Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 12-13, 2016

Ductile fracture simulation of SA508 Gr. 1a under LCF loading condition

Hyun Suk Nam[a], Yun Jae Kim[a*], Jin Won Kim[b]
[a] *Dept. of Mechanical Engineering, Korea Univ.*
[b] *Dept. of Nuclear Engineering, Chosun Univ.*
[*]Corresponding author: kimy0308@korea.ac.kr

1. Introduction

Recently, it has been reported that seismic events have occurred in nuclear power plants. In order to design and maintain piping system such as seismic accident, fracture mechanics analysis under seismic loading is important. For this reason, ductile fracture simulation under cyclic loading condition is very important in structural integrity analysis of pipeline and nuclear piping. The author have recently proposed a numerical method to simulate ductile tearing under quasi-static, dynamic loading conditions, based on the ductility exhaustion concept using the multi-axial fracture strain energy model [1~3].

In this paper, the numerical method to simulate ductile tearing is extended to cyclic loading conditions. The presented method is applied to fracture toughness test under cyclic loading condition.

2. Experiment

To calibrate the damage parameters, tensile test and fracture toughness test were compared with FE results. This paper consider fracture toughness test results conducted by Prof Kim [4]. In Ref [4], SA508 Gr. 1a, typically used in Class 2 piping system of Light Water Reactors was considered in experiment. In this section, experiment results are introduced briefly. All experiment results were performed at room temperature.

2.1 Tensile test

Tensile properties were obtained using smooth round bar under two type of loading condition. One is quasi-static loading condition, the other is cyclic loading condition. Specimen dimension is showed in Fig. 1. Test results under quasi-static loading condition are tabulated in Table 1. Cyclic tensile test were performed considering 0.4%, 0.8 % and 1.2% strain rage.

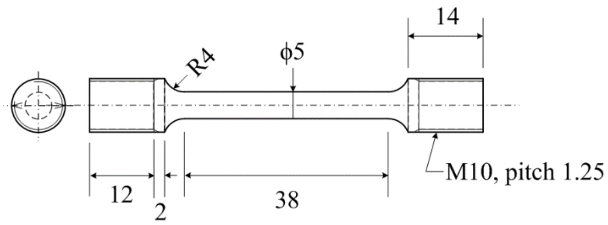


Fig. 1. Geometry of tensile specimen

Table I: Material properties of the SA508 Gr. 1a

Strain rate	Yield Strength (MPa)	Tensile Strength (MPa)
3.95×10^{-4}	363	539

Table II: The material parameters for non-linear kinematic hardening model

C_1	γ_1
200000	10000
C_2	γ_2
35000	420
C_3	γ_3
446	10

2.2 Fracture toughness test

For fracture toughness (*J*-resistance), CT (compact tension) test was conducted using standard 1T C(T) specimens machined from SA508 Gr. 1a pipe. The specimens were oriented such that crack growth was in the circumferential direction (L-C orientation) and were side-grooved for 10 percent of the thickness on both sides. In order to verify the R-ratio effect at cyclic loading condition, 2 type (R=-0.5, -1) of fracture toughness test were performed.

3. Finite element analysis

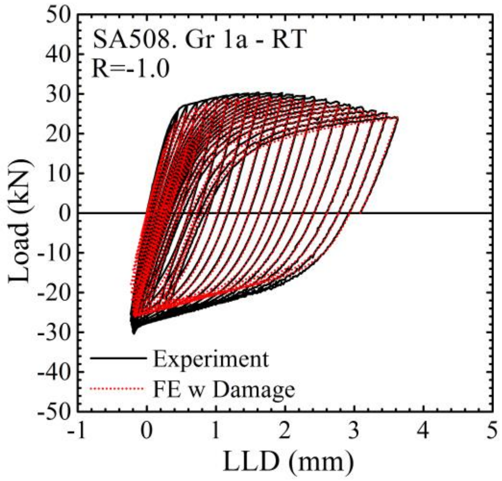
3.1Determination kinematic hardening property

To define a cyclic material properties, the kinematic hardening model in ABAQUS [5] was adopted to make numerical analysis. Using cyclic tensile test results (saturated stress-strain curve), non-linear kinematic hardening coefficient was defined which was tabulated in Table 2.

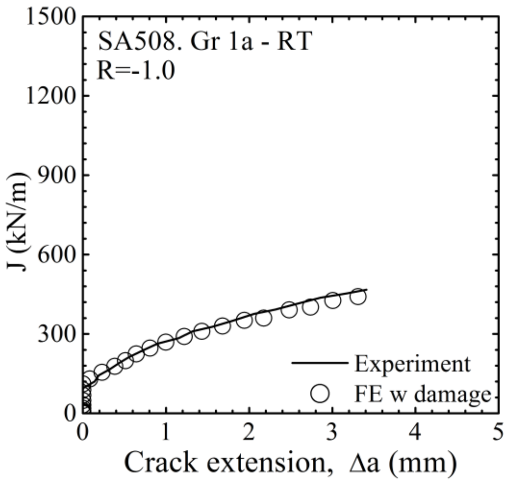
3.2 Damage model for ductile tearing simulation

To determine the multi-axial strain energy model, fracture strain energy was used. Fracture strain energy means the area under the stress-strain curve up to point of fracture. The multi axial fracture strain energy is assumed to be given in terms of stress triaxiality,

$$W_f = A \exp(-c \frac{\sigma_m}{\sigma_e}) + B \quad (1)$$



(a)



(b)

Fig. 2. Comparison of simulated results with CT test results (a) Load-LLD curve (b) J-R curve

Using smooth bar tensile test results under quasi-static condition, constant *A*, *B*, *C* in Eq. (1a) were determined as below,

$$W_f = 2980 \ \exp(-1.82\frac{\sigma_m}{\sigma_e}) + 70 \qquad (2)$$

Base on the this locus, incremental damage due to plastic deformation, $\Delta\omega$, can be calculated using the following equation,

$$\Delta\omega = \frac{\Delta W_p}{\Delta W_f} \qquad (3)$$

When the accumulated damage becomes critical ductile failure is assumed locally and incremental crack growth is simulated simply by sharply reducing all stress components at the gauss point.

3.3 FE results

FE damage simulation is carried out using the multi-axial fracture strain energy model. The proper value of critical accumulated value is chosen to fit the crack initiation toughness (*J* value corresponding 0.2mm to crack growth, $J_{0.2}$) using CT test results under quasi-static loading condition. Based on the damage parameters, CT test results under cyclic loading condition are simulated. Figure 2 shows FE results compared with experiment results. Simulated results shows good agreement with experiment results.

4. Conclusion

This paper present a numerical method to simulate ductile tearing fracture toughness test under cyclic loading condition performed by Prof Kim []. The proposed method is based on the stress-modified fracture strain energy model. To validate the method, simulated results of smooth bar and fracture toughness test under quasi-static loading condition are compared with experimental data. Using calibrated damage parameters, fracture toughness test under cyclic loading condition are simulated. The results shows that the proposed method predicts experimental data well.

These conclusions may, however, depend on materials and specific specimen geometry. Therefore, in the future work, more parametric studies will be performed for different materials and various specimen geometries.

This research was supported by National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT and Future Planning (NRF-2013M2A8A1040924) and by the Nuclear Power Core Technology Development Program of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), the Ministry of Trade, Industry & Energy, Republic of Korea (No. 20141520100860).

REFERENCES

[1] C.-S. Oh, N.-H. Kim, Y.-J. Kim, J.-H. Baek, Y.-P. Kim and W.-S. Kim, A Finite Element Ductile Failure Simulation Method using Stress-modified Fracture Strain Model, Engineering Fracture Mechanics, Vol.78, p. 124, 2010.

[2] H.-S. Nam, Y.-R. Oh, Y.-J. Kim and N. Miura, Application of engineering ductile tearing simulation method to CRIEPI pipe test, Engineering Fracture Mechanics, Vol.153, p. 128, 2016.

[3] H.-S. Nam, J.-Y. Jeon, J.-S. Kim, J.-W. Kim and Y.-J. Kim, A strain rate dependent computational model of ductile damage for C(T) specimen, Procedia engineering, Vol.130, p. 861, 2015.

[4] J.-W. Kim, M.-R. Choi, J-R Fracture Toughness of Nuclear Piping Materials under Excessive Seismic Loading Condition, Engineering Fracture Mechanics, PVP2016-63456, 2016. (Submitted)

[5] Abaqus 6.11, Analysis User's Manual, Dassault Systemes Simulia Corp., Providence, RI, 2011.