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Development of Procedures of Leak Before Break Assessment for Sodium Cooled Fast Reactor

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1. Introduction

Generally, To exclude Double-Ended-Guillotine-Break(DEGB) design, the Leak-Before-Break(LBB) assessment is conducted. In SFRs, if the coolant pipe ruptures and leaks large amounts of coolant sodium, it may cause large fires. Therefore, in DEGB design in SFRs considers installing large fire extinguishing system and many firewalls. On the other hands, DEGB in pipes can be prevented by detecting a leakage that occurs at the through-wall stage of a crack opening under those conditions. A consideration of these LBB characteristics can enlarge the degree of design freedom with respect to the materials, piping layouts, and safety measures against a leakage, thus leading to improved plant reliability and economy.

For the LBB assessment of SFR pipes, creep crack growth could be considered, because SFRs are operated above 500^{o}C. But the LBB assessment procedure for high temperature has not been established yet.

In this study, we analyze RCC-MR A16 and propose procedure for the LBB assessment based on RCC-MR A16. For verification of this procedure, we conduct an example of LBB assessment. And we found partial procedure, equation and constant that has not been provided in RCC-MR A16.

2. LBB assessment procedure

In this study, procedure of the LBB assessment for SFRs is proposed based on RCC-MR A16. This procedure consist of nine steps. Of those steps, ninth step, which is procedure of to determine the critical crack length has not been provided in RCC-MR A16.

2.1 Selection of evaluation region

The maximum value of principal stress range subjected to a region of the evaluation that is determined by the result of finite element analysis (Step 1).

For selected region, the initial crack select that is normal to principal stress direction(Step 2). The initial crack is assumed as semi-elliptical.

2.2 Crack assessment

A crack assessment procedure consists of three steps that are crack initiation(Step 3), crack growth(Step 4) and crack instability(Step 5). It must be determined that whether creep effect is significant or not from negligible creep curve of RCC-MR A3.

In the step 3 determines whether crack is tearing or not. This procedure is conducted, respectively, in case of negligible creep or significant creep following A16.3221.2 or A16.3221.3. The crack initiation time is obtained by this procedure. If the crack initiation time is shorter than life time of replacement cycle of a structure, procedure in step 4 is executed.

In the step 4 evaluates crack growth. This procedure is conducted, respectively, in case of negligible creep or significant creep following A16.3322.2 or A16.3322.3. The output of this procedure is crack growth from crack initiation time to end-of-life time or replacement cycle. In the result of this procedure, it can be confirmed whether final crack penetrates in life time or not. If final crack not penetrates in life time, procedure of the step 5 is executed or else the step 6.

In the step 5 evaluates reduced section and crack instability. An evaluation of reduced section is as RB3251 for negligible creep. In case of significant creep, both RB3251 and RB3252 must be satisfied on reduced section by crack. Instability of crack is evaluated, respectively, in case of negligible creep or significant creep following A16.3321.4 or A16.3322.4. If crack or reduced section is instable, LBB concept can be not applied.

2.3 Detectable crack size determination

The step 6 to the step 9 determine LBB condition of the pipe containing the crack. In each step, calculate detectable leak crack length(C_L), penetration crack length(C_p), detectable crack length(C_d) and critical crack length(C_G). Fig. 1 present C_L, C_p, C_d and C_G.

In the step 6, detectable leak crack length(C_L) is determined as pressure difference and crack opening. The crack opening displacement(δ) is calculated using Eq. 1.

$$\delta = \delta_{el} \frac{E\varepsilon_{ref}}{\sigma_{ref}} \qquad (1)$$

$$\delta_{el} = \frac{4C_L}{E}(k_m\sigma_m - k_b\sigma_b)$$

The flow section area is calculated as detectable crack length and crack opening displacement. Using Eq. 2, detectable leak crack length is calculated.

$$C_L = \left[Q_{\text{det}} \frac{6\mu_{Na} h E^3}{\pi^3 \Delta P (k_m \sigma_m - k_b \sigma_b)} \right]^{\frac{1}{4}} \qquad (2)$$

Where, Q_{det} is equal to 10 times the minimum detectable leak flow.

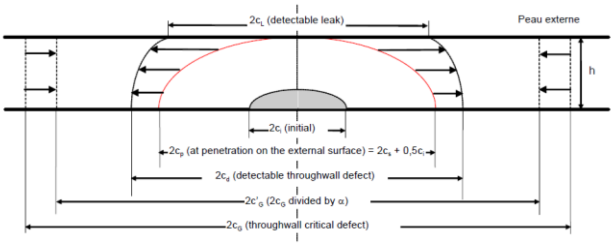

Fig. 1. Change of the semi-elliptical crack shapes after penetration

2.4 Through-wall crack size determination

In the step 7, crack length at penetration is determined using mater curve of A16.3441a. C_s is read on master curve. Where, X is function as a ratio of bending stress to membrane stress. Penetration crack length(C_p) can be obtained using rule of A16.3441.

2.5 Crack length after penetration

After penetration, crack length grows at internal and external. In step 8, detectable crack length(C_d) is determined when external crack length is equal to C_L. detectable crack length is read from master curve that is selected by rules of A16.3442, C_p and C_i.

2.6 Through-wall crack instability assessment

A16.3420 describe that LBB condition can is established in case of $2C_d<2C'_G$. Nevertheless, a method is not provided for determining critical crack length(C_G) at RCC-MR A16. This method and procedure will be proposed by following study.

3. Example of LBB assessment

To confirm LBB procedure proposed, example of LBB assessment is conducted. In this example select Piping of intermediate heat transport system(IHTS) as the subject of LBB assessment.

3.1 Subject of assessment

Procedure in the step1 make use of finite element model that is written based on 3D model of IHTS piping. Using material properties were obtained from RCC-MR A3. Operating condition was assumed as Fig. 2.

The maximum principal stress subjected to indicated elbow in Fig.4 that had selected as a region of this assessment. Partially, equations and constants is assumed to be equal to straight pipe because those equations and constants for to evaluate elbow have not been provided in RCC-MR A16.

In selected region, initial crack was assumed that crack is 3mm of depth and 24mm of length.

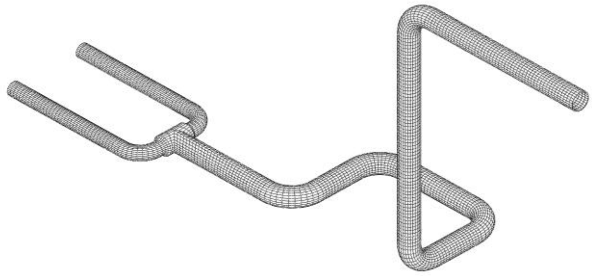

Fig. 2. Finite element model for IHTS piping

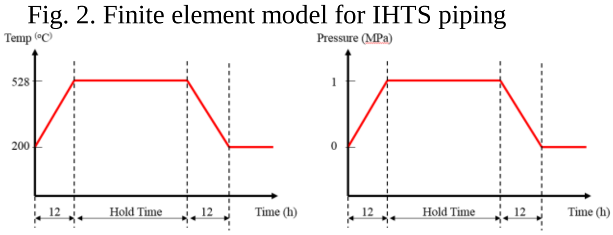

Fig. 3. Operation condition of IHTS piping

3.2 Result of assessment

The fatigue usage factor and creep usage factor are 0.0051 and 1.7448, respectively, from the step3. Because this value is located on the outside of creep-fatigue interaction diagram in RCC-MR A3, we decided occurring crack initiation. The crack initiation time and residual life time are 300240hr and 225360hr, respectively.

The fatigue crack growth and creep crack growth are $1.16\text{x}10^{-5}$mm and 0.8202438mm, respectively. Therefore, total crack growth is 0.8202553mm.

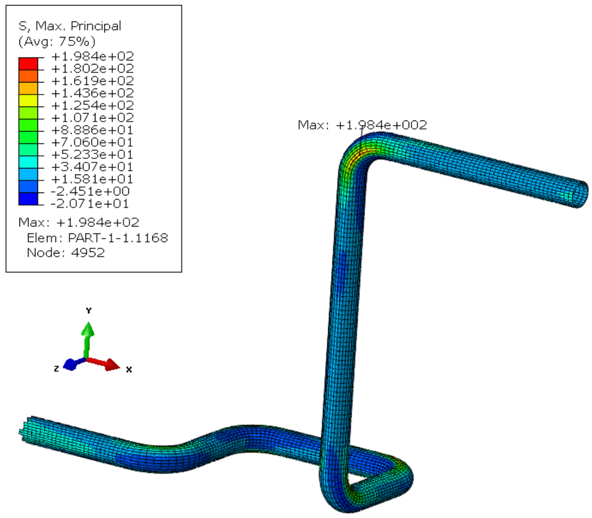

Fig. 4. Selection of evaluation region

The J-R curve is needed for the evaluation of crack instability in the step 5. We make use of J-R curves(Fig. 5) tested in KAERI because in RCC- MR A3 not provides J-R curves of X10CrMoVNb9-1. Fig. 6 is F-J diagram that obtained by procedure of the step 5. The crack instability not occur because the instability load is 35Mpa lager than 1Mpa applied load.

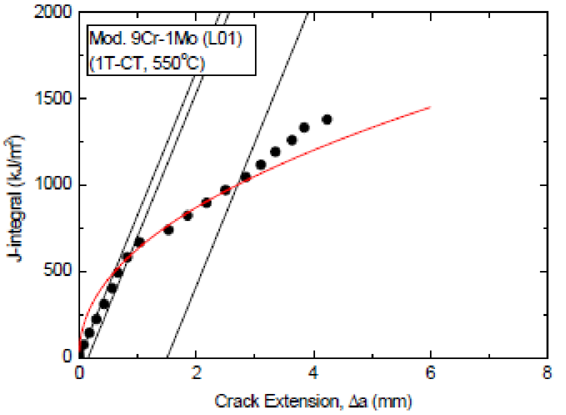

Fig. 5. J-R curve of X10CrMoVNb9-1(KAERI)

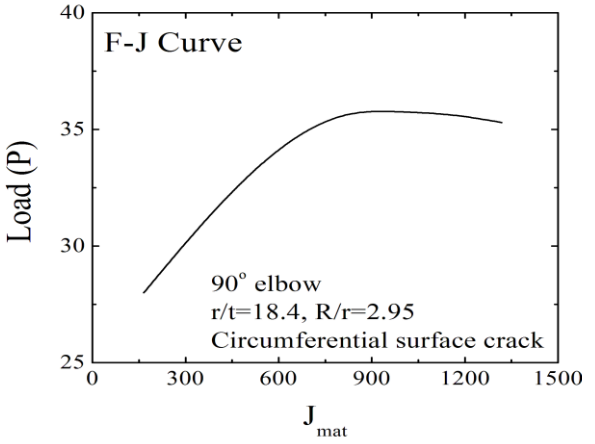

Fig. 6. F-J diagram

The detectable leak crack length and crack opening displacement are 20.39mm and 0.0081mm from the step 6. The penetration crack length is 69mm from the step 7. The detectable crack length is 165mm from the step 8. It had not been proposed that procedure of step 9 for to determine the critical crack length.

4. Conclusions

In this study, LBB assessment procedure has been proposed for SFRs design based on RCC-MR A16. Also, proposed procedure was verified by conducting an example assessment. As a result of those draw two conclusions as follow:

- The LBB assessment of SFRs can be conducted by proposed procedure based on RCC-MR A16.
- However, it is needed to develop determination of critical crack length methodology.

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