

Combined Effect of Hydrogen and Dynamic Strain Aging on Low Cycle Fatigue Behaviors of SA508 Gr.1a Low Alloy Steels in 310°C Deoxygenated Water

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1. Introduction

Significant reduction of fatigue life of structural materials in nuclear power plants is one of the issues of considerable significance to maintain superior integrity throughout their service life. From extensive studies, hydrogen induced cracking (HIC) is widely accepted mechanisms for reduction of fatigue life of low alloy steels (LAS) used as structural materials [1-2]. Some of authors reported that hydrogen content in reactor pressure vessel could reach 2 ~ 5 ppm during reactor operation [3]. Hydrogen was resulted from corrosion reaction at the metal surface or crack tip in water. In addition, it has been reported that LAS is susceptible material for dynamic strain aging (DSA) in PWR environment at specific strain rate [4-5]. Therefore, it is possible that the synergism between DSA and hydrogen might induce more significant LCF damage in PWR environment. In this regard, combined effect of DSA and hydrogen was investigated in this study. For that, LCF tests of SA508 Gr.1a LAS in various environments and tensile tests of hydrogen charged (H-charged) samples in DSA range were conducted.

2. Experimental

2.1 Test Material

SA508 Gr.1a LAS which is piping material of reactor coolant system were used for test material. The measured chemical composition was shown in Table 1. The microstructure of test material showed ferrite-pearlite structure [1].

Table 1. The chemical composition (% wt.)

C	N	S	P	Si	Mn	Cr	Ni	Mo
0.22	.008	.004	.008	0.21	1.16	0.17	0.20	0.04

2.2 LCF & Tensile Test

LCF tests were conducted with fully reversed triangular waveform. Test environments were air at RT and 310°C and deoxygenated water at 230 and 310°C. The strain amplitudes were from 0.4 to 1.0%. The strain rate was fixed at 0.04%/s. To investigate the combined effect, several tensile tests of as-received and H-charged specimens were performed at temperature range of RT to 380°C and strain rates of 0.576, 1, 5 mm/min.

3. Results & Discussion

3.1 Fatigue Life of SA508 Gr.1a LAS

Figure 1 shows the fatigue life of SA508 Gr.1a in various environments. The fatigue life in 310°C deoxygenated water was slightly shorter or comparable to those in 310°C air. It has been already published that the reduction of fatigue life in 310°C deoxygenated water is due to operation of EAC mechanisms [1-2]. On the other hand, the fatigue life in 310°C air was significantly shorter than those in RT air and 230°C deoxygenated water. Although the oxidation effect may be one of the causes of reduction of the fatigue life in 310°C air, there still have a point of question because fatigue life in 230°C deoxygenated water is much longer than those in 310°C air.

3.2 Cyclic Stress Responses

Cyclic stress behaviors were compared as shown in Fig. 2. Steep cyclic hardening was observed in specimen tested in 310°C air compared to that in 310°C deoxygenated water. Because DSA is independent on temperature, the stable cyclic behaviors in 310°C deoxygenated water could be induced by operation of other mechanisms during LCF process.

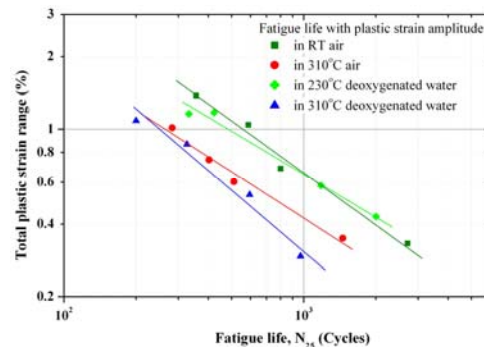


Fig. 1. Fatigue life of SA508 Gr.1a LAS.

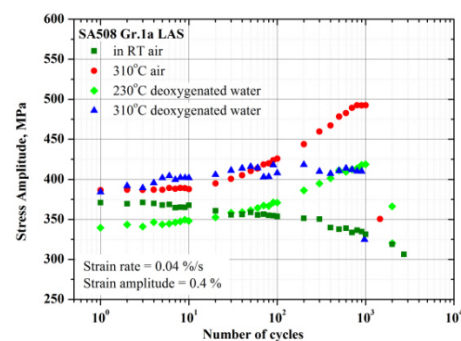


Fig. 2. Cyclic stress responses.

3.3 Tensile Behaviors

The tensile properties of the as-received and H-charge specimens are shown in Fig. 3. While the YS of as-received specimen showed plateau above 250°C, the YS of H-charged specimen were decreased up to 310°C above which YS is stable with increasing temperature. Also, distinct reduction of UTS of H-charged specimen was observed in range of 288°C and 310°C which are corresponding to DSA temperature. UTS of H-charged specimens are continuously increased up to 340°C. The lowest elongation value was changed from 250°C to 300°C.

Figure 4 shows the UTS variation with strain rates. At 310°C air, UTS of H-charged specimens were decreased at all of strain rates. However, at 340°C air, UTS of H-charged specimens were higher than case of as-received specimens and UTS of H-charged specimen at 310°C air. From Fig. 3 and 4, the DSA range of H-charged samples is moved to more high temperature.

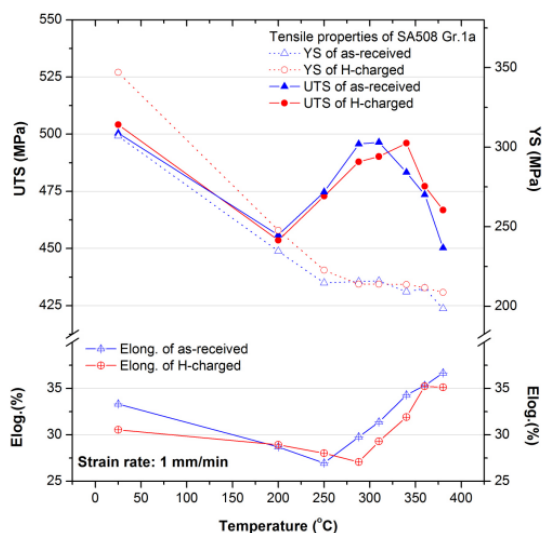


Fig. 3. Tensile properties of SA508 Gr.1a.

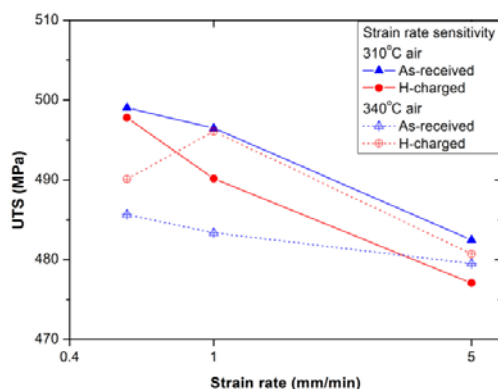


Fig. 4. UTS variation at various strain rates.

3.4 Combined Effect of Hydrogen and DSA

In DSA range, although the dislocation movement tends to be relatively difficult because of immobilization or pinning of diffusing solute atoms on mobile dislocations, the absorbed hydrogen could impede the diffusion rates of diffusing atoms, such as

carbon and nitrogen because the hydrogen could diffuse relatively faster than other interstitial atoms [4]. For occurrence of DSA, it could be needed to higher temperature due to combined interaction with hydrogen. Therefore, it is thought that the absorbed hydrogen could affect the susceptibility of DSA. The DSA susceptibility in 310°C deoxygenated water could be suppressed by softening effect of hydrogen. In addition, the large reduction of fatigue life in 310°C air could be caused by DSA through higher cyclic stress and localization of deformation. The fatigue life in 310°C deoxygenated water may enhanced by reduced cyclic stress. However, the effect of DSA on fatigue life still has uncertainty because of their complexity [6]. Therefore, the study on contribution of DSA on fatigue life is still needed to understand LCF behaviors of SA508 Gr.1a LASs.

3. Conclusions

From the LCF and tensile tests and related analysis, following conclusions can be drawn:

- (1) Tensile properties represented that the DSA range was changed to higher temperature due to hydrogen. Also, the remarkable softening of UTS was observed in H-charged specimen at 288 and 310°C.
- (2) The DSA could be reduced by combined effect with hydrogen. Therefore, in 310°C deoxygenated water, the LCF behavior of SA508 Gr.1a could be relatively less affected by DSA due to absorbed hydrogen.

REFERENCES

- [1] H. Jang, H. Cho, C. Jang, T. S. Kim, C. K. Moon, Effect of cyclic strain rate and sulfides on environmentally assisted cracking behaviors of SA508 Gr.1a low alloy steel in deoxygenated water at 310°C, Nuclear Engineering and Technology, Vol. 40, p. 225, 2008.
- [2] O.K. Chopra, W.J. Shack, Effect of LWR coolant environments on the fatigue design curves of carbon and low alloy steels, NUREC/CR-6583, 1997.
- [3] J.K. Charkravarty, G.E. Prasad, T.K. Sinha, M.K. Asundi, Hydrogen embrittlement of ASTM A203 D nuclear structural steel, Journal of Nuclear Materials, Vol. 138, p. 107, 1986.
- [4] X. Wu, W. Katada, S.G. Lee, I.S. Kim, Hydrogen-involved tensile and cyclic deformation behaviors of low alloy pressure vessel steel, Metallurgy and Materials Transaction A, Vol. 35A, p. 1477, 2004.
- [5] B.H. Lee, I.S. Kim, Dynamic strain aging in the high temperature low cycle fatigue of SA508 Cl. 3 forging steel, Journal of Nuclear materials, Vol. 226, p. 216, 1995.
- [6] O.K. Chopra, W.J. Shack, Effect of LWR coolant environments on the fatigue life of reactor materials, NUREC/CR-6909, 2006.