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Defect Growth Assessment of High Temperature Piping for a Sodium-cooled Fast Reactor

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1. Introduction

SFR(Sodium-cooled Fast Reactor) is generally operated at the high temperature about 500℃ and low pressure near atmospheric pressure. The creep and fatigue caused by the long life time, high temperature condition and operating cycle events of SFR affect the structural integrity. The reactor structures are designed as a thin-shelled structure type to minimize the thermal stress and they have to be manufactured as defect-free structure. But actually, the defect on the structures may be caused by welding or initiated by creep-fatigue load during the operating life time.

The defect growth evaluation is important to assure the structural integrity. And, the defect behavior is an essential item to the LBB(Leak Before Break) application[1]. In this study, the defect growth evaluation for an SFR hot leg piping is studied by using RCC-MR A16 procedure.

2. Defect Growth Evaluation

2.1 Evaluation Method

RCC-MR is the design and construction rules for mechanical component of FBR(Fast Breeder Reactor) and Appendix A16 is the guide for LBB analysis and defect assessment[2]. A16 guides that the defect growth is dependent on the fatigue only in the non-significant creep condition. But in the significant creep condition, the defect growth is composed of both fatigue and creep defect growths. The total defect growth is a linear summation of them. After each cycle, the calculated growth length is added to the initial defect size and the new defect size is regarded as an initial defect size for a next cycle. But the initial defect size is not necessary to be recalculated if the propagated length is less than 10 % of initial length because the propagated growth length has little effect on the growth length of next cycle.

The fatigue defect growth is estimated from a Paris law with effective stress intensity factor range(ΔK_{eff}) and it is a function of *J*-integral parameter. The creep defect growth is obtained by applying C* parameter. A16 provides the simplified analytical methods of both parameters for the loading conditions.

2.2 Hot Leg Piping and Defect Geometry

The evaluation structure of this study is an IHTS(Intermediate Heat Transport System) hot leg piping of a demonstration SFR which has been developing by KAERI. IHTS is adopted to prevent the direct contact of the primary sodium from the sodium-water reaction with the steam generator(SG) feed water[1]. IHTS hot leg piping is made of Mod.9Cr - 1Mo steel which has a good thermal expansion capacity comparing with stainless steels. Its inner diameter and thickness are 60.0cm and 9.5mm, respectively.

The hot leg piping is assumed to contain the circumferential semi-elliptical defect on the external surface for this study. The defect is affected by axial load, internal piping pressure, temperature gradient and global stress caused by global bending deformation.

A16 specifies the applicability criteria for structural shapes and 5 items are provided for cylindrical structure. The defect of interesting is on the straight piping section and is located away 1.0m from IHX junction and located 10.1m away from a junction of elbow-straight piping. And radius-thickness ratio of piping satisfies it.

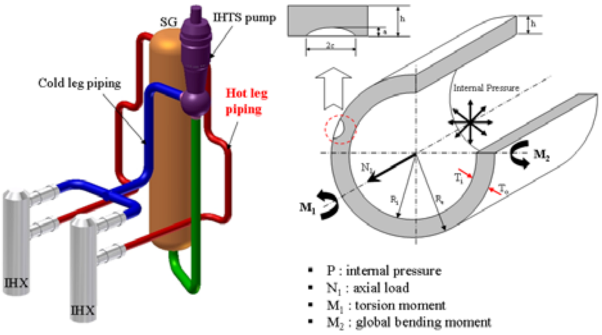
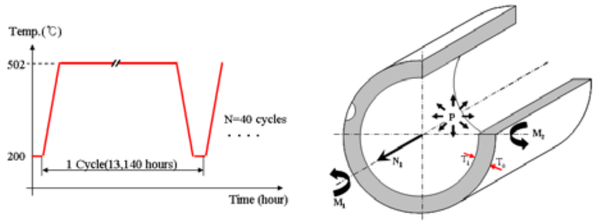


Fig. 1. IHTS piping layout and external part-through wall defect geometry with loading conditions for cylindrical structure.

2.3 Loading Conditions

The refueling cycle is assumed as a loading cycle event for this evaluation. The refueling period is 18 months and plant life time is 60 years. Thus, the total number of cycle for a given cycle event is 40. For the refueling cycle event, upper and lower extreme temperatures are 502℃ and 200℃, respectively. The loading data at the defect section is obtained through the Finite Element(FE) analysis by using ANSYS[3]. In the FE analysis, the temperature is assumed to increase linearly and the creep-fatigue interaction effect is not taken into account. The coolant pressure exerting on the inner surface of piping is assumed to be 0.5MPa and the dead weight includes the coolant, insulation and piping materials. Figure 2 shows the loading cycle history and the loading data for evaluation section.



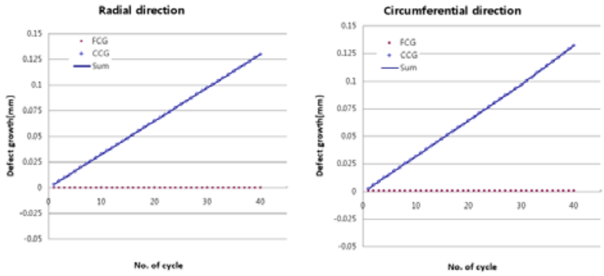
Mechanical load	
Dead weight	Piping Coolant Insulation
Internal pressure	0.5MPa
Intermediate support	No

	Full power	Refueling
P (Mpa)	0.5	0.5
N_1 (N)	10,640	4,559
M_1 (N·m)	16,128	23,310
M_2 (N·m)	491,415	350,026
ΔT_{wall} (℃)	1℃	1℃

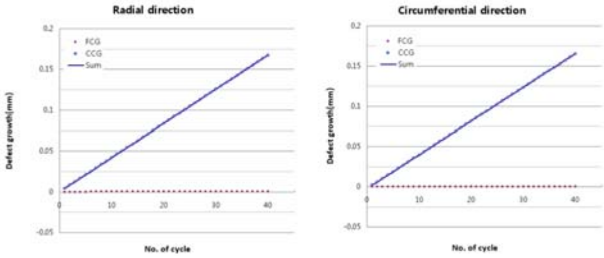
Fig. 2. Loading cycle history and loading data.

2.4 Evaluation Results

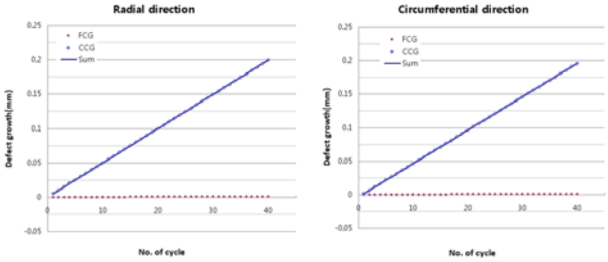
A16 describes that the defect depth(a) is less than 0.25 times of thickness(h) in case of long width($2c$) defect. Defect growth is evaluated for three cases of initial defect size. The defect widths for each case are 1.0h, 2.0h, 4.0h but the defect depth is constant as 0.25h. The initial defect dimensions for Case-1 are 1.0h (9.53mm) width and 0.25h(2.38mm) depth.



(a) Case-1 (a=2.38mm, $2c$=9.53mm)



(b) Case-2 (a=2.38mm, $2c$=19.05mm)



(c) Case-3 (a=2.38mm, $2c$=38.10mm)

Fig. 3. Defect growth behavior for three cases

The defect growth for fatigue and creep is calculated by using following two equations. A16 provides the fatigue defect growth law but creep defect growth law is not specified yet. So, reference data[4] is used for the creep defect growth law.

- Fatigue defect growth : $\left(\frac{da}{dN}\right)_f = 4.07\times10^{-8}\left(\Delta K_{eff}\right)^{3.5}$
- Creep defect growth : $\left(\frac{da}{dt}\right)_c = 4.8\times10^{-3}\left(C^*\right)^{0.642}$

Figure 3 shows the creep and fatigue defect growth behaviors for radial and circumferential directions. As shown in Fig.3, creep defect growth is dominant and fatigue defect growth is almost negligible comparing with creep defect growth for all cases because of limited number of cycle. The cumulative defect growth length is less than 10% of initial defect size even for the Case-3. Thus the defect growth shows the linear behavior.

3. Conclusions

In this study, creep-fatigue defect growth for a SFR IHTS hot leg piping by using A16 procedure is evaluated. For a given duty cycle event, the global bending moment is the most critical loads and the creep is more dominant than fatigue on the defect growth. The fatigue defect growth is almost negligible comparing the creep defect growth. Radial growth is close to the circumferential growth and the initial defect does not penetrate the piping wall for a given cycle and defect sizes. The material data sheet for Mod.9Cr-1Mo steel are not enough to cover the evaluation procedure yet and thus they should be provided to maintain the reliable consistent results.

Currently, RCC-MRx A16 2010 Edition is ready to be published and future studies for defect behavior evaluation by applying the latest A16 Edition will be followed.

ACKNOWLEDGEMENTS

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