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High Temperature Fatigue Crack Growth Rate of G91 Steel with Applying 30 Seconds Hold Time

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1. Introduction

The Mod.9Cr-1Mo (G91) steel which was developed by ORNL at USA is an advanced material to be applied for the structures at high temperature condition in sodium-cooled fast reactor. It was selected as a material for components like heat exchanger for Prototype Gen-IV 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 database of creep and creep-fatigue crack growth rate of G91 steel is necessary for the structural integrity evaluation of the SFR structures because the database of these properties of materials is insufficient through the world. Moreover, it is difficult to use the database which is gained by the research center of advanced countries because it is not to be opened.

Therefore, it is necessary to make an effort to get the database of material properties. 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] 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.

In this research, the creep-fatigue crack growth rate tests were performed using trapezoid loading condition of G91 steel with applying 30 seconds of hold time to make a database of the material.

2. Fatigue Crack Growth Tests

1/2" CT specimen, made of G91 steel, were used for creep-fatigue crack growth tests as shown in Fig. 1 and ASTM E647 standard [9] 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 creep-fatigue crack growth (CFCG) test facility of which capacity is 100kN.

Creep-fatigue crack growth rate tests using trapezoidal loading by applying the holding time were performed to measure the da/dN-ΔK curves of G91 steel. Test conditions of creep-fatigue crack growth rate test at high temperature are as follow.

- Temperature : 500, 550, 600℃
- Stress ratio : 0.1 (loading frequency : 1 Hz)
- Holding time : 30 sec.

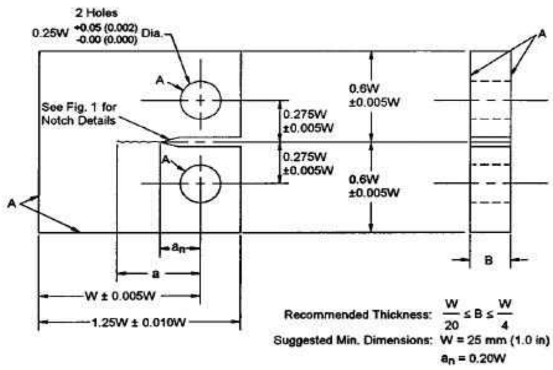

Fig. 1 CT specimen for the creep-fatigue crack growth test

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

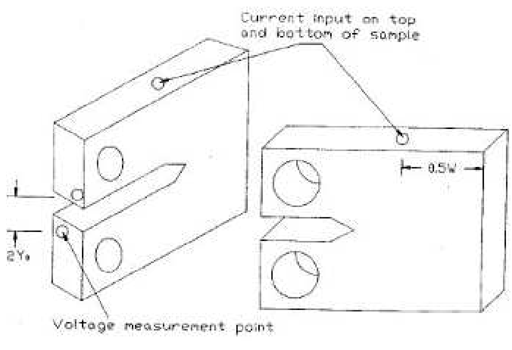

Fig. 2 Input current and voltage lead locations

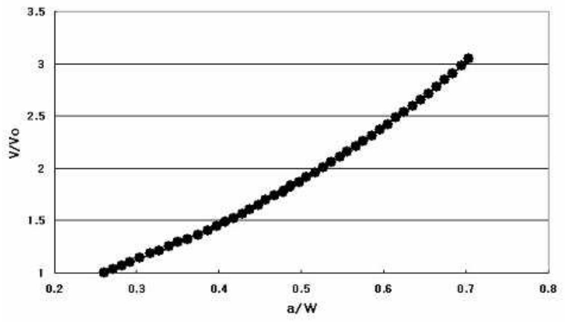

Fig. 3 V/Vo-a/W calibration curve

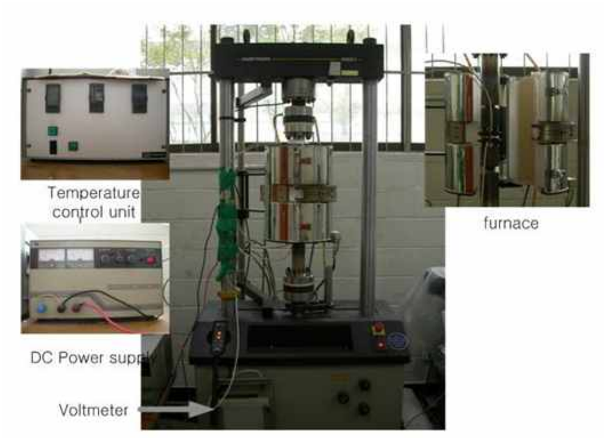

Fig. 4 High temperature creep-fatigue crack growth test facility

Fig. 5 ~ Fig.7 show the crack growth rates with respect to $\triangle K$ for the load ratio of 0.1 by applying 3 different temperatures 500℃, 550℃, and 600℃, respectively.

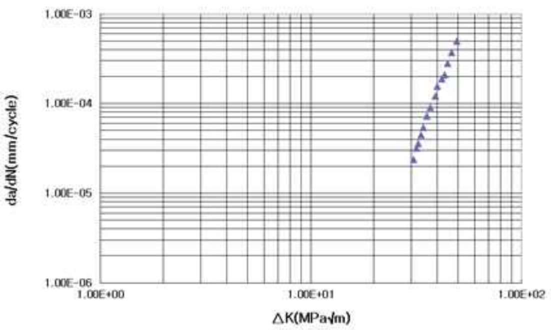

Fig. 5 da/dN-$\triangle K$ at 500℃

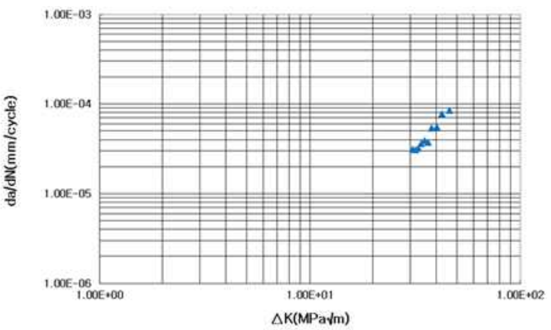

Fig. 6 da/dN-$\triangle K$ at 550℃

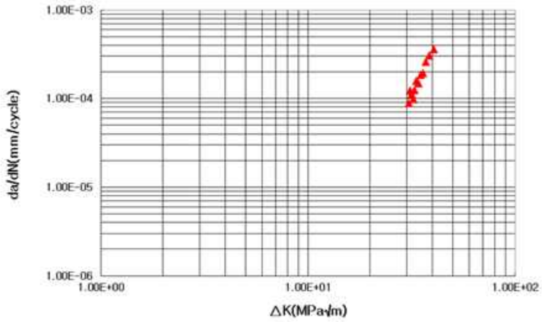

Fig. 7 da/dN-$\triangle K$ at 600℃

Fig. 8 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. Blue symbol, black symbol, and red symbol in Fig. 8 indicate the result at 500℃, 550℃, and 600℃, respectively.

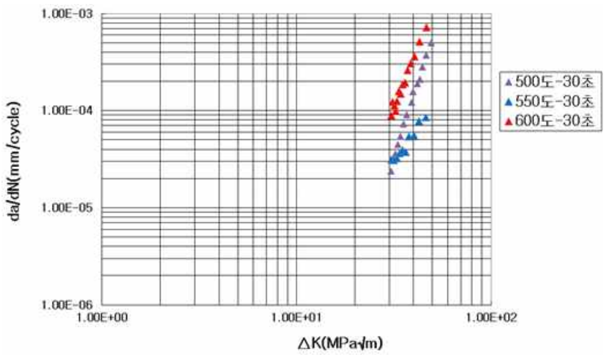

Fig. 8 Comparisons of da/dN-$\triangle K$ at various temperatures

3. Results and Discussion

In this research, the creep-fatigue crack growth rate properties of G91 steel were studied by applying 30 second of holding time. Creep-fatigue crack growth rate were compared in terms of different temperature range. Tests were performed at temperatures of 500, 550 and 600℃, respectively. Stress ratio was set to 0.1 and trapezoidal shape of stress condition was applied to the specimens to perform the creep-fatigue crack growth rate tests. Each specimen's surface was polished and fatigue pre-crack was manufactured by fatigue test before the high temperature test. And DCPD method was adopted to measure the crack length in the high temperature.

As a result, da/dN-ΔK curves and Paris law were carried out from creep-fatigue crack growth tests. Crack growth rate was faster and the slope of da/dN-ΔK curve at steady-state crack growth rate range was higher as temperature increases, because micro void by creep damage was accelerated at high temperature. In addition, fatigue life was decreased by increasing of plastic deformation zone range at high temperature.

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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