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Creep-fatigue Crack Initiation and Growth Tests for Mod.9Cr-1Mo Tubular Specimens

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1. Introduction

Mod.9Cr-1Mo steel (G91) is the currently favored structural material for several high temperature components of a Sodium-cooled Fast Reactor[1] and it became a registered material for ASME Section III, Subsection NH[2] in 2004. The preliminary tests of a creep-fatigue crack initiation and growth for a G91 tubular specimen including a machined defect have been performed by Kim[3].

In this study, creep-fatigue crack initiation and growth tests were performed for 15 tubular specimens and the test results were reviewed.

2. Test Procedures

A creep-fatigue crack initiation and growth test facility was established and the tests for the Mod.9Cr-1Mo tubular specimen have been carried out. The test facility was installed as shown in Fig. 1. It is composed of three sections; i.e., a 100kN hydraulic actuator system, a 10kW induction heating and cooling system, and a measurement system.

Fig. 1 A creep-fatigue crack test facility

A Mod.9Cr-1Mo tubular specimen was machined of which outer diameter and thickness are 11mm 1mm, respectively, following the ASTM standard E2207[4] and E2368[5] procedures. A through-wall defect was prepared by an electric discharge machining along the circumferential direction to obtain a crack initiation and growth development ahead of a defect front. Its width and corner radius were 0.18mm and 0.1mm, respectively, and different values of the defect length were considered as 2mm and 3mm. The chemical composition of specimen is shown in Table 1.

Table 1 Chemical composition of specimen (wt%)

C	Si	Mn	P	S	Cr	Ni	Mo	N	V	Nb
0.08 – 0.12	0.20 – 0.50	0.30 – 0.60	Max. 0.025	Max. 0.025	8.00 – 9.50	Max. 0.40	0.85 – 1.05	0.03 – 0.07	0.18 – 0.25	0.06 – 0.10

Fig. 2 Schematic of tubular specimen with a defect

Seven channels of K-type thermocouples were spot welded along the center region of a specimen to acquire and control the temperature of the test specimen as shown in Fig. 2. A thermal load was applied to the center region of the test specimen by using a high-frequency induction heater. It took about 30 seconds for the temperature of the test specimen to reach 550℃ and the thermal load was controlled to maintain the temperature of the test model at 550℃ for 5 minutes, and then removed. One loading cycle took 7 minutes and a test was continued until a specimen ruptured.

Three different values of a tensile loading were applied; i.e., 6.5kN, 8.0kN, and 9.4kN. Tensile load was increased to its maximum value for 30 seconds, maintained for 5 minutes, and removed in a phase with a thermal loading.

Long working distance zoom microscope system with a maximum magnification ratio of 325 times at a distance of 285 mm was used to monitor the crack initiation and growth behavior ahead of a defect front in real-time. KON-Measure program was utilized to save photos at certain intervals. And a DCPD (Direct Current Potential Drop) measurement system was installed to measure the voltage drop across a defect as a crack grows. The capacity of the power supply was 5A and a nonresistance nickel wire was spot welded across a defect of the specimen to measure the voltage drop. High temperature extensometer, whose gage length is 12.5mm, was installed by a ceramic cord to measure the strain changes.

3. Test Results and Discussions

Creep-fatigue crack initiation and growth tests have been in progress. Seven tests and eight tests of a tubular specimen with a 2mm long defect (CF2-Tx) and a 3mm long defect (CF3-Tx), respectively, were finished and the corresponding number of rupture cycles is quite different among them as shown in Table. 2.

Table 2 Creep-fatigue crack tests for the tubular specimens

Specimen (*a*=2mm)	Load (kN)	Rupture Cycle	Specimen (*a*=3mm)	Load (kN)	Rupture Cycle
CF2-T1	6.5	17	CF3-T1	6.5	95
CF2-T2	6.5	8030	CF3-T2	6.5	8
CF2-T8	8	48	CF3-T3	6.5	570
CF2-T9	8	333	CF3-T5	6.5	365
CF2-T10	8	161	CF3-T6	8	216
CF2-T6	9.4	15	CF3-T8	8	104
CF2-T7	9.4	14	CF3-T9	9.4	7
			CF3-T10	9.4	7

Fig. 3 and Fig. 4 show the evolutions of the crack growth emanating from the edge of a defect for the tubular specimen with a 2mm long defect and the tubular specimen with a 2mm long defect, respectively.

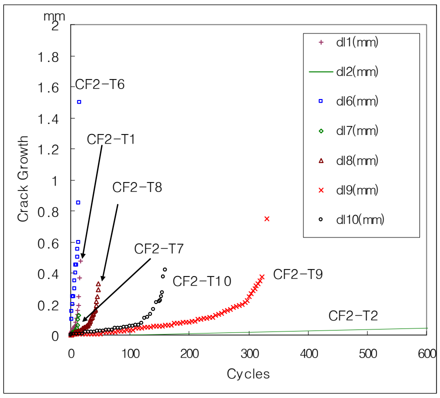

Fig. 3 Crack length growth of the 2mm defect specimens

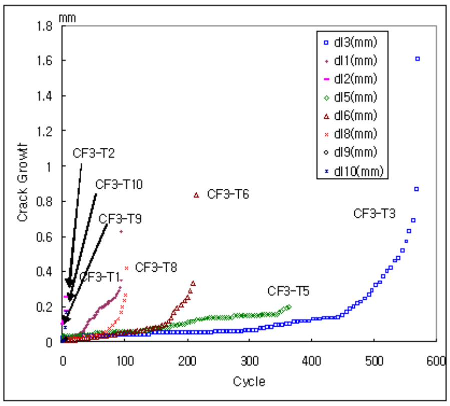

Fig. 4 Crack length growth of the 3mm defect specimens

In this study, it is premature to treat the test results since more tests are under way. The collected data such as the DCPD voltage output, strain gage output, captured images, and the longitudinal displacement are now under examination. Among the collected captured images, Fig.5 shows the defect area before the test with the CF2-T10 specimen and Fig. 6 shows the instable crack growth at 161 cycles just before immediate rupture.

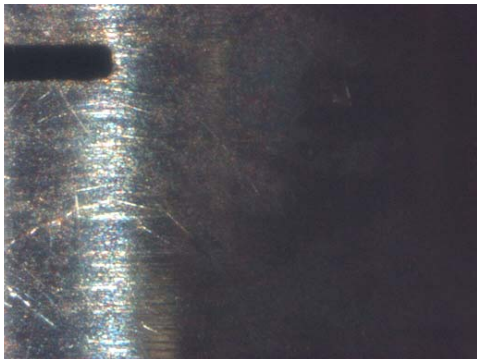

Fig.5 Defect area at the start of the test for CF2-T10 (x120)

Fig.6 Instable crack growth at 161 cycles for CF2-T10 (x120)

These test results would be used to validate the creep-fatigue crack initiation and growth evaluation methodology for Mod.9Cr-1Mo structures which has been in progress in parallel with the test efforts. This will contribute to the development of a high temperature leak before break assessment for a Mod.9Cr-1Mo steel pipe in a SFR.

Acknowledgement

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