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Evaluation of fatigue crack growth behavior of type 347 stainless steels under Thermo-mechanical load conditions

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1. Introduction

Nuclear power plant facility is operated in a hot and highly pressurized environment for a long period of time, it is necessary to study the relevant fracture factors such as the strength, fracture toughness, fatigue, and to establish suitable resources after careful research. Localized thermal mechanical fatigues occur in the pressurizer surge line due to a thermal stratification and, consequently, the thermal stripping phenomena is caused by the flux characteristics of the hot liquid and cool liquid in a piping system[1].

AISI type 347 stainless steel(SS), an Nb-stabilized austenitic stainless steel, is the material used for the Korea Standard Nuclear Power Plant (KSNPP) pressurizer surge line.

The code for fatigue characterization is included in section XI of the ASME Boiler and Pressure Vessel Code. The code provides the methodology for a flaw evaluation based on the Paris' law Fatigue Crack Growth Rate (FCGR) equation and a reference fatigue crack growth curve for austenitic stainless steels[2].

In this study, the isothermal FCGR test including the near-threshold area and the thermo-mechanical FCGR test were performed for two types of 347. The objective of this study was to evaluate the effects of the distribution and contents of precipitates on the fatigue crack growth behavior and the results compared with the ASME reference curve.

2. Experimental

Two AISI type 347 austenite stainless steel plates with different chemical compositions were used as test materials. The commercial steel plates have very limited contents of alloy elements such as C and N, so they are not suitable for ethodically studying the effect of additional elements.

Therefore, the production technique of type 347 steel plates was followed to produce 30 kg ingots of type 347 alloys which had different contents of C, N and Nb by using a vacuum induction melting technique. Detail chemical property analysis of each test material is summarized in Table 1.

The specimen to measure the fatigue crack growth was a 25 mm wide and 2 mm thick ESET (Eccentrically-loaded Single Edge crack Tension) type of specimen.

Isothermal fatigue crack growth experiment was performed at temperatures of 167℃and 345℃, a pressurizer surge horizontal line transitional operation temperature range, and room temperature, a stress ration of 0.1, and a frequency of 10 Hz. A traveling microscope with a 0.01 mm precision was used for a crack development measurement. In order to describe the FCGR, the parameters were determined from Paris law[3]. The stress intensity factor range, ΔK, for the ESE(T) specimen was calculated using ASTM E 647 [4]:

Thermo-mechanical fatigue crack growth experiment was performed in the temperature range of 167℃~345℃, with on in-phase and a triangular wave form, and a frequency of 0.0083 Hz. A traveling microscope with a 0.01 mm precision was used for a crack development measurement. The load of a pre-crack was reduced in three steps.

Table 1. Chemical compositions of the type 347 SSs.

	C	N	Nb	Cr	Ni
SS-L	0.020	0.030	0.26	17.81	10.04
SS-H	0.049	0.110	0.63	17.60	9.95
Std.spec.	0.08max	-	Cx10 min	17.0~ 20.0	9.0~ 13.0

3. Results and Discussion

Figs.1. (a) and (b) show the pictures of the SS-L and SS-H specimens taken with the optical microscope. Sizes of the grains were similar; size of the SS-L grain was 42μm and the size of the SS-H was 39μm.

As a result of the observation by SEM, a Nb(C,N) coarse precipitates was observed in the rolling direction of the matrix, where the sizes and distributions of the precipitates were very different. As shown in Figs. 2. (a) and (b), an SS-L specimen which had low contents of C, N, and Nb, a microstructure smaller than 0.1μm, had second phase particles evenly distributed in the intergranular and transgranular grain of the austenite matrix structure. However, for an SS-H specimen which has high contents of C, N, and Nb, it was observed that 1~10 μm coarse particles were locally distributed along with microscopic particles smaller than 0.1 μm.

An electrolytic extraction method was used to separate the precipitates from the matrix structure to measure the weight percent for the whole specimen in order to analyze the precipitates in more detail. As Fig. 3. shows, the precipitates contents of the SS-L and SS-H specimens were 0.22 wt% and 0.81 wt% respectively.

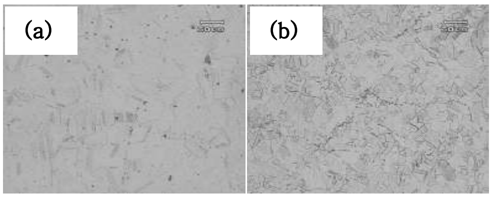

Fig. 1 Optical micrographs of type 347 SSs. ; (a) SS-L, (b) SS-H

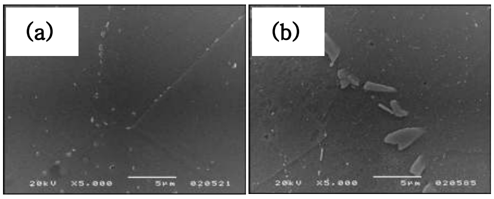

Fig. 2 SEM micrographs showing the precipitates in the 347 SSs ; (a) SS-L, (b) SS-H

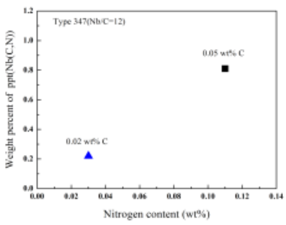

Fig. 3. Quantitative analysis of the precipitates in type 347 with respect to the Nitrogen content.

Fig. 4. shows the fatigue crack growth curve of the SS-L specimen based on temperature changes using equation (2) from Appendix C, Article C-3000 in Section XI of the ASME Code. In Fig. 4 (a), in the stage I region, early stage of a crack growth, the fatigue crack growth rate of the SS-L specimen increases as the temperature rises, but in the stage II region, the crack growth rate was almost identical at each temperature. This trend was also found in the SS-H specimen as in Fig. 4 (b).

The fatigue crack growth increases as the plastic zone size increases. The plasticity increase as the yield stress increases due to an increment of the temperature, it is deduced that the FCGR increases as the temperature rises[5].

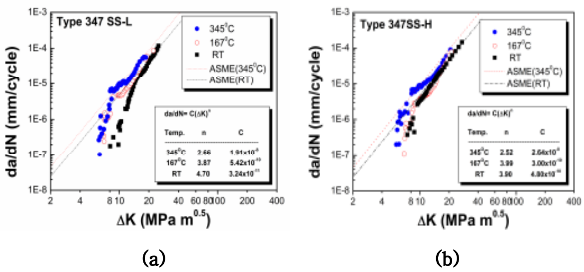

Fig. 4. The effect of temperature on FCGR in type 347. ; (a) SS-L , (b) SS-H

In-phase thermo-mechanical fatigue crack growth rate test result is presented in Fig. 5 along with the isothermal(167℃, 345℃) fatigue crack growth rate test result. The thermo-mechanical fatigue crack growth rate showed relatively higher rate than when the temperature was maintained at certain constant temperatures.

It is essential to compare a TMF and an isothermal FCGR at similar crack propagation rates. As result of comparison the time-dependent damage mechanisms in both cases correspond with each other[6].

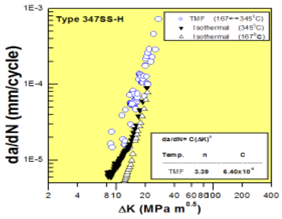

Fig. 5. Comparison of the obtained Thermo-Mechanical Fatigue crack growth rate with the Isothermal FCGR for type 347.

4. Summary

Evaluation of fatigue crack growth behavior of type 347 stainless steels was examined and the following results were obtained.

1. Under the isothermal test conditions, the fatigue crack growth rate of type 347 increased with increasing the test temperature from 25℃ to 167℃ and 345℃.
2. The fatigue crack growth rates of type 347 at a temperature range of 25℃ ~ 345℃ were slightly lower than ASME reference da/dN-Δ K curve.
3. The thermo-mechanical fatigue crack growth rate at a the temperature range from 167℃ to 345℃ was higher than those obtained from isothermal tests and the ASME reference da/dN-ΔK curve.
4. The lower ΔK_{th} was obtained for type 347 having the higher precipitate content, even though the effect of the precipitate was not obvious in the Paris law region,

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REFERENCES

[1] L.Frank et al., *U.S NRC Report NUREG-679*, Aug. (1980)
[2] ASME (1998) *ASME BPV Code*, Section XI, Appendix A, Article-C3000, New York: ASME
[3] P.C.Paris and F.Erdogan, *J.Basic Eng*., 55 (1963) 528
[4] ASTM E 647-00, *Annual Book of ASTM Standards*, ASTM International (2000).
[5] J.H.Yoon,E.P.Yoon and B.S.Lee,*Scripta Mat*.,57(2007) 25
[6] Gary R. Halford: in Thermal Stresses II, R. B. Hetnarski, ed., (1987) 330~428