Preliminary Results of a Corrosion Fatigue Test of Ferritic/Martensitic steel, T91, in a Supercritical Water Condition

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1. Introduction

Recently, an international forum started to develop future-generation nuclear energy systems, known as Generation IV systems. Among the six systems that were selected in the program, the Supercritical Water-cooled Reactor (SCWR) is anticipated to operate above the thermodynamic critical point of water (22.1 MPa, 374°C) to achieve a thermal efficiency approaching 44% [1]. Owing to the SCWR's higher operating temperature than conventional reactors and the unique properties of SCW, material behavior in the SCW condition has been one of the main issues to be investigated [2]. Corrosion and corrosion-related cracking of various alloys for SCWRs have been investigated at KAERI. This paper reports on the preliminary results of the corrosion fatigue tests of a ferritic/martensitic steel, T91, in an SCW condition.

2. Methods and Results

2.1 Experimental

The material used in this study is Alloy T91 and the chemical compositions are given in Table 1. Using samples with a width of 30 mm and a thickness of 6 mm, fatigue tests were performed in air and water environments according to ASTM E-657-00. Table 2 summarizes the mechanical loading conditions of the fatigue tests. Corrosion fatigue tests were performed in a SCW loop system with a C-276 vessel, where deionized water was circulating. The concentration of dissolved oxygen in the water was controlled to below 10 ppb by bubbling pure nitrogen. The electrical conductivity was held to below 0.1 µS/cm.

Test temperatures in water were 370°C and 500°C and the pressure was maintained at 25 ± 1 MPa. To prevent samples from being galvanically coupled with other metallic parts, alumina insulators were secured between the samples and the grips.

Table 1 Chemical compositions of T91 (wt%)

Fe	C	Si	Mn	P	S	Cr
Bal.	0.10	0.28	0.45	0.009	0.003	8.37
Ni	Mo	V	Nb	Al	N	Cu
0.21	0.9	0.216	0.076	0.022	0.048	0.17

Table 2 Fatigue loading conditions in air and water

Environment	air	water
Frequency [Hz]	1	0.004 - 0.0045
R-ratio	0.1	0.12
Initial ΔK [MPa√m]	23~24	25

2.2 Test results

Fig. 1 shows the optical micrographs of the fracture surfaces of the samples tested in air at 600°C and in supercritical water at 500°C. Using the micrographs, the fatigue crack growth rates (FCGRs) were determined. Crack lengths at five locations for each sample were measured and averaged. In Fig. 2, the resulting crack growth rates of T91 at 320, 370, 500, and 600°C, respectively in air were plotted as a function of stress intensity factor range (ΔK) along with those of 9Cr-1Mo steels from a literature [3]. The figure shows that the FCGRs of T91 measured in this study are comparable to the previous data. During the tests in air, the crack length was monitored using a DCPD

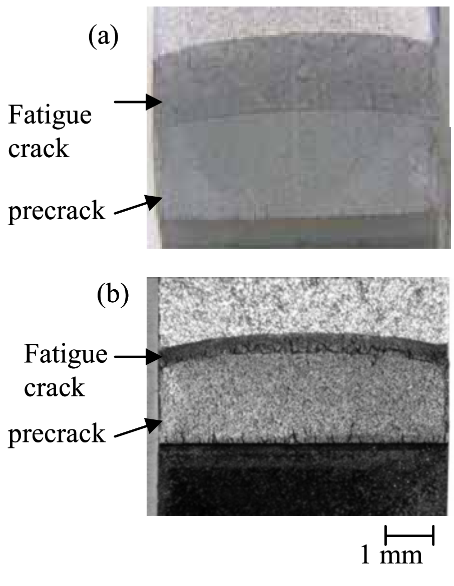

Figure 1. Optical micrographs of fracture surfaces of the samples tested in (a) air at 600°C and (b) the supercritical water at 500°C.

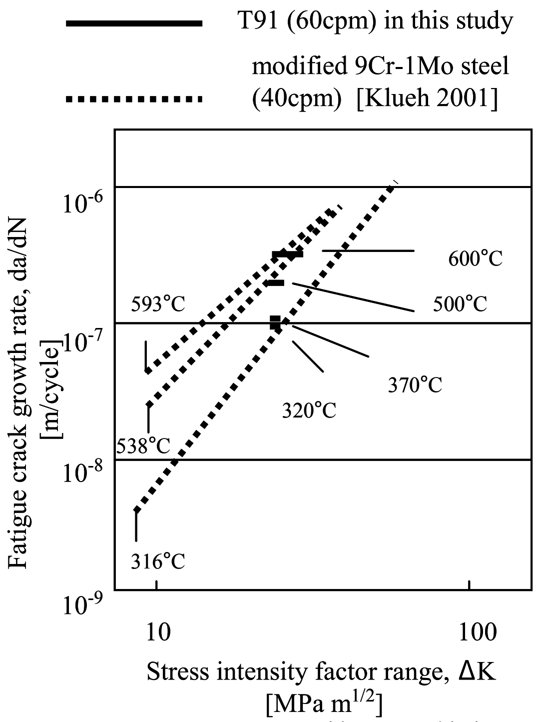

Figure 2. Comparison of fatigue crack growth rates of T91 with those of 9Cr steel from a literature [3].

(Direct current potential drop) technique. The results showed that there was no significant change in the FCGRs with the small ΔK change during the tests.

In the water environment, corrosion fatigue tests were performed at 370°C and 500°C. It has been known that, at a temperature condition just below the critical point, corrosion rates of materials are the highest [4]. For this reason, besides an SCW condition (500°C), 370°C was selected. During the tests, an abnormal loading had happened several times. The plots of load vs. time showed that during the cyclic loading the actual load had been held at the maximum value for several hours which might cause a pure stress corrosion cracking (SCC). Therefore, the FCGRs were calculated for two cases; i) assuming that the CGRs of the corrosion fatigue and SCC are in the same range and ii) assuming that a crack did not grow by the pure SCC condition. By this, the maximum (by the latter assumption) and minimum (by the former assumption) FCGRs could be determined.

Figure 3 shows the FCGRs estimated for the two cases. In this figure, the FCGRs were plotted as a function of 1/T and compared with those in air. The FCGRs between air and water could not be quantitatively compared due to the loading problem mentioned above. However, it is evident that the FCGR of T91 increased significantly in the water conditions. As summarized by Klueh [3], a cyclic strain rate in fatigue tests has a very small effect on the fatigue behaviors of 9Cr steels below 550°C. This draws a conclusion that the increase in the FCGR in the SCW condition is due to corrosion.

A study on the effect of the temperature on the corrosion of T91 is underway. Corrosion fatigue tests in the SCW condition are being performed.

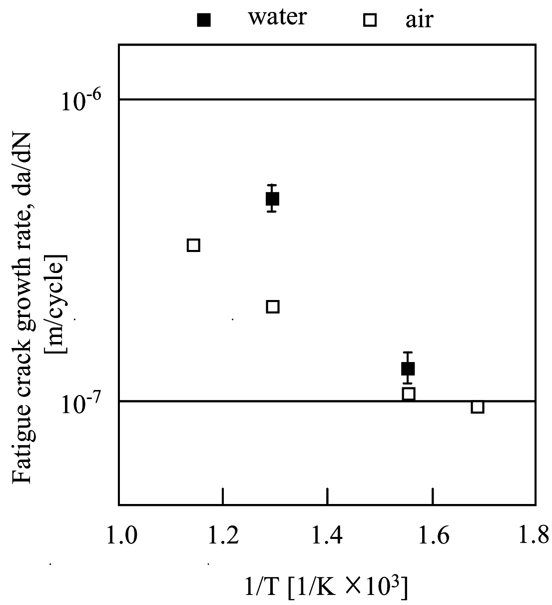

Figure 3. The Arrenius plot of da/dN vs. the reciprocal of temperature, 1/T.

3. Conclusion

Using ferritic/martensitic steel, T91, corrosion fatigue tests were performed in high temperature water conditions including supercritical water at 500°C. In the SCW condition, the fatigue crack growth rate of T91 was increased significantly by a corrosion. This suggests that a quantitative evaluation of the crack growth behaviors of the candidate materials of SCWRs should be performed for the material selection and component design.

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