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The Cyclic Strain Rate Dependence on Environmentally Assisted Cracking Behaviors of SA508 Gr. 1a Low Alloy Steel in 310°C Deoxygenated Water

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1. Introduction

Environmental fatigue damage is well known as a significant degradation mechanism in nuclear power plant (NPP). So, the environmental fatigue behaviors should be cautiously considered for assessment of the integrity and the safety of NPP.

In result of many researches, it is reported that the reduction in fatigue life of low alloy steels (LASs) is induced by the environmentally assisted cracking (EAC) mechanisms, such as the metal dissolution and the hydrogen-induced cracking (HIC) [1]. However, since these mechanisms are usually influenced by multiple factors, there are no clear explanations about fatigue cracking behaviors in high temperature water.

In this study, low cycle fatigue (LCF) tests were conducted to investigate the fatigue life of SA508 Gr. 1a LAS in 310°C deoxygenated water. Also, the fatigue surface and sectioned area were observed for evaluation of cyclic strain rate dependent EAC mechanism in high temperature water.

2. Experimental Details

The test material was ASME SA508 Gr. 1a LAS which is used as piping materials of reactor coolant system. The test material was normalized at 920°C for 10 min, followed by quenching in water, and then tempered at 650°C for 130 min in air. The chemical composition was C: 0.22; Si: 0.21; Mn: 1.16; P: 0.008; S: 0.004; Ni: 0.20; Cr: 0.17; Mo: 0.04; Al: 0.02; Cu: 0.12. The test specimen was a round bar type with 19.05 mm gauge length and 9.63 mm gauge diameter. Table 1 shows the detailed test conditions.

Table 1. Test condition of low cycle fatigue test of SA508 Gr. 1a LAS

Wave form	Fully reversed triangular
Strain rate	0.008, 0.04, 0.4 %/s
Strain Amplitude	0.4, 0.6, 0.8, 1.0 %
Test environment	RT & 310 °C air, 310 °C water
Dissolved Oxygen	< 1 ppb
Conductivity	< 0.1 μS/cm

3. Results & Discussion

Figure 1 shows the fatigue life of SA508 Gr.1a LAS with various loading conditions in various environments. As shown in figure 1, under the same loading condition, the fatigue life in 310°C deoxygenated water was shorter than that in air. The fatigue life of SA508 Gr. 1a LAS in 310°C water reduced with a decreasing strain rate, from 0.4 to 0.008 %/s. As I mentioned previously, it is reported that the reduction in the fatigue life in 310°C water is related with the EAC mechanisms.

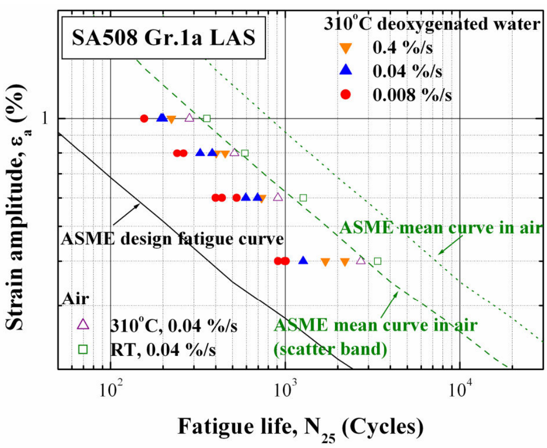

Figure 1. Fatigue life of SA508 Gr.1a LAS.

Figure 2 shows the fatigue surfaces of the specimens tested in RT air and 310°C deoxygenated water. As shown in figure 2 (a), the well developed ductile striations were observed on fatigue surface of the specimen tested in RT air. However, in figure 2 (b), the unclear ductile striations observed on fatigue surface of specimen tested at the strain rate of 0.008 %/s in 310°C deoxygenated water. It may reveal the occurrence of metal dissolution. Also, in figure 2 (c) and (d), the brittle cracks and the flat facets were generally observed on fatigue surfaces of specimen tested at the strain rate of 0.04 and 0.4 %/s. These features might be the evidences for the HIC.

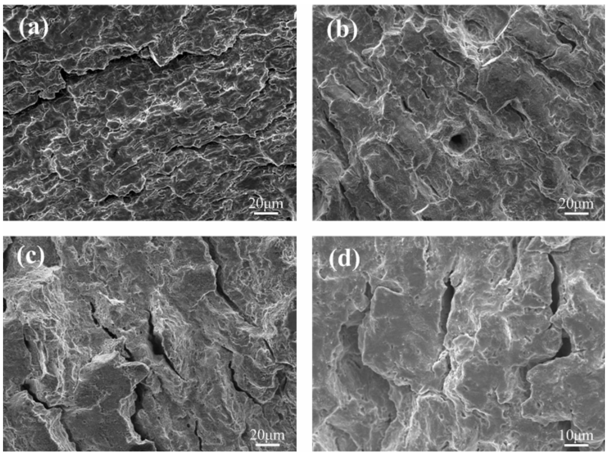

Figure 2. Fatigue surfaces of the specimens tested at the strain amplitude of 0.4 % and the strain rate of: (a) 0.04 %/s in RT air, (b) 0.008, (c) 0.04, and (d) 0.4 %/s in 310°C deoxygenated water.

Figure 3 shows the sectioned area of the LCF tested specimens in various conditions. As shown in figure 3 (a), the sharp and clear crack tip was observed on sectioned area of specimen tested in RT air. But in case of sectioned area of specimen tested in 310°C deoxygenated water, such as figure 3 (b), (c), and (d), the blunt crack tip was observed for specimen tested in 310°C water. It is thought that it revealed the occurrence of metal dissolution. Also, as shown in figure 3 (c), micro-cracks around main crack were mainly observed for specimen tested at the strain rate of 0.04 %/s. the crack propagation might be accelerated by linkup between main crack and micro-cracks. From the observation of figure 3 (d), the tendency of crack linkage was also observed for specimen tested at the strain rate of 0.4 %/s. The existence of micro-cracks might be the evidence of HIC.

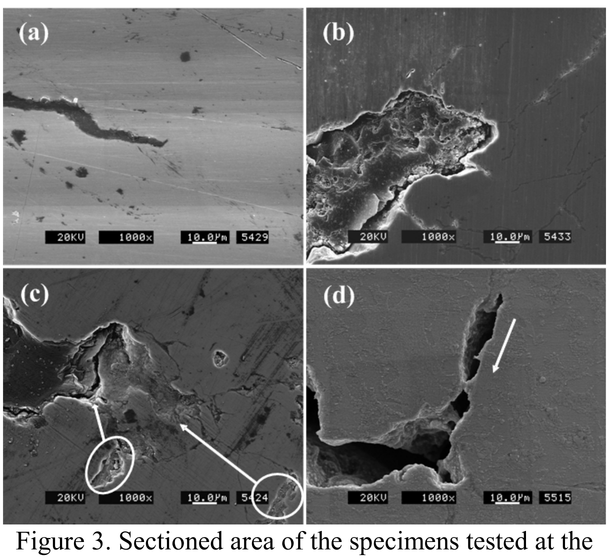

Figure 3. Sectioned area of the specimens tested at the strain amplitude of 0.4 % and the strain rate of: (a) 0.04 %/s in RT air, (b) 0.008, (c) 0.04, and (d) 0.4 %/s in 310°C deoxygenated water.

The absorbed hydrogen is transported to local stressed region along a stress gradient, such as the grain boundaries and the interface of inclusion/matrix which are strong trapping sites for the absorbed hydrogen. So, the hydrogen concentration may be increased at those regions thereby increasing local stress. Therefore, the crack growth may be accelerated by the absorbed hydrogen [1].

During cyclic loading, the lower cyclic strain rate, the longer the crack opening time which provides relatively sufficient time for mass transfer, such as O_2, thereby increasing dissolved oxygen level [2]. It is believed to promote the oxide formation reaction along the crack wall. Since the oxide layer may play as a strong barrier to absorption of hydrogen, HIC could be retarded along the crack wall. Also, as the rupture rate of oxide film is proportional to applying strain rate, at the low strain rate, the slower rupture of oxide film could occur at the crack tip, thereby decreasing exposure time of fresh bare metal [1]. It may effectively prevent the absorption of hydrogen into matrix. Therefore, at low strain rate, the dominant EAC mechanism may be metal dissolution. On the other hand, at high strain rate, fresh bare metal may be easily exposed to corrosive environment due to high rupture rate of oxide film. So, it is thought that HIC mainly affected the acceleration of fatigue crack growth.

4. Conclusions

The fatigue life of SA508 Gr. 1a LAS in 310°C deoxygenated water was shorter than that in air, and moreover, it was different from the strain rates. It is thought that the reduction in the fatigue life is accelerated by EAC mechanisms.

From the microstructure observation, the evidences of metal dissolution, such as unclear ductile striations and the blunt crack tip, were mainly observed at the strain rate of 0.008 %/s. Therefore, the metal dissolution may be the main mechanism.

On the other hand, the evidences of HIC, such as the flat facets and the brittle cracks were observed at the strain rate of 0.04 and 0.4 %/s. Additionally, the fatigue crack propagation with linkage between main crack and micro-cracks were mainly observed at the strain rate of 0.04 %/s. The micro-cracks might be generated by HIC. Therefore, it is thought that HIC is a dominant EAC mechanism at the strain rates of 0.04 and 0.4 %/s.

REFERENCES

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[2] Xinqiang Wu, Yasuyuki Katada, Strain rate dependence of low cycle fatigue behavior in a simulated BWR environment, Corrosion Science, volume 47, issue 6, pp. 1415-1428, 2005.