 7. Specimen is a round bar type and dimensions are gauge length 19.05 mm and gauge diameter 9.05mm. Detailed shape is shown at figure 1.

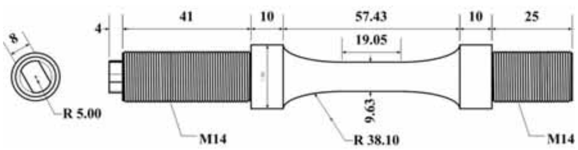

Figure 1. Test specimen dimension (all units are in mm)

2.2 Test system and Test condition

The test system is composed of three parts. That is a chemically controlling water loop, a servo-electric fatigue testing machine, a data acquisition and a actuator. Test temperature was 310±2 °C and test pressure was 150 MPa. Dissolved oxygen (DO) level is less than 1 ppb. Conductivity was maintained under 0.1 μ S/cm. Test cycle was a fully reversed triangular wave form. Test mode was a strain controlled mode. Strain rate was 0.04 %/s ,0.008 %/s and strain amplitude was 1.0 %, 0.8 %, 0.6 %, 0.4 %. Fatigue life(N_{25}) was determined as cycles when load was dropped 75 % of maximum load.

3. Results and Discussions

3.1 Cyclic stress response

Cyclic stress responses of type 316 stainless steel are shown in Figure 2. The figure shows negative strain rate sensitivity, primary and secondary hardening behavior. Negative strain rate sensitivity for cyclic stress response was shown more clearly as the strain amplitude getting smaller. And this is one of the characteristics of dynamic strain aging (DSA) .

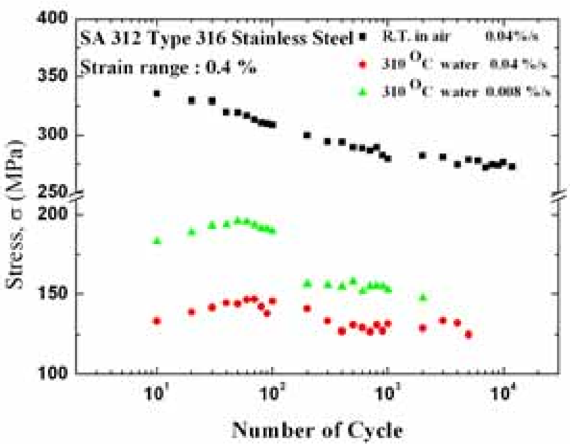

Figure 2. Strain rate effect on cyclic stress response of Type 316 stainless steel

And serrated flow in stress-strain hysterisis loops is also observed. Hardening mechanism of Type 316 stainless steel is known as DSA, second phase precipitation and dislocation structural change[1,2,3]. By the negative strain rate sensitivity for cyclic stress response and serrated flow, the primary hardening is thought to be happened by DSA. For the secondary hardening, second phase precipitation and dislocation structural change are related[4]. In order to define what causes secondary hardening , Transmission electron microscope observation will be needed.

3.2 *Fractography*

Fracture surface of fatigue tested specimens are shown in Figure 3. Figure 3 (A), (B), (D) is arranged by strain amplitude and figure 3 (A), (C) is in the order of crack length. All of the figures show very well defined striations.

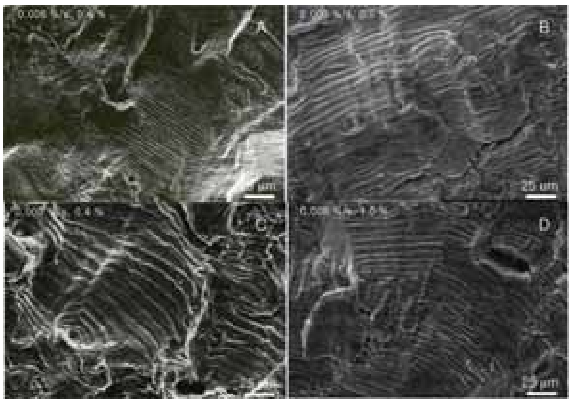

Figure 3. Fatigue surface fractography in different crack length and strain amplitude

As the strain amplitude become larger, the striation width grows wider and it's shape changes from ductile uniform shape to brittle uneven form. And the similar phenomenon happened as the crack length increased. This was well matched with the fatigue life shortage in high strain amplitude and accelerated crack growth rate at later stage of fatigue life.

3.3 *Strain-life (ε -N) curve*

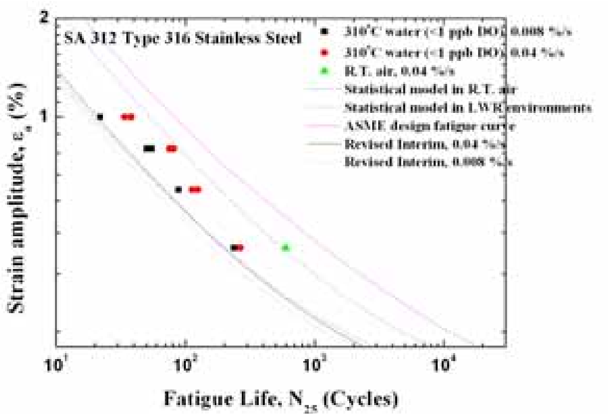

Figure 4. ε - N curves of Type 316 stainless steel in 310 °C low oxygen level environment

The strain – life design curve and test data were shown in Figure 4. The data is divided by factor 20 to compare with the ASME design curve. The data is located between ASME design fatigue curve and statistical model in light water reactor environment which was produced by Argon National Laboratory[5]. Fatigue life was shorten as the stain rate goes from 0.04 %/s to 0.008 %/s. And fatigue life was enormously shortened in high temperature water environment than in room temperature air. DSA and water environment chemistry is thought to be major fatigue life reducing factors. More experiment and analysis will be needed to confirm this.

3. Summary

Low cycle fatigue test results of Type 316 stainless steel in 310 °C water environment can be summarized as follows.

1. Cyclic stress response of Type 316 stainless steel shows negative strain rate sensitivity ,primary hardening and secondary hardening.
2. Fatigue life in 310 ° C water environment was shorter than fatigue life in room temperature air environment. This was because of water environment and temperature effects.

REFERENCES

[1] Dae Whan Kim, Woo-Seong Ryu, Jun Hwa Hong and Si-Kyung Choi, 1998, "Effect of nitrogen on high temperature low cycle fatigue behaviors in type 316L stainless steel," Journal of Nuclear Materials, 254, pp. 226-233.

[2] Srinnivasan, V. S., Sandhya, R., Valsan, M., Bhanu Sankara Rao, K., Mannan, S. L., and Sastry, D.H., 1997, "The influence of dynamic strain ageing on stress response and strain-life relationship in low cycle fatigue of 316L(N) stainless steel." Scripta Materialia, 37(10),pp. 1593-1598.

[3] Alain, R., Biolan, P., and Mendez, J., 1997, "Low cycle fatigue behavior in vacuum of a 316L type austenitic stainless steel between 20 and 600 °C Part Ⅰ: fatigue resistance and cyclic behavior," Materials Science and Engineering A, 229, pp. 87-94.

[4] Srinivasan, V. S., Valsan, M., Sandhya, R., Bhanu Sankara Rao, K., Mannan, S. L., and Sastry, D. H., 1999, "High temperature time-dependent low cycle fatigue behavior of a type 316L(N) stainless steel," International Journal of Fatigue, 21, pp. 11-21.

[5] Chopra, O. K., and Shack, W. J., 2004, "Effects of LWR coolant environments on fatigue crack initiation in carbon and low-alloy steels and austenitic stainless steels," Proceedings of 3rd International Conference on Fatigue of Reactor Components, Seville, Spain 3-6 October.