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

Investigation on the Fracture behavior of Piping Materials under Seismic Loading Condition

Myung Rak Choi*, Jin Weon Kim*† , Yun Jae Kim**
**Department of Nuclear Engineering, Chosun University, Korea*
***Department of Mechanical Engineering, Korea University, Korea*
† *Corresponding author: jwkim@chosun.ac.kr*

1. Introduction

The piping components of nuclear power plants (NPPs) should be designed and maintained to ensure their structural integrity under seismic condition as well as normal operation condition [1,2]. Thus, the reliability of integrity assessments of piping components under the seismic loading condition is an important issue. In the current integrity assessment procedures [2,3], seismic loading is treated as monotonic and applied once; the mechanical properties obtained under the monotonic and quasi-static loading conditions are used for the assessment. However, the seismic load has both dynamic and cyclic characteristics and the mechanical properties under dynamic and cyclic loading conditions are different from those under monotonic and quasi-static loading conditions. Hence it is important to clearly understand the dynamic and cyclic loading characteristics in the mechanical properties of materials.

Although a number of studies have investigated the cyclic loading effect on the fracture behavior of materials [4,5], the loading rate effect on the fracture behaviour under the seismic loading condition is not clear yet. Therefore, this study conducted J-R fracture toughness testing of two piping materials commonly used in NPPs under monotonic and cyclic loading conditions at various displacement rates at room temperature (RT) and operating temperature of NPPs (316ºC). The loading rate effect on fracture behavior is investigated under monotonic and cyclic loading conditions by comparing J-R curves for different displacement rates.

2. Experiment

2.1 Test materials and specimen

The materials used for these experiments were SA508 Gr.1a low alloy steel (LAS) and SA312 TP316 stainless steel (SS) piping materials.

In this study the fracture resistance of piping materials was evaluated using compact tension (CT) specimen; 1T-CT specimen with thickness of 25.4mm was used for SA508 Gr.1a LAS and 0.5T-CT specimen with thickness of 10.6mm was used for SA312 TP316 SS. Both specimens were designed in accordance with ASTM E1820-09 [6] and machined in L-C direction.

2.2 Experimental procedures

J-R fracture toughness tests were conducted under

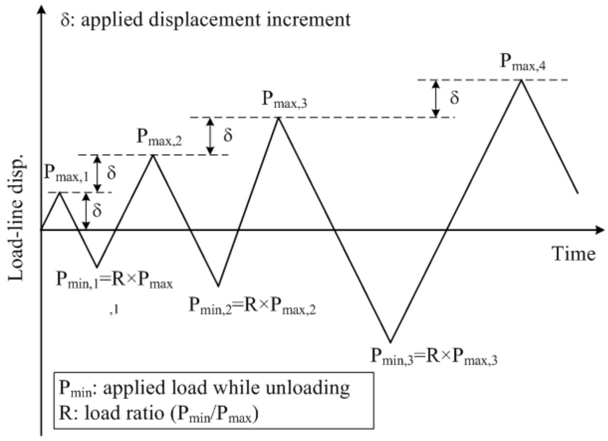

Fig. 1 Cyclic loading sequence applied for cyclic J-R fracture toughness tests

both monotonic and cyclic loading conditions at RT and 316ºC. Four different displacement rates (V_{LL}) were considered in the monotonic tests, i.e., V_{LL}=0.9, 9.0, 90, and 2280mm/min for SA508 Gr.1a LAS and V_{LL}=0.45, 4.5, 45, and 1140mm/min for SA312 TP316 SS. In the cyclic tests, V_{LL}=0.9, 9.0, 90, and 2280mm/min were used for SA508 Gr.1a LAS and V_{LL}=0.45 and 45mm/min for SA312 TP316 SS. For monotonic J-R tests, a tensile displacement was monotonically applied to the specimens without unloading. For cyclic J-R tests, an incremental displacement-controlled cyclic load was applied following the loading sequence shown in Fig. 1. In the cyclic tests, the constant displacement increment (δ) of 0.15mm was applied after each cycle and the cyclic load ratios of R= -0.5 and -1.0 were employed.

In the monotonic J-R tests, crack extension was determined by normalization method that is provided by ASTM E1820-09 [6], and J-integral was calculated in accordance with the standard procedure [6]. Crack extension in the cyclic tests was determined by d-c PD method, and J-integral was calculated from the envelope area under the load versus load-line displacement (LLD) curve and above zero load, ignoring compressive loading portion [4,5]. Fig. 2 shows a sample of load (P) versus LLD curve and direct-current potential drop (d-c PD) versus LLD curve obtained from the cyclic J-R test.

3. Results and Discussion

J-R tests conducted under monotonic loading condition indicated that SA312 TP316 SS showed only

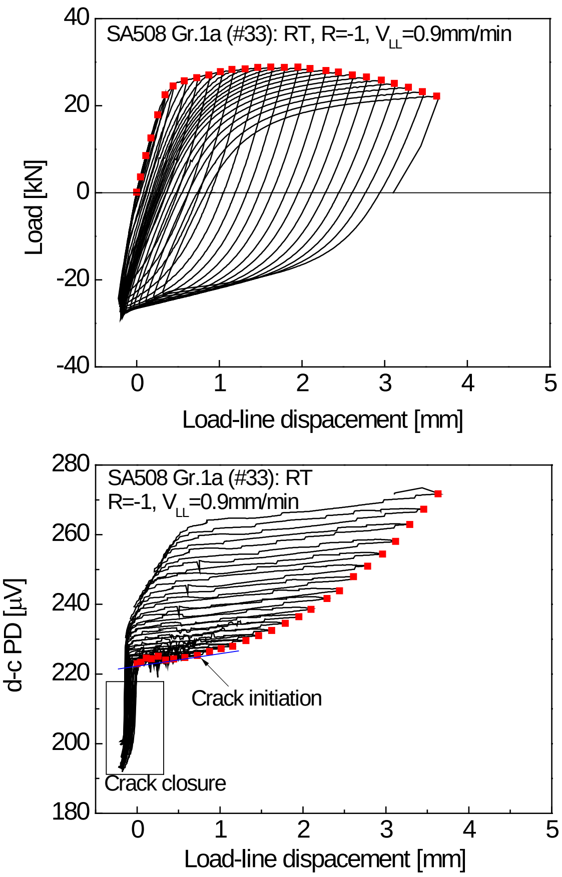

Fig. 2 Sample data of cycle J-R fracture toughness test

a slight effect of loading rate on the fracture behavior at both RT and 316°C, while SA508 Gr.1a LAS showed a more pronounced loading rate effect at 316°C. The fracture resistance of SA508 Gr.1a LAS decreased with increase in displacement rate and reached a minimum at V_{LL}=9.0~90mm/min, and then it increased with further increase in displacement rate. Thus, the fracture resistance at dynamic loading rate (V_{LL}=2280mm/min) became almost the same as that at quasi-static loading rate (V_{LL}=0.9mm/min). According to the previous study [7], the appearance of minimum fracture resistance in the range of displacement rates of 9.0~90mm/min is attributed to the occurrence of DSA in SA508 Gr.1a LAS at 316°C.

The results of cyclic J-R tests showed that the reversible cyclic loading considerably reduced the fracture resistance of materials regardless of loading rate, test temperature, and type of material. The reduction in fracture resistance was more significant when the cyclic load ratio was more negative. Also, the results showed that the loading rate effect on fracture behavior under cyclic loading condition was negligible for SA312 TP316 SS regardless of test temperatures. However, the effect was appreciable for SA508 Gr.1a LAS at 316°C and the minimum fracture resistance appeared at an intermediate loading rate, V_{LL}=9.0~90mm/min. This shows that the loading rate effect for both piping materials under cyclic loading condition was basically the same as that observed under monotonic loading condition. But, it is noticeable that the loading rate effect of SA508 Gr.1a LAS was dependent on the cyclic load ratio; i.e., the loading rate effect was almost diminished when the cyclic load ratio is -1.0. This is because the crack-tip sharpening dominated crack extension as the cyclic load ratio became more negative.

4. Conclusions

In order to clearly understand the fracture behavior of piping components under seismic condition, the monotonic and cyclic J-R fracture toughness testing of SA508 Gr.1a low alloy steel (LAS) and SA312 TP316 stainless steel (SS) pipe materials were conducted at various displacement rates at room temperature (RT) and 316°C, and the effect of loading rate on the fracture behavior under cyclic loading conditions was investigated.

Acknowledgements

This research was supported by National Research Foundation of Korea(NRF) funded by the Ministry of Science, ICT and Future Planning(NRF-2013M2A8A1040924) and the Nuclear Power Core Technology Development Program of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea(20141520100860).

REFERENCES

[1] ASME, ASME B&PV Code Sec.III, “Nuclear components,” 1998ed.

[2] ASME, ASME B&PV Code Sec.XI, “Rules for Inservice Inspection of Nuclear Power Plant Components,” 1998ed.

[3] USNRC, 1984, Evaluation of potential pipe break, NUREG-1061, Vol.3.

[4] Singh, P.K., et al., 2003, “Effect of cyclic loading on elastic-plastic fracture resistance of PHT system piping material of PHWR,” Int. J. Pres. Ves. Piping, Vol.80, pp.745-752.

[5] Chowdhury, T., et al., 2015, “Cyclic fracture behaviour of 20MnMoNi55 steel at room and elevated temperatures,” Fat. & Frac. Eng. Mater. Struc., Vol. 38, pp.813-827.

[6] ASTM, 2009, “Standard Test for Measurement of Fracture Toughness,” ASTM E1820-09.

[7] Kim, J.W. and Choi, M.R., 2015, “Effect of loading rate on the deformation behavior of SA508 Gr.1a low alloy steel and TP316 stainless steel pipe materials at RT and 316°C,” Trans. of KSME (A), Vol.39, pp.383-390.