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On the Effects of Temperature and Loading Frequency on the Fatigue Crack Growth Rate of G91 Steel

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1. Introduction

Mod.9Cr-1Mo steel (G91) is a promising structural material for high temperature components of a Sodium-cooled Fast Reactor and a Very High Temperature Reactor. It was selected as a material for components like heat exchanger for Korea Prototype Sodium cooled Fast Reactor (PGSFR) [1], Japan Sodium-cooled Fast Reactor (JSFR) [2], Indian Prototype Sodium Fast Reactor (PFBR) [3], and French Industrial Prototype Sodium Fast Reactor (ASTRID) [4]. G91 steel is a registered material in ASME Section III, Subsection NH[5] since 2004. The material data of fatigue crack growth and creep crack growth for robust structural integrity evaluations lacks in Subsection NH while it provides material properties of G91 steel for design purposes at high temperature conditions.

Creep-fatigue crack initiation and growth tests for a G91 tubular specimen, including a machined defect, have been performed by Kim[6] and it attempted to assess a high temperature crack behavior of G91 side plate specimen by Lee[7]. The fatigue crack growth tests of a G91 compact tension (CT) specimen were performed by Kim[8~11] at three different temperatures (500℃, 550℃, and 600℃), three loading frequencies (0.1Hz, 1Hz, and 20Hz), and two loading ratio values of 0.1 and 0.3, respectively; thus total 18 test conditions were applied. In this study, complementary tests were performed for selected 8 test conditions among total 18 test conditions to assess the effects of temperature and loading frequency on the fatigue crack growth rate of G91 steel and the test results were discussed.

2. Fatigue Crack Growth Tests

1/2” CT specimen, made of G91 steel, were used for fatigue crack growth tests as shown in Fig. 1 and ASTM E647 standard [12] was applied in this test. Table 1 shows the chemical composition of the G91 steel and the fatigue crack growth rates from a near threshold to K_{max} controlled instability were determined. A Chevron notch was prepared by electric discharge machining and a 3mm pre-crack was made according to the E647 standard.

DCPD (Direct Current Potential Drop) method was utilized to measure the crack growth size as shown in Fig. 2 and Fig. 3 shows the appropriate calibration curve which was obtained by applying the ASTM E647 procedure. Fig. 4 shows the FCG test facility of which capacity is 100kN.

In previous studies, fatigue crack growth tests were performed at three temperature values of 500℃, 550℃, and 600℃, respectively, by applying the load ratio of 0.1 and 0.3, respectively. And loading frequencies of 0.1Hz, 1Hz, and 20Hz were applied, respectively. Total 18 test conditions were applied so far and, in this study, complementary tests were performed for 8 test conditions as shown in Table 2 to assess the effects of temperature and loading frequency on the fatigue crack growth rates of G91 steel.

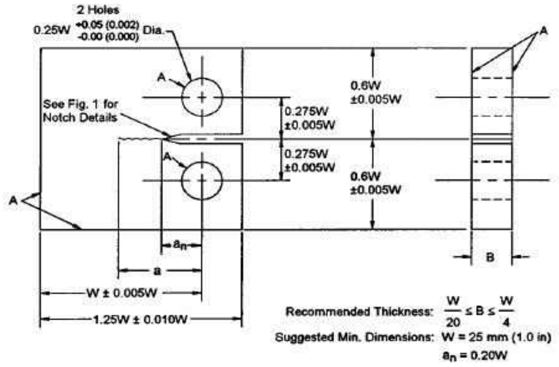

Fig. 1 CT specimen for the fatigue crack growth test

Table 1. Chemical composition of the G91 steel (wt.%)

C	Si	Mn	S	P	Cr	Mo	V	Nb	Al	Ni	N
0.1	0.41	0.4	0.001	0.013	8.49	0.94	0.21	0.08	0.01	0.1	0.06

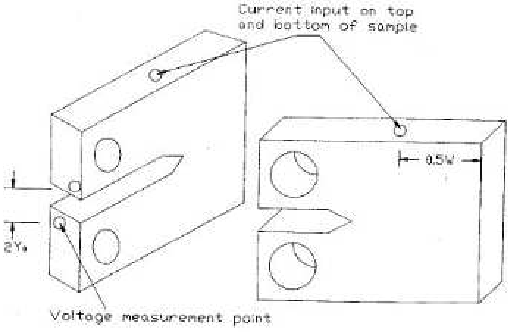

Fig. 2 Input Current and Voltage Lead Locations

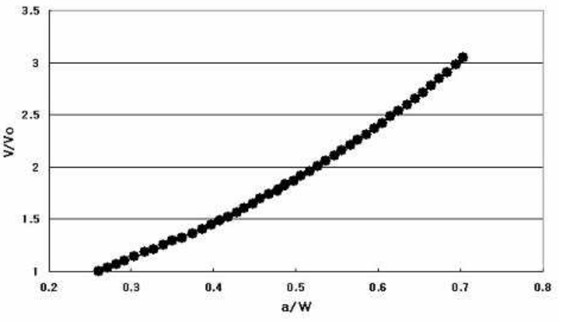

Fig.3 V/Vo-a/W calibration curve

Table 2. Test conditions for fatigue crack growth

Temp (℃)		500	550	600
0.1Hz	R=0.1	-	-	-
	R=0.3	O	-	-
1.0Hz	R=0.1	O	O	O
	R=0.3	-	O	O
20Hz	R=0.1	-	O	O
	R=0.3	-	-	-

Fig. 4 High temperature FCG test facility

Fig. 5 shows the crack growth rate with respect to $\triangle K$ for the load ratio of 0.1 by applying 3 different temperatures 500℃, 550℃, and 600℃, respectively, at 0.1Hz loading frequency.

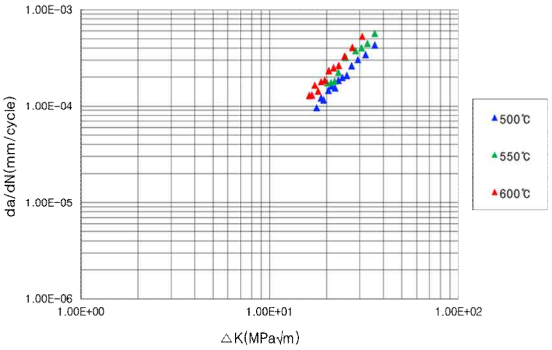

Fig. 5 da/dN-$\triangle K$ for various temperatures (load ratio of 0.1 at 0.1Hz)

Fig. 6 shows the crack growth rate with respect to $\triangle K$ for the load ratio of 0.3 by applying 3 different temperatures 500℃, 550℃, and 600℃, respectively, at 0.1Hz loading frequency. Blue square symbol, green triangle symbol, and red circle symbol indicate the result at 500℃, 550℃, and 600℃, respectively.

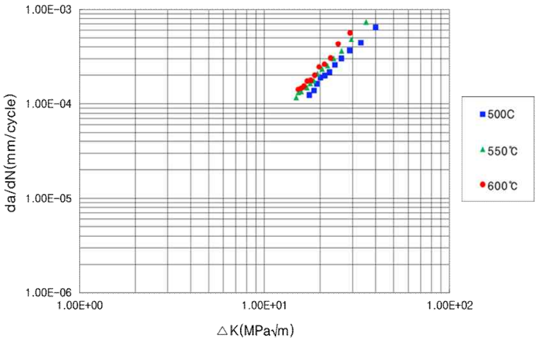

Fig. 6 da/dN-$\triangle K$ for various temperatures (load ratio of 0.3 at 0.1Hz)

Figs. 7~10 show the crack growth rate with respect to $\triangle K$ for the load ratio of 0.1 and 0.3 by applying 3 different temperatures 500℃, 550℃, and 600℃ at 0.1Hz, 1Hz, and 20Hz loading frequency, respectively.

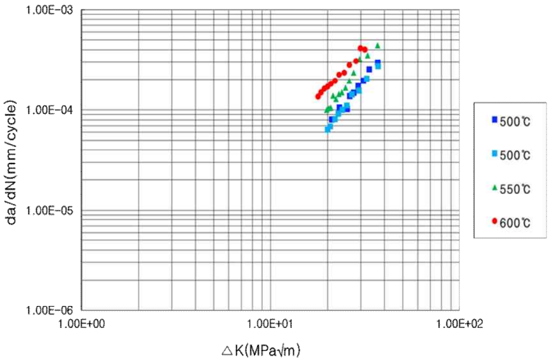

Fig. 7 da/dN-$\triangle K$ for various temperatures (load ratio of 0.1 at 1Hz)

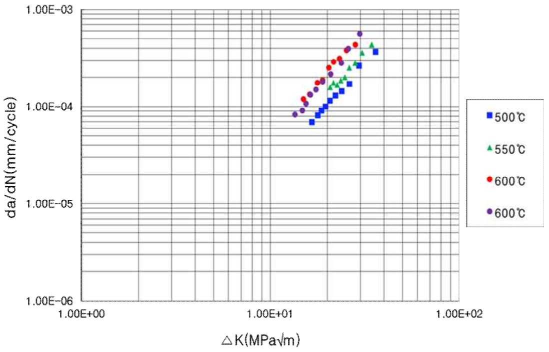

Fig. 8 da/dN-$\triangle K$ for various temperatures (load ratio of 0.3 at 1Hz)

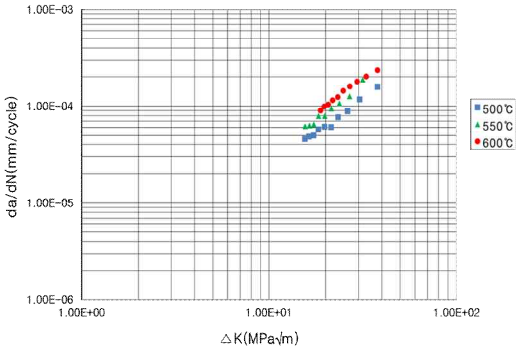

Fig. 9 da/dN-△*K* for various temperatures
(load ratio of 0.1 at 20Hz)

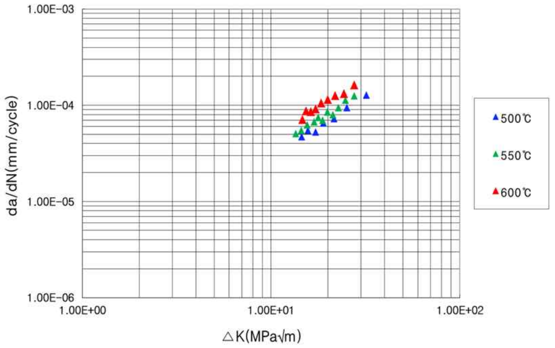

Fig. 10 da/dN-△*K* for various temperatures
(load ratio of 0.3 at 20Hz)

3. Results and Discussion

It is known that the fatigue crack growth rate increases as loading frequency decreases, as temperature increases, and load ratio (R) increases [13], it depends on the test conditions and relative sensitivity.

In this study, the fatigue crack growth tests for a G91 compact tension specimen were performed for a various loading frequencies, loading ratios, and temperatures. As shown in Fig.5 ~ Fig.10, it was confirmed that the fatigue crack growth rate increases apparently as temperature increases. The effects of loading frequency and load ratio were assessed by comparing above results and it was found that the fatigue crack growth increases as loading frequency decreases from 20Hz to 0.1Hz and load ratio increases from 0.1 to 0.3.

Collected data for high temperature fatigue crack growth of G91 steel would be utilized for the structural integrity assessment of SFR components.

Acknowledgement

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