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High Temperature Fatigue Crack Growth Tests for Mod.9Cr-1Mo Steel at 0.1 Hz Loading Frequency

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1. Introduction

Mod.9Cr-1Mo steel (G91) is adopted as the structural material for several high temperature components of a Sodium-cooled Fast Reactor[1] after it became a registered material in ASME Section III, Subsection NH[2] in 2004. It was chosen as a candidate for IHTS piping and heat exchangers used in KALIMER-600[3] as well as Japan Sodium-cooled Fast Reactor JSFR[4]. The material data of fatigue crack growth and creep crack growth for robust structural integrity evaluations is lack in ASME B&PV Code while Subsection NH provides some material properties of Mod.9Cr-1Mo 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[5] and it attempted to assess a high temperature crack behavior of Mod.9Cr-1Mo side plate specimen by Lee[6]. The fatigue crack growth tests of a Mod.9Cr-1Mo compact tension (CT) specimen were performed by Kim[7] at 20Hz loading frequency. In this study, the fatigue crack growth tests at 0.1Hz loading frequency, which is a feasible loading condition for SFR, have been conducted and reviewed.

2. Fatigue Crack Growth Tests

Fatigue crack growth tests have been performed using the 1/2" CT specimen shown in Fig. 1 by satisfying ASTM E647 standard[8] and the chemical composition of the Mod.9Cr-1Mo 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 precrack 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 the appropriate calibration curve was obtained by applying the ASTM E1457 procedure[9]. The relationship between the voltage output and the crack growth is shown in Fig. 3.

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 0.3 and 0.1, respectively, at 20Hz loading frequency. In this study, fatigue crack growth tests were conducted at 500℃, 550℃, and 600℃ by applying the load ratio of 0.3 and 0.1, respectively, at 0.1Hz loading frequency. The 0.1Hz loading frequency is considered as a feasible loading condition for high temperature SFR structures and it takes much longer time to obtain test results compared to the case of 20Hz loading frequency. Two specimens were tested for each condition except for the case of 600℃ and the load ratio of 0.3. More tests are in progress now.

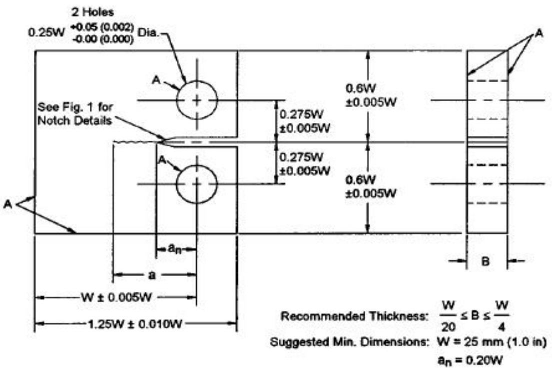

Fig. 1 CT specimen for the fatigue crack growth test

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

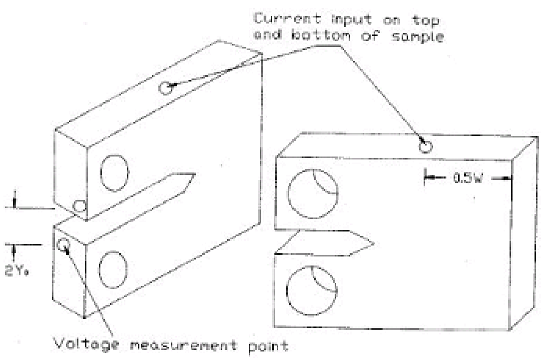

Fig. 2 Input current and voltage lead locations

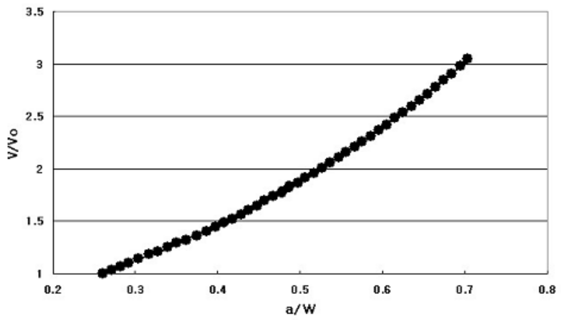

Fig. 3 V/Vo-a/W calibration curve

Fig. 4 shows the crack growth rate with respect to $\triangle K$ for the load ratio of 0.1 and Fig. 5 shows the results for the load ratio of 0.3.

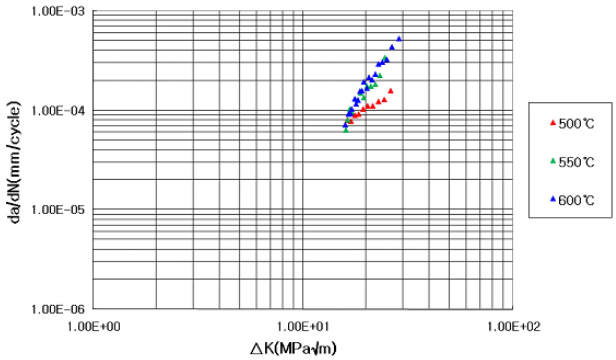

Fig. 4 da/dN-$\triangle K$ for the load ratio of 0.1 (0.1Hz)

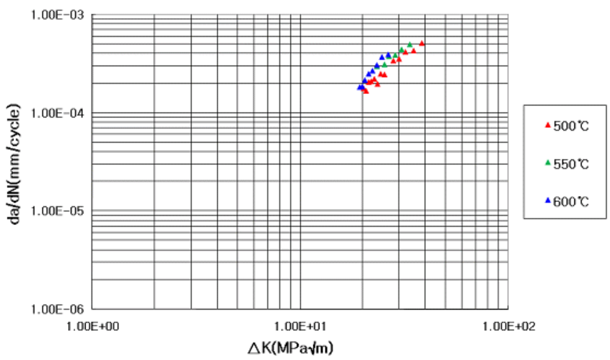

Fig. 5 da/dN-$\triangle K$ for the load ratio of 0.3 (0.1Hz)

Fatigue crack growth is often expressed as the Paris Law as shown in Eq. (1) and this can also describe the linear growth region. The crack growth speed (da/dN) as a function of $\triangle K$ obtained from the test results shown in Fig. 4 and Fig. 5 can be expressed as Eq.(1) and corresponding parameters C and m in the Paris Law equation are determined as shown in Table 2.

$$da/dN = C\left(\Delta K\right)^m \qquad (1)$$

Table 2. Comparison of fatigue crack growth rate equations for different load ratios of 0.1 and 0.3 (0.1Hz)

Stress ratio	Frequency (Hz)	Temperature (℃)	$da/dN = C(\Delta K)^m$
0.1	0.1	500	$da/dN = 2\times10^{-6}\Delta K^{1.40}$
		550	$da/dN = 1\times10^{-8}\Delta K^{3.13}$
		600	$da/dN = 1\times10^{-8}\Delta K^{3.21}$
0.3	0.1	500	$da/dN = 1\times10^{-6}\Delta K^{1.724}$
		550	$da/dN = 5\times10^{-7}\Delta K^{2.002}$
		600	$da/dN = 2\times10^{-7}\Delta K^{2.344}$

3. Results and Discussion

The fatigue crack growth tests for a Mod.9Cr-1Mo compact tension specimen were performed for a load ratio of 0.1 and 0.3, respectively, at high temperature conditions of 500℃, 550℃, and 600℃, respectively, at 0.1Hz loading frequency. Test results were reviewed and the corresponding crack growth speeds for each load ratio were obtained as a function of Δ K. It was found out that the fatigue crack growth speed increases as temperature increases, and the load ratio increases.

Acknowledgement

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