Effect of Loading Frequency on the Behavior of High Temperature Fatigue Crack Growth for Mod.9Cr-1Mo Steel

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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 lacks 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, 8] at 20Hz and 0.1Hz loading frequencies, respectively. In this study, the fatigue crack growth test at 1.0Hz loading frequency was performed and the effect of loading frequency on the behavior of high temperature fatigue crack growth 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 [9] 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 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[10].

In a previous study, 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. Loading frequencies of 20Hz and 0.1Hz were applied, respectively. In this study, fatigue crack growth test was conducted at 550℃ by applying the load ratio of 0.1 at 1.0Hz loading frequency. The effect of loading frequency was assessed and the test results were compared with those of RCC-MR A16[11].

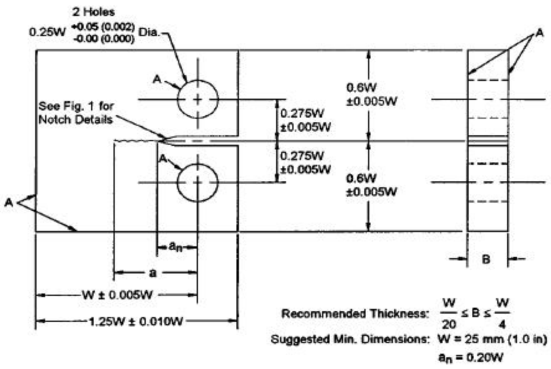

Fig. 1 CT specimen for the fatigue crack growth test

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 shows the crack growth rate with respect to $\triangle K$ for the load ratio of 0.1 by applying 3 different values of loading frequencies 0.1Hz, 1.0Hz, and 20Hz, respectively, at 550℃.

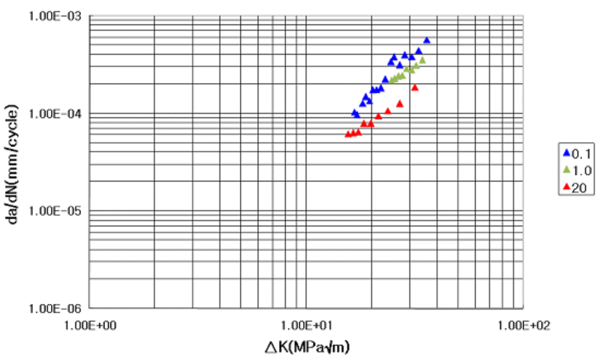

Fig. 2 da/dN-$\triangle K$ for various loading frequencies (load ratio of 0.1 at 550℃)

It is known that the fatigue crack growth rate increases as loading frequency decreases at high temperature while the effect of loading frequency is not significant at low temperature. As shown in Fig. 2, the fatigue crack growth rate increases as loading frequency decreases even though it is not clear to recognize the differences between the cases of 0.1Hz and 1.0Hz.

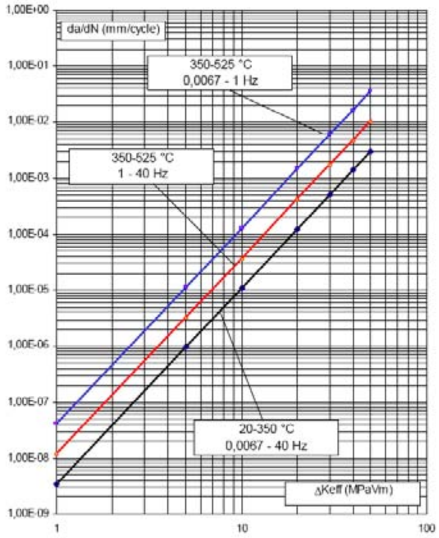

Fig. 3 da/dN-△K of RCC-MR A16 (2007Ed.)

Fig. 3 shows the fatigue crack growth rates of RCC-MR A16 for various conditions. Since it shows two curves at temperature range of 350℃~525℃ and applied loading frequency ranges are 0.0067~1Hz and 1~40Hz, it is not suitable to compare the current test results with those of RCC-MR A16 directly. The fatigue crack growth rate for 1.0~40Hz agree well with a current test result at 20Hz while the fatigue crack growth rate for 0.0067~1Hz is faster than a current test results at 0.1Hz and 1.0Hz.

Fatigue crack growth is expressed as the Paris Law as shown in Eq. (1) and this can also describe the linear growth region. The cyclic crack growth rate (da/dN) as a function of $\triangle K$ obtained from the test results 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. Fatigue crack growth rate equations

Stress ratio	Frequency (Hz)	Temperature (℃)	$da/dN = C(\Delta K)^m$
0.1	20	500	$da/dN = 1\times10^{-6}\Delta K^{1.29}$
		550	$da/dN = 2\times10^{-5}\Delta K^{0.54}$
		600	$da/dN = 1\times10^{-5}\Delta K^{0.69}$
0.3	20	500	$da/dN = 1\times10^{-6}\Delta K^{1.33}$
		550	$da/dN = 3\times10^{-6}\Delta K^{1.13}$
		600	$da/dN = 6\times10^{-6}\Delta K^{0.98}$
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	$da/dN = 2\times10^{-7}\Delta K^{2.344}$
0.1	1.0	550	$da/dN = 2\times10^{-6}\Delta K^{1.425}$

3. Results and Discussion

The fatigue crack growth tests for a Mod.9Cr-1Mo compact tension specimen were performed for a various loading frequencies. The effect of loading frequencies on the fatigue crack growth behavior was reviewed and the corresponding crack growth rates for each load ratio were obtained as a function of ΔK. It was found out that the fatigue crack growth rate increases as temperature increases and the load ratio increases at a specific loading frequency. At a specific temperature condition, the fatigue crack growth speed increases as a loading frequency decreases.

Acknowledgement

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