The Effect of Temperature and Loading Frequency on the Fatigue Crack Growth of G91 Steel for Load Ratio of 0.3

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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 IHTS piping and heat exchangers for Korea demonstration Sodium cooled Fast Reactor as well as Japan Sodium-cooled Fast Reactor[1] after it became a registered material in ASME Section III, Subsection NH[2] in 2004. The material data of fatigue crack growth and creep crack growth for robust structural integrity evaluations lacks in Subsection NH while it provides some 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[3] and it attempted to assess a high temperature crack behavior of G91 side plate specimen by Lee[4]. The fatigue crack growth tests of a G91 compact tension (CT) specimen were performed by Kim[5, 6] at 20Hz and 0.1Hz loading frequencies, respectively. The effect of loading frequency on the behavior of high temperature fatigue crack growth was assessed for load ratio of 0.1 and at various temperatures 500℃, 550℃, and 600℃, respectively[7]. In this study, more tests were performed and the effect of loading frequency for load ratio of 0.3 and at various temperatures 500℃, 550℃, and 600℃ was assessed.

2. Fatigue Crack Growth Tests

Fatigue crack growth tests were performed using the 1/2” CT specimen shown in Fig. 1 by satisfying ASTM E647 standard [8] and the chemical composition of the G91 steel is shown in Table 1. The fatigue crack growth rates from a near threshold to a 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 and the appropriate calibration curve was obtained by applying the ASTM E1457 procedure[9]. Fig. 2 shows the FCG test facility of which capacity is 100kN.

In a previous study[7], fatigue crack growth tests were performed at three temperature values of 500℃, 550℃, and 600℃, respectively, by applying the load ratio of 0.1. Loading frequencies of 0.1Hz, 1Hz, and 20Hz were applied, respectively. In this study, fatigue crack growth tests were conducted at same temperature values and for same loading frequencies by applying the load ratio of 0.3. And then, the effect of loading frequency and temperature was assessed.

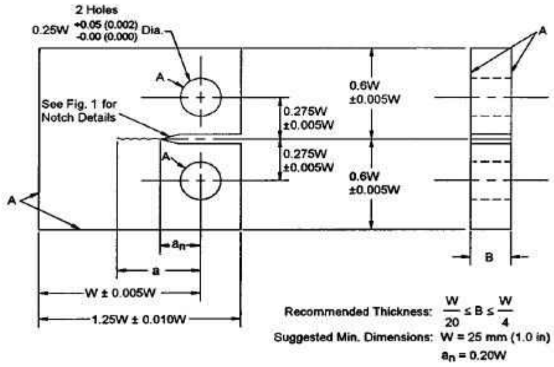

Fig. 1 CT specimen for the fatigue crack growth test

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 High temperature FCG test facility

Fig. 3 shows the crack growth rate with respect to $\triangle K$ for the load ratio of 0.3 by applying 3 different loading frequencies 0.1Hz, 1.0Hz, and 20Hz, respectively, at 500℃.

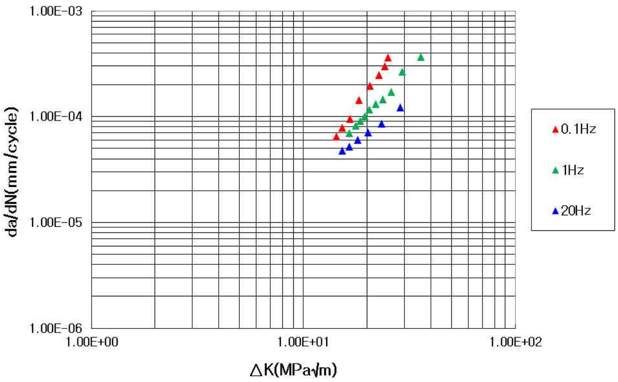

Fig. 3 da/dN-$\triangle K$ for various loading frequencies (load ratio of 0.3 at 500℃)

Fig. 4 and Fig. 5 show the crack growth rate with respect to $\triangle K$ at 550℃ and 600℃, respectively.

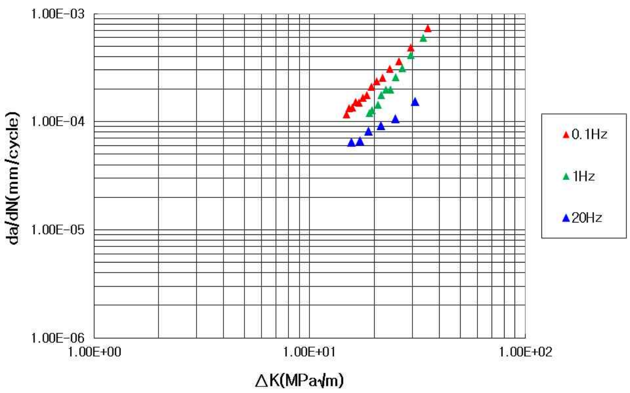

Fig. 4 da/dN-$\triangle K$ for various loading frequencies (load ratio of 0.3 at 550℃)

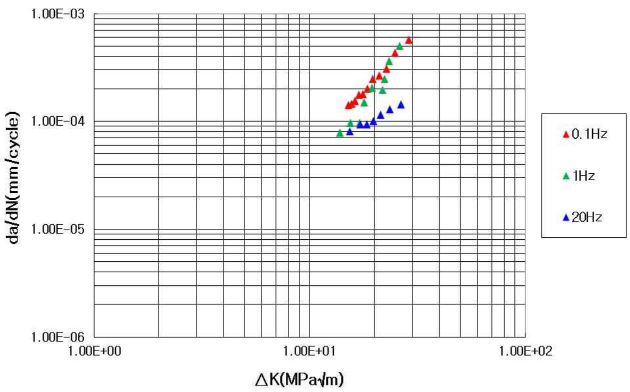

Fig. 5 da/dN-$\triangle K$ for various loading frequencies (load ratio of 0.3 at 600℃)

While it is known that the fatigue crack growth rate increases as loading frequency decreases, as temperature increases, and load ratio (R) increases[10], it depends on the test conditions and relative sensitivity. As shown in Fig.2 ~ Fig.4, the fatigue crack growth rate increases as loading frequency decreases and as temperature increases. The effect of load ratio was assessed by comparing above results from those of previous test results[7] and it was found that the fatigue crack growth increases as load ratio increases from 0.1 to 0.3.

3. Results and Discussion

The fatigue crack growth tests for a G91 compact tension specimen were performed for a various loading frequencies and at various temperatures. The effect of loading frequencies and temperatures on the fatigue crack growth behavior was reviewed and it was found out that the fatigue crack growth rate increases as temperature increases and the loading frequency decreases. It was also observed that the fatigue crack growth increases as load ratio increases.

Acknowledgement

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REFERENCES

[1] Kazumi Aoto, et.al. "JSFR Design Study and R&D Progress in the FaCT Project," Int'l Conf. on Fast Reactors and Related Fuel Cycles (FR09), Kyoto, 2009

[2] ASME Section III, Subsection NH, Class 1 Components in Elevated Temperature Service, 2004

[3] J.B.Kim, C.G.Park, H.Y.Lee, J.H.Lee, "Creep-fatigue Crack Initiation and Growth Tests for Mod.9Cr-1Mo Tubular Specimens," Trans. of the KNS Spring Meeting, 2009

[4] H.Y.Lee, J.B.Kim, J.H.Lee, "Assessment of High Temperature Crack Growth in Mod.9Cr-1Mo Steel Wide Plate," Proceedings of the KSME Spring Conference, 2010

[5] J.B.Kim, C.G.Park, H.Y.Lee, J.H.Lee, "High Temperature Fatigue Crack Growth Tests for Mod.9Cr-1Mo Compact Tension Specimen at 20 Hz Loading Frequency," Trans. of the KNS Autumn Meeting, 2010

[6] J.B.Kim, C.G.Park, H.Y.Lee, J.H.Lee, "High Temperature Fatigue Crack Growth Tests for Mod.9Cr-1Mo Steel at 0.1 Hz Loading Frequency," Trans. of the KNS Spring Meeting, 2011

[7] J.B.Kim, C.G.Park, H.Y.Lee, J.H.Lee, B.J.Kim"High Temperature FCG of G91 Steel for Different Frequencies," Trans. of the KNS Spring Meeting, 2012

[8] Standard test method for measurement of fatigue crack growth rate, ASTM Standard E647, pp. 578-614, 2002

[9] Standard test method for measurement of creep crack growth times in metals, ASTM Standard E1457-07, pp. 1-25, 2007

[10] R.Viswanathan, Damage Mechanisms and Life Assessment of High-Temperature Components, ASM International, 1989