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A Modified Method to Predict Failure Pressure of Steam Generator Tubes with Through-Wall Cracks

Han-Sang Lee [a], Nak-Hyun Kim [a], Yun-Jae Kim [a*], Jong-Sung Kim [b], Jin-Won Kim [c]
[a] *Mechanical Engineering, Korea University, Seoul, Republic of Korea*
[b] *Mechanical Engineering, Sunchon National University, Sunchon, Republic of Korea*
[c] *Nuclear Energy Engineering, Chosun University, Gwangju, Republic of Korea*
[*] *Corresponding author: kimy0308@korea.ac.kr*

1. Introduction

Multiple axial cracks in the stream generator tubes is often found. An assessment method of such multiple axial cracks is important for safe operation of plant components. However, assessment method of multiple cracks is no yet well established due to the fact that plastic failure behavior can be very complex. One efficient way to predict plastic behavior is to perform FE damage analyses. This paper proposes a new numerical method to predict ductile failure behavior of steam generator tubes with multiple through-wall cracks. In this new method based on the former method [1], ductile failure criterion was assumed to be a function of the finite element size. To validate the new method, simulated results are compared with experiment results of Alloy 600 thin plates and tubes with through-wall cracks.

2. Methods and Results

In this section the new assessment method of multiple axial cracks is described. Simulated results by using new method compared with experiment results.

2.1 Review of publish test data

Test data published in the literature, Ref. [2-3]. Test data include thin plates and tubes with two through-wall cracks, made of Alloy 600. Engineering stress-strain curves resulted from tensile using two plate specimens with the 1.6mm thickness. Averaged yield (0.2% proof) strength $\sigma_{0.2}$, tensile strength σ_u and reduction of area (RA) of the material were about 322MPa, 660MPa and 60%. Test data are available for Alloy 600 tube specimen, having the outer diameter of 19.05mm and the thickness of 1.09mm. Three types (singe crack, collinear crack, and non-aligned crack) of cracked tube specimens were tested. The tubes were pressurized by water and burst pressures.

2.2 Damage model

Our propose damage model is based on the phenomenological model for ductile fracture. In this model, fracture strain ε_f for simple fracture is assumed to depend exponentially on the stress triaxiality (defined by the ratio of the mean normal stress σ_m and equivalent stress σ_e) [4-7]

$$\varepsilon_f = A\exp\left(-C\frac{\sigma_m}{\sigma_e}\right)+B \qquad (1)$$

$$\frac{\sigma_m}{\sigma_e} = \frac{\sigma_1+\sigma_2+\sigma_3}{3\sigma_e} \qquad (2)$$

A, B and *C* are a material constant

To complete the damage model, FE damage analysis is performed to simulate single-cracked tube test with c=5mm. To reduce the number of variables, the constant C is assumed to be C=-1.5, according to Rice and Tracey [4]. As our experience on various structural steels suggests that the fracture strain at σ_m/σ_e=2.5 ranges from 10% to 20% of uni-axial fracture strain, two initial trials of the fracture strain criteria (see Eqs. (3) below) were used, as shown in Fig. 1

$$\begin{aligned} &Criteria\,1:\ \varepsilon_f=1.130\times\exp(-1.5\times\frac{\sigma_m}{\sigma_e})+0.138 \\ &Criteria\,2:\ \varepsilon_f=1.272\times\exp(-1.5\times\frac{\sigma_m}{\sigma_e})+0.052 \end{aligned} \qquad (3)$$

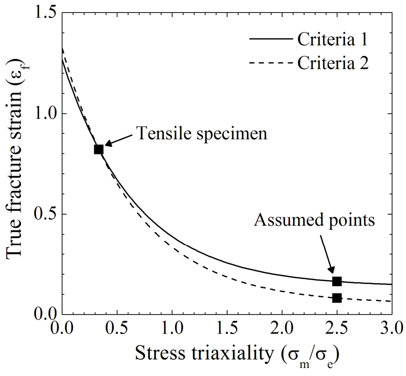

Fig. 1. The stress-modified fracture strain for Alloy 600

Predicted burst pressures should depend on the critical damage ω_c and dependence is shown in Fig. 2. Ratios of predicted and experimental burst pressures increase almost linearly with increasing ω_c. Results suggest that the use of two different criteria in Eq. (3) gives close results but the criterion 2 gives slightly conservative results. They further suggest that for the 0.25mm element size, ω_c=0.55 gives the best result.

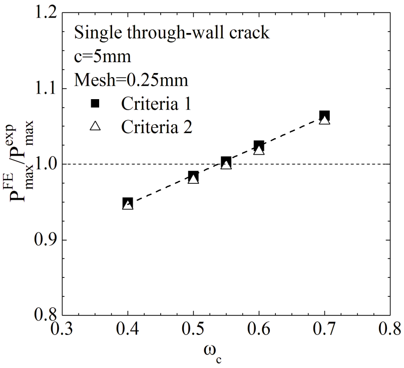

Fig. 2. Burst pressure of single though-wall crack

2.3 FE damage simulations

FE damage analyses were performed using the damage model in the previous sub-section. The element size of 0.25mm was used with ω_c=0.55. The eight-node brick elements with full integrations within ABAQUS (element type C3D8) were used in analyses.

Predicted maximum loads for cracked plate tests are compared with experimental data in Fig. 3. Results show that simulated results agree well with experiment data.

Predicted burst pressures for cracked tube tests are compared with experimental data in Fig. 4. Results show that simulated results have 10% error with experiment data.

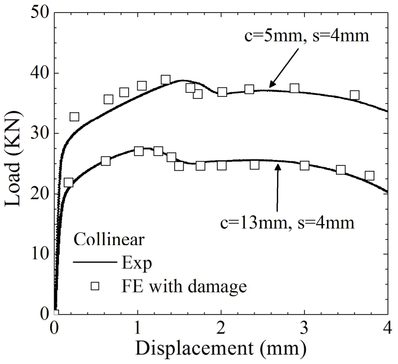

Fig. 3. Comparison of experiment load-displacement curves with simulated ones

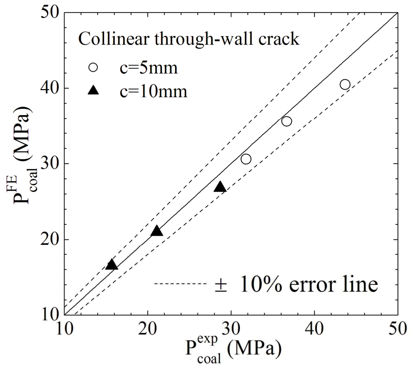

Fig. 4. Comparison of experiment burst pressures with simulated ones

3. Conclusions

A new numerical method to predict failure behavior of Alloy 600 steam generator tubes with two through-wall cracks is proposed in this paper. In this new method, ductile failure criterion was assumed to be a function of the finite element size. To validate the new method, simulated results are compared with experiment results of Alloy 600 thin plates and tubes with through-wall cracks. Results show that FE damage analyses by using the new method predict well experiment data.

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