Assessment of a Creep-Fatigue Crack Initiation for a Cylindrical Structure with Defects

Hyeo-Yeon Lee, Jong-Bum Kim, Seok-Hoon Kim, Young-Sang Joo, Jae-Han Lee
KAERI, 150 Dukjin-dong, Yuseong-gu, Deajeon,305-606, Korea, hylee@kaeri.re.kr

1. Introduction

The creep-fatigue crack initiation was evaluated for an austenitic stainless steel cylinder with defects using a structural test and assessment guideline. The structural specimen is a cylindrical shell made of 316L and 304 stainless steels with welded joints. The creep-fatigue test with a hold time of one hour at 600°C and a primary nominal stress of 45.1MPa was carried out. Eight artificial defects were machined and the defect behaviors were examined, and the test results were also compared with those of the assessments. 3D FE analysis with a half symmetric model was carried out with the temperature data measured from the structure test. The conservatisms of the French high temperature design guideline, RCC-MR[1] A16[2] were quantified with the observed results. It was shown that the σ_d method of the A16 procedure was reasonably conservative when compared with the observed images of the creep-fatigue damage. This type of assessment for a creep-fatigue load should be done for the design and assessment of a high temperature structure[3].

2. Details of the Welded Cylindrical Specimen

The structural test model is a welded cylindrical structure as shown in Fig. 1. The materials at the upper half and lower half part are 304 and 316L stainless steel, respectively.

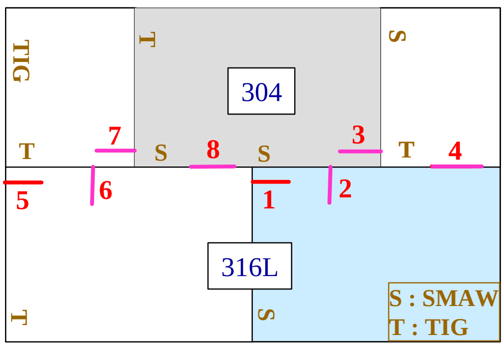


Fig.1 Structural test model (development figure)

Eight defects were machined to examine the defect behavior and to apply a high level of the stresses to the specimen. Six defects are for a thickness having a length of 40mm and height of 0.3mm. Two defects are surface defects having a length of 40mm and a height of 0.3mm, and machined up to half of the thickness as a rectangular shape.

The creep-fatigue test facilities and the specimen are shown in Fig. 2.

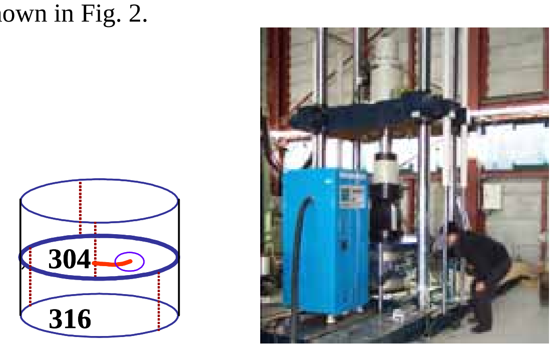
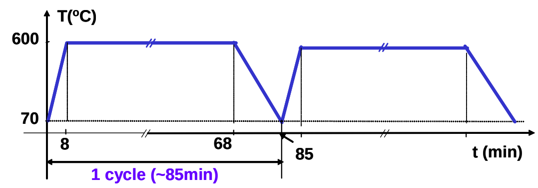


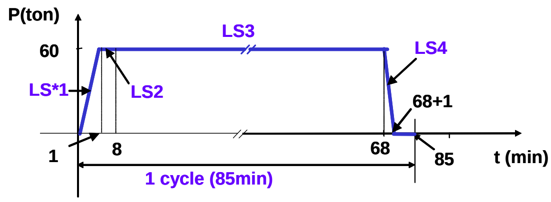
Fig. 2 Creep-Fatigue Structural Test Facility

3. Loading Conditions

The thermal cycles applied using the inductance coil are shown in Fig. 3. One full load cycle takes about 85minutes. The mechanical load of 60ton from the hydraulic actuator system is applied at each load cycle, which induces a nominal stress of 45.1MPa in the axial direction.



(a) Thermal load



(b) Mechanical load

Fig. 3 Creep Load conditions

This type of creep-fatigue load was applied to the cylindrical structure and periodically, the surface damage was observed by a portable optical microscope.

4. Evaluation of the Creep-Fatigue Damage

The stress at the location of '*d*' can be determined by using the stresses at the Gauss point as in the following eq.(1) based on the Creager's formulae; Analysis was carried out using ABAQUS[5].

$$K_I = \sigma_d \sqrt{2\pi\left(d+\frac{\rho}{2}\right)} = \sigma_{G\cdot P}\sqrt{2\pi\left(l+\frac{\rho}{2}\right)} \qquad (1)$$

where σ_d and $\sigma_{G.P}$ are the stresses at the '*d*' and at the Gauss point, respectively. Here '*d*' is specified as 50μm. The strain range due to the present creep-fatigue load is

$$\overline{(\Delta\varepsilon)}_i = \overline{\Delta\varepsilon_{el+pl}} + \overline{\Delta\varepsilon_{fl}} = 0.004316 \qquad (2)$$

Then the endurance limit at this strain range of 304SS is 6572.9cycles.

The creep usage fraction of A16 is the Robinson's time fraction rule and the creep law for 304SS is given in Technical Appendix A3[4] of RCC-MR, and is calculated as in eq.(3);

$$\varepsilon_f = \varepsilon_t(1-e^{-rt}) + \varepsilon_x(1-e^{-st}) + \dot{\varepsilon}_m t = 0.044(\%) \qquad (3)$$

The creep rupture time for this creep strain is determined as T_d=75.8(hr).

Therefore, the creep-fatigue damage for the parent metal part is determined by eq.(4)

$$V + W = \frac{n}{6573} + \frac{t}{76} \qquad (4)$$

Eq.(5) means that a creep-fatigue crack would be initiated in about 76 cycles with 76 hours of hold time.

For the welded joint the creep-fatigue crack initiation envelope is given as in eq.(5),

$$V + W = \frac{n}{2420} + \frac{t}{44} \qquad (5)$$

which means a creep-fatigue crack initiates in about 44 cycles and the initiation would occur due to a creep around the point *P* in Fig. 4.

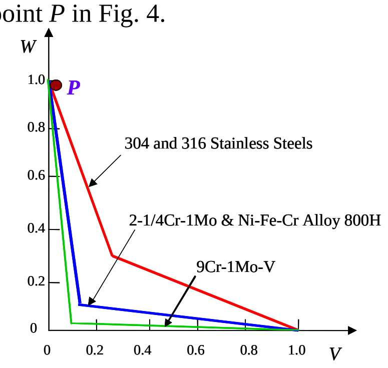


Fig.4 Creep-Fatigue damage envelope

The damages at the horizontal defect No. 3 of the 304SS part are shown in Fig. 5. Usually the welded joint is weaker than the base metal part but more damage was observed at defect No.3. It seems that some prior defects or damage might have existed at the base metal part.

The most critical damage occurred at defect No.3 of the 304SS part. As the cycles are increased the damage tends to be increased as shown in Fig. 5. The micro-crack was observed to grow along the grain boundaries.

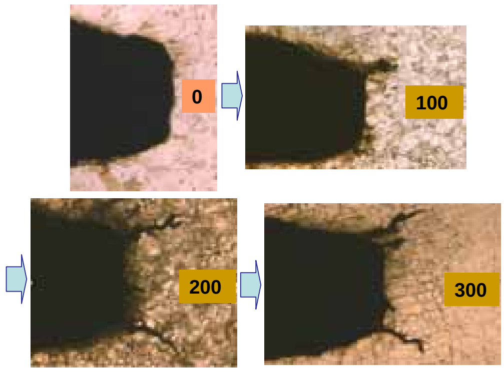


Fig.5 Observed image of the horizontal defect(No.3)

5. Conclusion

In this study, a creep-fatigue structural test with a welded cylindrical shell has been carried out and the test results were compared with those by an elastic analysis according to the design / assessment guidelines of RCC-MR A16. The creep-fatigue damage was observed after around 200 load cycles at the defects. The assessment results for the structural creep-fatigue problem according to the A16 procedure showed that the creep-fatigue crack was initiated after about 76 cycles and 44 cycles at the parent metal and weld metal part, respectively. From the evaluation and observation it was concluded that the A16 procedure is reasonably conservative.

Acknowledgements

This study was supported by the Korean Ministry of Science & Technology through its National Nuclear Technology Program.

References

1. Design and Construction Rules for Mechanical Components of FBR Nuclear Islands, RCC-MR, 2002 Edition, AFCEN (2002).
2. Technical Appendix A16, "Guide for Leak Before Break Analysis and Defect Assessment," AFCEN (2002)
3. D.H. Hahn *et al.*, *KALIMER Conceptual Design Report*, KAERI/TR-2204, Korea Atomic Energy Research Institute, Daejeon (2002).
4. Technical Appendix A3, AFCEN (2002)
5. ABAQUS Users manual, Version 6.4, H.K.S, USA (2004).