

Evaluation and Test of a Crack Initiation for a 316SS Cylindrical Y-junction Structure in a Liquid Metal Reactor

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1. Introduction

KALIMER-600(Korea Advanced LIquid MEtal Reactor, 600MWe)[1] which has been developed at the Korea Atomic Energy Research Institute(KAERI) is a pool type sodium-cooled liquid metal reactor. It is normally operated in the condition of a high temperature above 500 and a low pressure under 10 bars. The major structures such as a reactor vessel are designed as thin shell structures to reduce the influence of thermal loadings. Defects can be included in the structure material or created in the manufacturing and fabrication procedures. These defects can be initiated and propagated under the cyclic loading condition during the reactor operation. Through wall defects induce a sodium leak or a structural instability of the thin structure. So the defect front behavior has to be investigated.

In this paper, the creep-fatigue crack initiation evaluation of a circumferential through wall defect with the FE(Finite Element) analysis result was carried out by the RCC-MR[2] A16[3] guide. The FE stress analysis was performed to characterize the stress distribution near the defect front of a 316SS cylindrical Y-junction structure. With this result, the cycle number of a crack initiation was calculated. Additionally, a high temperature creep-fatigue crack initiation test was performed. The defect front was observed with an optical microscope and it was compared with the A16 evaluation result after the 100th cycle.

2. Creep-Fatigue Crack Initiation

2.1 Crack Initiation Model

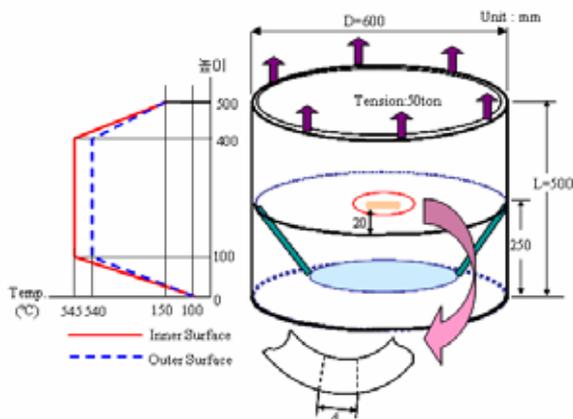


Figure 1. Crack initiation evaluation model

Fig.1 shows the crack initiation evaluation model. The model is a cylindrical structure with a welded Y-junction simulating the reactor baffle structure. The structure is made of 316SS and the thickness, outer diameter and height of the cylinder are 5mm, 600mm, 500mm, respectively. The crack is penetrating the wall, 20mm in length and 0.25mm in corner radius and arranged in the circumferential direction at 230mm from the upper surface of the model.

The loading condition is composed of both a thermal loading and a mechanical loading. The mechanical loading is an axial tensile load simulating the dead weight. The cyclic axial tensile load is increased to 50ton for a 10 seconds startup, maintained for 1hour and removed. The thermal load also has a cyclic history as shown in Fig.2. The temperature difference between the inner surface and the outer surface is approximated as 5 as shown in Fig.1.

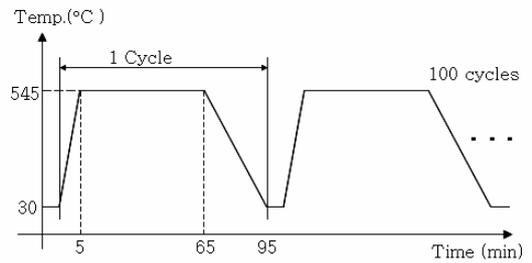


Figure 2. Temperature loading history

2.2 Evaluation per RCC-MR A16

The creep-fatigue crack initiation is assessed based on the σ_d method[4]. The σ_d method consists of the fatigue usage fraction(A) and the creep usage fraction to a rupture(W) as shown in equation (1),(2).

$$A_i = \frac{n_i}{N_{ai}}, \quad W_i = \frac{t_i}{T_i} \quad (1), (2)$$

To calculate the fatigue usage fraction for the model, the total real strain range has to be calculated as shown in equation (3).

$$\Delta \varepsilon = (\Delta \varepsilon)_{el+pl} + \Delta \varepsilon_{cr} \quad (3)$$

In equation (3), the elastic plus plastic strain range, $(\Delta \varepsilon)_{el+pl}$ can be obtained by using the sum of the four strain components as shown in equation (4).

$$(\Delta \varepsilon)_{el+pl} = \Delta \varepsilon_1 + \Delta \varepsilon_2 + \Delta \varepsilon_3 + \Delta \varepsilon_4 \quad (4)$$

where, $\Delta \varepsilon_1, \Delta \varepsilon_2, \Delta \varepsilon_3, \Delta \varepsilon_4$ represent the strain ranges defined in A16[3].

To calculate the elastic stress range $\Delta\sigma_{de}$ at the crack front at the distance $d=0.05mm$ for the evaluation model, FE analysis was carried out as shown in Fig.3 by using the ANSYS 9.0 software[5]. In the FE analysis, a 1/4 axisymmetric modeling is applied. From the FE analysis result as shown in Fig.3, $\Delta\sigma_{de}$ is 819.4MPa and the strain range $(\Delta\varepsilon)_{el+pl}$ is 1.059%.

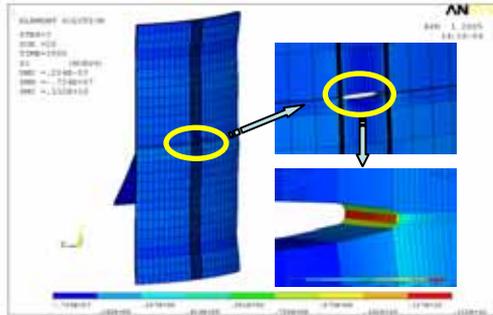


Figure 3. FE analysis result

The creep strain is obtained by equation (5). The coefficients C_1 , C_2 and n_1 are the values from the function of the temperature given in table A3.63[2].

$$\Delta\varepsilon_{cr} = C_1 \cdot t^{C_2} \cdot \sigma^{n_1} \quad (5)$$

The creep strain $\Delta\varepsilon_{cr}$ is 0.076% and therefore the real strain range $\Delta\varepsilon$ in equation (4) is 1.135%. From this, the fatigue usage fraction and creep usage fraction are calculated as shown in equation (6), (7) respectively.

$$A = \frac{n}{241}, W = \frac{t}{125} \quad (6), (7)$$

From equations (6) and (7), the crack initiation evaluation point (A,W) is located along the path(O-P) in the creep-fatigue interaction diagram as shown in Fig.4. The point J located at (0.004,0.008) is the evaluated position for a 1st cycle. The crack is initiated at the point I where the path(O-P) intersects with the diagram curve(C-D). Therefore, the creep-fatigue crack for this model would initiate in 57 cycles and 57 hours of a high temperature hold time.

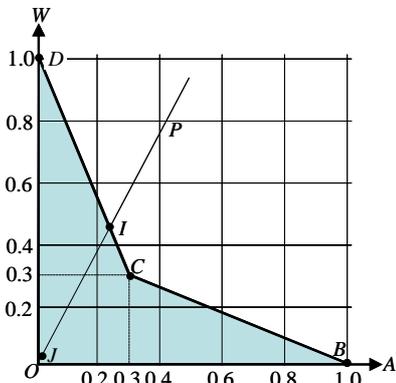


Figure 4. Evaluation result of crack initiation

2.3 Test of Crack Initiation

The creep-fatigue crack initiation test was carried out on a cylindrical Y-junction structure of 316SS containing a circumferential through wall defect subjected to cyclic axial tensile loads with 1hr of a hold time at a temperature of 545 as shown in Fig.1 and Fig.2. Fig.5 shows the vicinity of the defect front after the 100th cycle, magnified 350 times. A minute crack initiation occurred along the grain boundary.

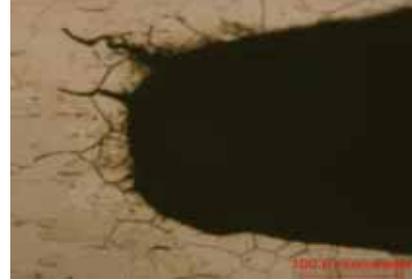


Figure 5. Defect front after 100th cycle($\times 350$)

3. Conclusion

In this study, an evaluation and the test of the creep-fatigue crack initiation for a 316SS Y-junction structure with a circumferential through wall defect were carried out. The creep-fatigue crack initiation by the RCC-MR A16 procedure was evaluated by the σ_d method which can be induced from the FE analysis and the real strain range $\Delta\varepsilon$ at a distance d from the crack tip. The evaluation result for the model shows that the creep-fatigue crack was initiated after about 57 cycles. An experimental test was performed to compare it with the evaluation result. After the 100th cycle, the defect front was investigated and a crack initiation had occurred.

From this result, it is confirmed that the creep-fatigue crack initiation for a high temperature structure can be predicted properly according to the RCC-MR A16 guide.

ACKNOWLEDGMENTS

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