Evaluation of the Creep Fatigue Crack Growth for the Cylindrical Specimen containing the Defects

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1. Introduction

In this paper, the evaluation of the creep fatigue crack growth for a welded cylindrical shell specimen has been carried out according to the defect assessment procedure of RCC-MR A16.

2. Methods and Results

2.1 Creep Fatigue Crack Initiation

The creep-fatigue crack initiation is based on the σ_d method like the fatigue crack initiation. The principle of this procedure is also to determine a stress and strain at a characteristic distance d from the crack tip and to compare them with usual material fatigue and creep data. An estimation of the fatigue damage usage factor is given by the ratio of the specified number of cycle n to the number of cycle prior to fatigue initiation N. This procedure is based only on K_I formulae and engineering rules and does not need the specific fracture mechanics material data except for the distance d. From the material fatigue curve, an estimation of the number of cycles prior to initiation N is made at the actual strain range $\Delta\varepsilon_d$ at the distance d from the defect allowing for strain amplification due to plasticity, and divided by 1.5[1].

An estimation of the creep damage usage factor is given by the ratio of the specified duration of the holdtime t to the time prior to creep initiation T obtained from to the usual creep rupture properties S_r and corresponding to the stress σ_d during the holdtime at the distance d from the defect.

2.2 Creep Fatigue Crack Propagation

The purpose of this analysis is to estimate the geometry of the defect at instant t_f using the given its geometry at instant t_o and number of occurrences of the each cycle. The following procedure calculates the fatigue propagation and creep propagation of the defect for each cycle of type i. The final size of the defect at the instant t_f is obtained by adding together the propagation obtained for all cycles corresponding to the different types of cycles. The updated size of the defect is $a + (\delta a_{fa}) + (\delta a_{fl})$.

2.2.1 Fatigue Crack Propagation

The fatigue crack growth is estimated from the Paris law of the material with a stress intensity factor range ΔK_{eff} derived from a simplified estimation of the cyclic J and
ΔJ during the cycle and a factor q for closure effects

$$\Delta K_{eff} = q\sqrt{E^*\Delta J}$$

E^*: E^* value used to calculate ΔJ_s
R : Load ratio
q : Closure($R < 0$) and mean stress($R > 0$) coefficient.

Depending upon the specified number of occurrences n_i, the propagation of the defect $(\delta a)_i$ is determined using the propagation law given for the specified material[2,3]:

$$\frac{da}{dN} = C[\Delta K_{eff}]^n$$

$$\delta a = \sum_{N=0}^{n_i} C[\Delta K_{eff}]^n$$

2.2.2 Creep Crack Propagation

The creep crack growth rate is here derived from a C^* evaluation based on the reference stress concept and the da/dt - C^* material curve.

. Calculation of creep propagation
- Calculate $C^*(t)$ during the holdtime
- Calculate the propagation of the defect due to creep during the holding time t_m taking account of the updated time and using the propagation law for the specified material[4]

$$(\delta a_i) = \int_{t_i}^{t_i+t_m} A(C^*(t))^q \, dt$$

2.3 Experiments

The structural specimen is made of 316L stainless steel(SS) for one half of the cylinder and 304 SS for the other half. The thermocouples were attached along the inner surface of the cylinder and the temperature history was measured as shown in Fig. 1. The measured data shows that the temperature of the mid part of the cylinder is about 600°C and those of the lower and upper parts are relatively low as shown in Fig. 2. In the creep-fatigue test, the hold time under a tensile load which produces the primary nominal stress of 45MPa was one hour at 600°C and creep-fatigue loads of 600 cycles were applied.

2.4 Results

In the cylindrical shell specimen, eight defects near the weld were machined as shown in Fig. 3. The amount of the creep fatigue crack growth was evaluated for the defect ⑦ as shown in Fig. 1. The amount of the fatigue crack growth per one cycle with relation to the base metal is 0.00129 and the amount of the creep crack growth for 1 hour of the hold time is 0.169. In the creep fatigue crack growth for the weld metal of the defect ⑦, the amount of the fatigue crack growth per one cycle is 0.00125 and the amount of the creep crack growth for 1 hour of the hold time is 0.119. Also, the creep fatigue crack propagation was observed by the optical microscope in the defect ⑦ machined on the weld. The length of the observed crack propagation was 0.6mm as shown in Fig. 3.

3. Conclusion

The evaluation results for the creep-fatigue crack propagation were compared with those of the observed images from the structural test. The results of the creep fatigue crack growth were calculated much larger than those of the experiments. Thus, the results for the creep fatigue crack growth in case of the short hold time according to RCC-MR A16 procedure were evaluated to be very conservative.

Acknowledgements

This work has been carried out under the Nuclear R&D Program by MOST in Korea.

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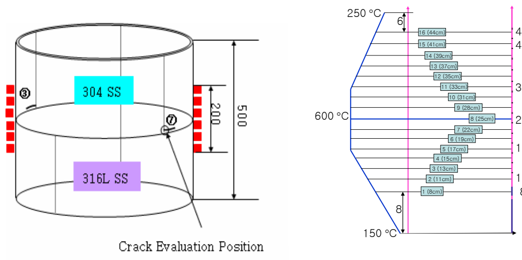

Fig. 1 The position of the defects and thermocouples for the cylindrical shell specimen

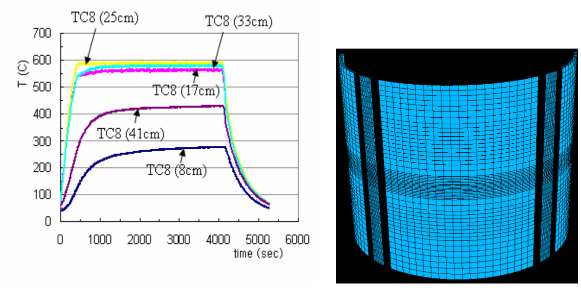

Fig. 2 Distribution for the measurement temperature of thermocouples and the finite element model

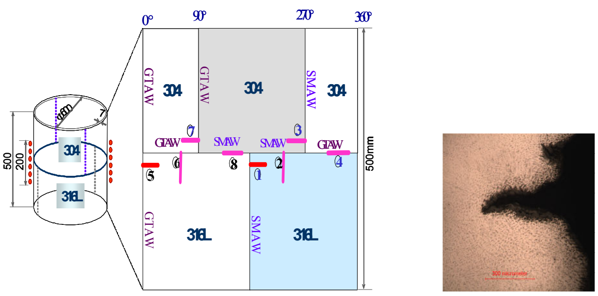

Fig. 3 Cylindrical shell specimen containing the machined eight defects and the crack propagation length by the observation