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Preliminary Tests of a Creep-fatigue Crack Initiation and Growth for a G91 Tubular Specimen with a Defect

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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. However, the material properties for Mod.9Cr-1Mo at elevated temperatures are not enough at this stage. In particular, it is not feasible to conduct a high temperature leak before break and flaw assessment for Mod.9Cr-1Mo structures due to the lack of material data concerning its fracture toughness, fatigue crack growth, creep crack growth, and creep-fatigue crack growth at elevated temperature conditions and the assessment technologies are not accomplished yet.

In this study, a creep-fatigue crack initiation and growth test facility was established and corresponding tests for Mod.9Cr-1Mo tubular specimen were carried out.

2. Test Facility and Preparation

A creep-fatigue crack initiation and growth test facility was installed as shown in Fig. 1. It is composed of three sections; i.e., (1) 100kN hydraulic actuator system, (2) 10kW induction heating and cooling system, and (3) measurement system.

Fig. 1 A creep-fatigue crack test facility

The material used in this study was Mod.9Cr-1Mo steel and its chemical composition is shown in Table 1. A creep-fatigue crack initiation and growth test specimen was aligned in the rolling direction and machined into a tubular shape with a 11mm outer diameter and a 1mm thickness according to ASTM standard E2207[3] and E2368[4] as shown in Fig. 2.

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

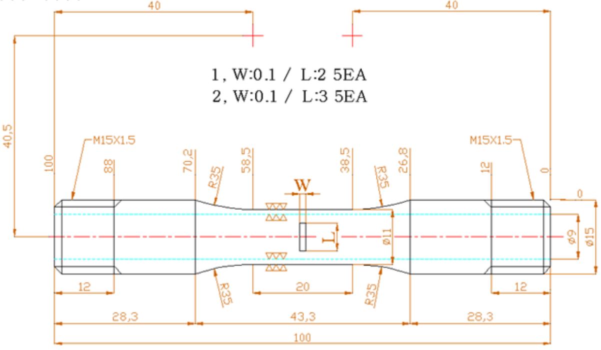


Fig. 2 Schematic of tubular specimen with a defect

Five 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. 3. 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 length are 0.18mm and 3mm, respectively, and the corner radius is 0.1mm.

Fig. 3 Measurement system arrangement

Tensile load was increased to 6.5kN for 30 seconds, maintained for 5 minutes, and removed. At the same time, a thermal load was applied to the center region of the test specimen by using a high-frequency induction heater. It took 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 cycle of a loading took 7 minutes and a test continued until the specimen broke off.

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 as shown in Fig. 3. And a DCPD (Direct Current Potential Drop) measurement system was installed to measure a voltage drop across the defect as a crack grows. The capacity of a power supply is 5A and a nonresistance nickel wire was spot welded across a defect of a specimen to measure a 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 for five specimens were preliminary conducted to confirm the adequacy of the test facility, test specimen and measurement system. The number of rupture cycles is quite different among them as shown in Fig. 4 even though the same test conditions were applied.

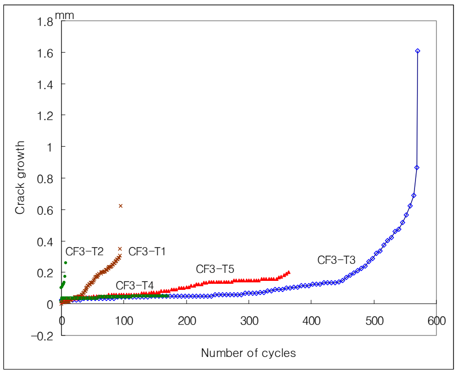


Fig. 4 Crack growth behaviors of five specimens

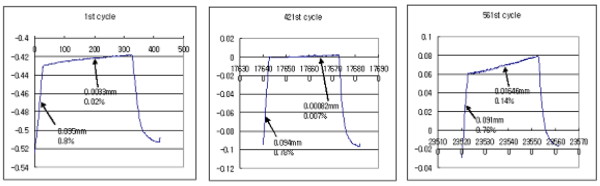
The first and second specimens broke off suddenly at the 95th and 7th cycles of a test, respectively, and the cause of the early rupture seems to be a poor alignment of the specimens. The third, fourth, and fifth specimens show rather consistent crack growth behavior until the rupture of the fourth specimen (170th cycles) and the fifth specimen (365th cycles). The third specimen (CF3-T3) showed a typical creep crack growth behavior throughout the 570th cycles of a test. The reason for an early rupture of the fourth and fifth specimens might be the interruption of the hydraulic actuator, mal-functioning of the actuator to induce a prompt increase of a tensile loading due to an uncertain reason, or the material characteristics having irregular fracture toughness. More efforts are necessary to analyze the cause of the wide range of rupture lives.

Fig. 5(a) shows the initial shape of a defect front. A 0.3mm length crack initiated after the 500th cycles of testing and grew to 0.65mm after 560th cycles of a test as shown in Fig. 5(b) which is magnified by 120 times. This crack grew to 1.6mm during the last 10 cycles of a test and it ruptured at the 570th cycle as shown in Fig. 5(c) which is magnified by 30 times.

(a) Start(1st) (b) Growth (560th) (c) Rupture(570th)

Fig. 5 A crack initiation and growth to a rupture (CF3-T3)

While the measured voltage changes using the DCPD system is under interpretation, the collected strain data by the extensometer is shown in Fig. 6. As seen in Fig. 6(a), 0.02% creep strain occurs during first cycle hold time which shows a primary creep behavior and it becomes close to a steady state creep behavior as a cycle continues. In the 421st cycle hold time, a 0.007% creep occurs and it became tertiary creep from the 561st cycle as shown in Fig. 6(c). 0.14% of creep strain occurs during the 561st cycle hold time and it is recognized that this creep is a dominant deformation mechanism in this test.



(a) Primary(1st) (b) Steady (421th) (c) Tertiary(561th)

Fig.6 Extensometer measurements (CF3-T3)

By reviewing the five preliminary creep-fatigue crack initiation and growth test results, a test facility will be tuned and adjusted to produce reliable results and further specimens will be tested in due sequence. Those test results would be used to validate the creep-fatigue crack initiation and growth evaluation methodology for Mod.9Cr-1Mo structures. This will contribute to the development of a high temperature leak before break assessment for a Mod.9Cr-1Mo pipes in a SFR.

Acknowledgement

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